Science and politics in innovation policy: The making and remaking of nanotechnology

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Science and politics in innovation policy: The making and remaking of nanotechnology

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This thesis explores the tensions inherent in late-modern, capitalist states' development of technology policy, using political and policy responses to nanotechnology in Australia and the United States (US) as case studies. Contemporary accounts have alternated between those that treat the emergence of novel technologies as the outcome of political construction and coordination, and those that emphasise the role of market infrastructures. This thesis offers a distinct view by illuminating the active work undertaken by government officials, entrepreneurial scientists and research funding bodies to build state support for nanotechnology, and the specificity and limits of their success. I argue that in both countries, the adoption of national nanotechnology policies might be best understood as a situated achievement, and that assumptions regarding the state's 'natural' interest in sponsoring emerging technologies merit closer inspection.

Drawing on interviews with nanotechnology stakeholders, archival documents and material obtained under *Freedom of Information Act* requests, I investigate the US political response to nanotechnology in the years preceding and following the National Nanotechnology Initiative's establishment (mid-90s to 2003), and that of Australia in the years the field grew and receded from political attention (2000 to 2013). By tracing the shifting enactments of nanotechnology in innovation policy in both countries, and in Australian regulatory policy, I reveal the ongoing (re)negotiation of science-state-market relations, and their divergent construction in 'innovation' compared to 'regulatory science'.

The imbrication of science, the state and the market revealed in this thesis is inconsistent with technologically determinist, market essentialist, or state-directed accounts of nanotechnology's elevation as a policy object. Instead, I show that the creation of national nanotechnology policy, in both the US and Australia, reflected the responsiveness of proponents' constitutive and promissory work to wider conflicts and accommodations within science policy, the confluence of favourable political and fiscal circumstances, and chance. Further, I find that Australian nanotechnology policy was constrained by market failure justifications for the state's role in innovation and by the limited credibility achieved for promissory claims. Highlighting the contingency of existing technology policy settlements, this study concludes by reflecting on how processes of state-backed innovation may be 'opened up' for reimagining.

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Abstract

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Contents

Acronyms

AAAS	American Association for the Advancement of Science
AAS	Australian Academy of Science
ACCC	Australian Competition and Consumer Commission
ACTU	Australian Council of Trade Unions
AEU	Australian Education Union
APS	American Physical Society
ARC	Australian Research Council
ATP	Advanced Technology Program
BA	Biotechnology Australia
BAA	Backing Australia’s Ability
CEO	Chief Executive Officer
CHOICE	Australian consumers’ association
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DISR	Department of Industry, Science and Resources
DITR	Department of Industry, Tourism and Resources
DEST	Department of Education, Science and Training
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education
DOD	Department of Defense
DOE	Department of Energy
EHS	Environment, health and safety
FASTS	Federation of Australian Scientific and Technological Societies
FOEA	Friends of the Earth Australia
GMR	Giant magnetoresistance
HSE	Health, safety and environment
ICONN	International Conference on Nanoscience and Nanotechnology
ICT	Information and communications technology
IT	Information technology
IWGN	Interagency Working Group on Nanoscience, Engineering and Technology
NEC	National Economic Council
NETS	National Enabling Technologies Strategy
NGO	Non-government organisation
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
nm	Nanometre
NMI	National Measurement Institute
NNI	National Nanotechnology Initiative
NNS	National Nanotechnology Strategy
NSET	National Science and Technology Council subcommittee on Nanoscale Science, Engineering and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
OECD	Organisation for Economic Co-operation and Development
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PACE	Public Awareness and Community Engagement
PCAST	President’s Council of Advisors on Science and Technology
PMSEIC	Prime Minister’s Science, Engineering and Innovation Council
R&D	Research and development
RS/RAE	Royal Society and Royal Academy of Engineering
SSG	Safe Sunscreen Guide

STEM	Science, technology, engineering and mathematics
STS	Science and technology studies
TGA	Therapeutic Goods Administration
UK	United Kingdom
US	United States
UV	Ultraviolet (radiation)
USAXS	Ultra-small-angle X-ray scattering
WTO	World Trade Organization

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Prologue

As I approached my PhD research, a foundational influence was my past work as an environment and social justice campaigner, particularly the eight years I spent working for Friends of the Earth Australia (FoEA). I joined FoEA's Nanotechnology Project with a strong interest in the politics of emerging technologies oversight, and concerns that the interests of certain branches of industry were being privileged over those of wider publics. I found the work demanding, rewarding, baffling and frustrating. Some observers suggest that non-government organisations (NGOs) made a significant contribution to shaping nanotechnology debates. Conversely, I felt that the systemic criticisms FoEA made were ignored or marginalised, while its work on the environment, health and safety risks of nanomaterials resulted in few changes to existing regulations, all the while amplifying scientistic framings for what the group had wanted to be wider sociopolitical debates about desirable futures and the role within that of science and technology.[1]

When I began my PhD, I didn't initially plan to work on nanotechnology as a case study, but rather to explore broader opportunities for public interest science. Yet, in common with many other students, the questions with which I began were not those to which I eventually turned. The core interests I brought to my thesis are enduring, particularly regarding how we might better engage science and technology to help us foster the kinds of relations we want to cultivate between people and planet, and why it is so difficult to appreciate that another world – in fact a great many worlds – are possible.[2] In the end I sought to explore the latter question by asking a slightly different one – how may we understand the world-making success of the proponents of one particular technology, nanotechnology?

I have been asked periodically about how I manage study of policy debates in which I played a role. It is a commonplace assumption that the interests and commitments of community activists present a barrier to rigorous scholarship – unlike those, for example, of individuals who were previously scientists, regulators, lawyers or public servants. My response to such assumptions is informed by work in the field of science and technology studies (STS) that explores relations between the normative and epistemic dimensions of knowledge claims.[3] I

[1] For an analysis of the role of non-government organisations in nanotechnology debates I co-wrote while a campaigner with Friends of the Earth Australia see Georgia Miller and Gyorgy Scrinis (2010).
[2] "Another world is possible" is the slogan of the World Social Forum; "it could be otherwise" is a "longstanding core slogan" of science and technology studies (STS, Woolgar and Lezaun 2013, 322).
[3] The relationship between normative commitments and epistemic authority has been of key interest to STS scholars who have asked how "a sceptical and reflexive stance in relation to scientific knowledge

recognise the "partial" and "situated" character of all knowledge (Haraway 1988, 1991) and that all scholarship plays a role in the politics of explanation. I employ the conceptual framework of co-production to understand the mutually constitutive relationship between science and society, and the scholar's role within it (Jasanoff 1996, 2004).[4] More specifically, in the investigation that follows, I have sought to be diligent in remaining open to new views and readings, to challenging my own assumptions regarding objects, policies and people, and to telling the complex story that my empirical research reveals. Indeed, in the course of study my understanding of objects, events, actors and their relations has been significantly transformed. Notwithstanding this, my perspective remains "partial". Further, the 'realities' that I describe, and which I help enact in this research, while always bounded by material 'truth', remain underdetermined by them (Law 2004; Mol 1999; 2002; see Part A Introduction).[5] However, what gradually became clear to me in the course of this research, as my theoretical and empirical grounding grew, is that this is the case for everyone involved in science policy. Scientists, politicians, bureaucrats, industry groups, technology analysts, social scientists, journalists, unions, NGOs and wider publics all play a role in building, transforming and resisting the 'realities' that are produced and elided in science and technology policy – even as the generative influence and normative ambitions of their work are sometimes obscured by its conformance with pre-existing world-making activities and extant patterns of power.

My thesis offers an investigation of this work of co-production.

[can] be reconciled with making authoritative recommendations for social policy", and, "reversing the argument... what value there can be in academic, scholastic or 'morally neutral' work on the sociology and politics of science if such work is not actively committed to the production of social change" (Jasanoff 1996, 393, 394). Sheila Jasanoff (1996, 2004) suggests that by illuminating the joint production of science and social order, and thereby collapsing distinctions between representation and intervention, the conceptual framework of co-production offers a means to overcome what some have cast as tensions between interpretative and normative scholarship. On the interplay between the instrumental, interpretative and normative traditions in STS see also Jasanoff (2011a), Edward Woodhouse and colleagues (2002) and Brian Wynne (2007). On shifting approaches within STS to conceptualising politics in science and technology, and to addressing questions of power and the structural dimensions of inequality, see David Hess and colleagues (2017).

[4] I elaborate my approach to co-production and my understanding of the co-construction of knowledge and social order in Chapter 1 and the Part A Introduction.

[5] Put differently, given that the 'reality' with which we live is underdetermined by its material correlates, "'truth' is not and cannot be the only arbiter" (Law 2004, 66). Even where analysis is strictly bound by 'the facts', multiple accounts of what 'really took place' are possible (see also Part A Introduction).

Chapter 1: Introduction

President Bill Clinton launched the National Nanotechnology Initiative (NNI) at a time of great optimism regarding the 'new economy'.[1] In the heady midst of the dot-com boom, and before the events of September 11 2001 that shattered a sense of United States (US) inviolability, Clinton hailed the power of technology to deliver a new century of US prosperity. He told his audience that, in addition to his administration's fiscal restraint and the economic globalisation it had supported, government-backed high-tech success had underpinned the nation's economic and social achievements:

> "*The real reason [the US is experiencing economic expansion] is the exponential growth in information technology, and how it is rifling through every other sector of our economy... So we have to say to people, if you like the fact that we have the lowest unemployment and welfare rolls [sic] in 30 years, the lowest minority unemployment rates ever recorded, the lowest female unemployment rate in 40 years, the lowest poverty rates in 20 years... you have to understand that all that, at least in large part, is because of the ability of the discoveries of science and technology*" (Clinton 2000b, 5).

Nanotechnology, which Clinton (2000b, 3) introduced as the "manipulat[ion of] matter at the atomic and molecular level", was heralded as the latest in a long line of ground-breaking technologies pioneered by visionary US entrepreneurs with the support of their government. Clinton's announcement of half a billion dollars in funding for the NNI was widely understood – as internal polling advice shows it was intended to be (Penn Schoen Berland Associates 1999) – as a practical instantiation of his commitment to build a "bridge to the 21st century" (Clinton 1996, unpaged). This "bridge" encompassed many areas of public policy. Nonetheless, consolidating US technological strength was key to Clinton's vision, as the means to perpetuate economic prosperity, achieve social goals, and maintain geopolitical hegemony (Clinton 2000a; Clinton and Gore 1993). At the same time, and often with explicit reference to the US example, governments in Europe, Asia and elsewhere adopted the 'new economy' discourse and sought to expand their own high-tech sectors (Drysdale 2004; Godin 2004, 2009), including by launching nanotechnology programs (Shapira and Wang 2010).

Yet in 2017, the key tenets of the Clinton era seemingly face unprecedented criticism, among them the promise of the 'new economy' and expectations of technology's axiomatic

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[1] For an introduction to endogenous growth theory and the 'new economy' it posits see Paul Romer (1990, 1994); on its then currency as a 'policy narrative' see Benoît Godin (2004, 2009).

progressive force (cf. Kleinman 2005; see also Sarewitz 1996; Stirling 2009a, 2010a). On the eve of Donald Trump's assumption of the US Presidency, outgoing Vice-President Joe Biden warned his World Economic Forum audience that, internationally, the inequitable distribution of "benefits" and "burdens" from globalisation and automation enabled by "advanced technology" was "effectively hollowing out the middle class – the traditional engine of economic growth and social stability in Western nations" (as quoted in Chan 2017, unpaged).[2] The conviction of the Clinton administration and that of its international contemporaries in cutting-edge technology as the means to achieve domestic and foreign policy aims no longer appears self-evident (if it ever did), but demands explanation.

The singling out of nanotechnology for prioritised funding and political support similarly begs elucidation. In the early 2000s nanotechnology was presented, often without apparent irony, as "the next industrial revolution" (IWGN 2000) and as *the* platform upon which a new era of high-tech innovation, economic activity, and geopolitical competition would be based. Yet, as the more recent rhetorical retreats away from the con-joined commitment to technological innovation and globalisation as *the* inexorable future reveal, the positioning of a field such as nanotechnology as necessarily 'next' in a long trajectory of technological progression is as much a contingent political accomplishment as it is any straightforward reflection of scientific achievement. In this light, this thesis asks how nanotechnology – then a heterogeneous field of largely non-commercial research – became seen as a 'revolutionary' new technology whose development merited dedicated national programs. The analytic task is to understand both how policy responses to nanotechnology were intertwined with broader political and economic developments, and how they responded to the ongoing work of making identity and meaning for the policy object 'nanotechnology' itself. As such, this thesis also asks how shifting enactments (cf. Law 2004; Mol 2002) of 'nanotechnology' help illuminate the political work performed by science and technology, and the ways in which science and science policy help to shape or maintain political orderings.[3]

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[2] In Joe Biden's statement, inadequately managed advanced technology is now cast as a threat to "the middle class", which is itself named as the "engine of economic growth" and "social stability". Similarly, in his final public address, President Barack Obama emphasised "the relentless pace of automation that makes a lot of good middle class jobs obsolete" (as quoted in TIME Staff 2017, unpaged).

[3] Notably, the maintenance of the National Nanotechnology Initiative (NNI) under Presidents Bill Clinton, George W. Bush and Barack Obama may in part be explained by the amenability of the policy object 'nanotechnology' to being (re)enacted concordant with shifting Presidential priorities. The largely civilian 'nanotechnology' that Clinton deployed was repurposed in the context of the Bush-era 'war on terror' (Chapter 4), and again to support Obama's aims to stimulate solar energy and sustainable manufacturing (see NSTC 2011).

Taking up these tasks with the objective of exploring wider science-state relations, this thesis probes the tensions in late-modern, capitalist states' efforts to sponsor technological innovation. I examine the emergence of nanotechnology as an object of research and innovation policy in the US and in Australia, and the subsequent design and implementation of Australian national nanotechnology policy. I argue that state support for nanotechnology, and indeed the policy object 'nanotechnology' itself, were situated achievements (cf. Balmer, et al. 2016). Conditioned by structural, institutional and ideational factors, they were also the product of contingent circumstances and the active work of intermediaries acting between the spheres of science, policy and politics (cf. Meyer and Kearnes 2013). This chapter begins by introducing the thesis rationale, before detailing my research questions and method, and providing an outline of the chapters that follow.

1.1. Thesis rationale

The coordination of states' responses to 'prospective techno-futures' (N. Brown, et al. 2000) offers a window on to how governments work, in sometimes unconscious, uncoordinated and unsuccessful ways, to bring wished-for futures into being. Science and technology policy is a site at which some 'imaginaries' – shared visions of desirable futures and the social, scientific and technological systems with which they are intertwined[4] – are privileged other others. Certain "imaginations of progress" condition "the ways our progress actually unfolds" (Stirling 2009a, 5); they attract research funding, reshape legislative agendas, motivate the efforts of the bureaucracy, and foreclose consideration of alternatives. Late-modern, capitalist states are often regarded as sharing an imaginary in which growth, progress and military advantage are based on technological innovation; on both ideational and instrumental grounds, the existence among them of "protechnology state policies" is often assumed (cf. Jasanoff 2005a, 8; see also Barry 2001; Block and Keller 2011; Wynne 2014). Yet 'technological progressivism' (Kleinman 2005) is not uniform among policy makers, and technoscience proponents are not always successful in securing government backing for particular projects. For this reason, policy and political responses to nanotechnology afford a rich opportunity to compare the efforts and outcomes of nanotechnology champions' attempts to secure priority support for their field, and broader approaches to state-sponsored technological innovation, in the US and Australia.

[4] For recent work tracing the use in science and technology studies (STS) of 'imaginaries' and its conceptual and etymological heritage see Maureen McNeil and colleagues (2017) and Sheila Jasanoff (2015a). My treatment of imaginaries is elaborated in the Part A Introduction.

In the late 1980s and 1990s, excitement surrounding developments in nanoscale physics, chemistry, materials science, engineering and biology was high. The new ability of scientists to manipulate individual atoms, the very building blocks of the material world, was touted as a dramatic breakthrough. The nanomaterials, nano-devices and nano-manufacturing this made possible were predicted to transform science, industry and social-ecological relations (Roco, et al. 1999). The NNI announced by Clinton (2000b) was the world's first major national nanotechnology program.[5] Widely understood as a quest to dominate an emerging site of economic and geopolitical competition, the NNI was observed to signal the ascendance of a more utilitarian, commercially-oriented US science policy (Johnson 2004; Rudd 2009), albeit one that had been gestating for some time (Brooks 1996; Ezrahi 1990; Greenberg 2001).[6] The NNI catalysed a period of heightened state interest in nanotechnology. It led to the establishment of over 60 national nanotechnology programs internationally (Shapira and Wang 2010), including in Australia, and investment to date by the US government alone of nearly US$24 billion in public funding for nanotechnology R&D (NSTC 2016). Yet by 2013 the early enthusiasm surrounding nanotechnology had dimmed amidst what some saw as disappointing outcomes from the research investment.[7] The Australian government, long riven by disagreement regarding the state's role in sponsoring innovation (Dodgson, et al. 2011; Marsh and Edwards 2008, 2009; Thurbon 2012), disbanded its dedicated nanotechnology policy apparatus.

Science and technology studies (STS) is a comparatively new academic field that takes as its central interest the relationship between science, technology and society. STS has both explored and developed methods for uncovering the indeterminacy of sociotechnical change and the specificity of the circumstances in which: particular technological applications become predominant (Bijker 1995; Latour 1992; Pinch and Bijker 1984; Winner 1986); technoscience[8]

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[5] Although, as sceptics have noted: "the NNI had no fiscal authority. It was simply a coordinating mechanism, its 'budget' the sum of the contributions of participating federal agencies (25 to date), which had the latitude to address the initiative's priorities as a function of their own missions" (Eisler 2013a, 245).
[6] On science policy's role in the earlier development of biotechnology see Nicolas Rasmussen (2014), Steven Vallas and colleagues (2011), and Susan Wright (1994).
[7] See, for example, one analysis that the United Kingdom had "given up on nanotechnology" (R.A.L. Jones 2011b, unpaged).
[8] The term 'technoscience' has a long and varied history of use. My employment of it is informed by that of Bruno Latour (1987) who emphasises the hybridity of 'facts' and 'artefacts', the production of knowledge and that of application-oriented inventions. I also draw on the more critical approach of Donna Haraway (1997, 4), who uses 'technoscience' to denote not only the collapse in distinctions between science and technology and between technical knowledge and political intervention, but also a broader array of "transgenic" fusions between subjects and objects, the 'natural' and the artificial. She

fields form (Balmer, et al. 2016; Hedgecoe 2003; Mody 2011; Molyneux-Hodgson and Meyer 2009; A. Powell, et al. 2007; Vallas, et al. 2011; Wright 1994); scientific and social classification systems are developed (Bowker and Star 1999; Hacking 1999; Haraway 1989, 1991, 1997); authority for knowledge claims is achieved (Barnes and Bloor 1982; Collins 1981; Gieryn 1999; Jasanoff 1990, 2005a, 2011c; Latour 1987, 1993, 1999; Wynne 1982, 1996); and epistemic and political order is co-constituted (Ezrahi 1990; Jasanoff 2004; Shapin and Schaffer 2011 [1985]), including in the appraisal, management and communication of risk (Beck 1992; Kinchy, et al. 2008; Moore, et al. 2011; Stirling 2008a; Winickoff and Bushey 2010; Wynne 2002). The political mobilisation of scientific knowledge and the ways in which the "ordering of *nature* through knowledge and technology" is intimately entangled with "the ordering of *society* through power and culture" (Jasanoff 2004, 14, emphases in original) has been a central concern of generations of STS research. It is therefore perhaps surprising that contingency and indeterminacy *within* the architectures of government and state policy designed to promote technological innovation have remained relatively under-examined.[9] While the state is commonly depicted as technopositive, the specificity of the forms in which such technopositivity is expressed, the impetus for particular research support mechanisms or innovation policies, and the frictions that occur within government between sponsoring technology development and competing objectives, have received limited attention in many STS accounts. This thesis aims to explore these dynamics as I investigate processes of co-production, "the simultaneous production of knowledge and social order" (Jasanoff 1996, 393; see also Jasanoff 2004), within science and technology policy itself.

1.2. Research questions and central argument

The key question asked by this thesis is: how can we account for the elevation of nanotechnology as an object of research and of innovation policy in the US and in Australia, and for the subsequent design and implementation of national nanotechnology policy in Australia? My central interest in technology policy as a site of world-making is explored through three additional research questions. Firstly, how did these late-modern, capitalist states understand, justify and prosecute their role in creating, fostering and overseeing this

associates these fusions with "late-twentieth century transnational capitalism" and points to the "feroci[ous]" "transformations in lived daily life" it has produced (Haraway 1997, 4).

[9] Notable exceptions to this observation include earlier studies such as those by Paul Forman (1987) and Donald Mackenzie and Graham Spinardi (1988a, b), and more recent work by innovation scholars (Block 2008; Block and Keller 2011; B. Martin and Nightingale 2000) and in the New Political Sociology of Science (Frickel and Moore 2006).

new field of technoscience? Secondly, how did nanotechnology proponents seek to embed within the architectures of the state their imaginary of future, nanotechnology-enabled prosperity, contingent only on present-day government support, and to what extent did they succeed? And thirdly, how did 'market failure' policy rationales (Dodgson, et al. 2011; Marsh and Edwards 2008)[10] and scientistic commitments (Doubleday and Wynne 2011; Kleinman 2005; Wynne 2006; see also Part B Introduction) shape the design and implementation of Australian national nanotechnology policy, and political and policy responses to nano-product regulatory debates?

The central argument developed in this thesis is that state support for nanotechnology, the form that this took, and the policy object 'nanotechnology' itself, were *situated achievements* and the product of *active work* (cf. Balmer, et al. 2016).[11] That is, the particular policy commitments that emerged were located in, responsive to and made possible by their historical, structural and ideational environments. Further, these policy commitments were accomplished via the extensive efforts of intermediaries acting between the spheres of science, policy and politics (cf. Bijker, et al. 2009; Guston 2000; Jasanoff 1990; Kleinman 1994, 1995; Meyer 2010; Meyer and Kearnes 2013). Nanotechnology policy making in each country was overdetermined by its macro-economic and political context (cf. Sunder Rajan 2006), and some important elements of this were common to both the US and Australia. Nonetheless, policy making was also shaped by features that pertained to the local context, and by the work of particular individuals and institutions (cf. Kleinman 1994, 1995; Mackenzie and Spinardi 1988a, b; Wright 1994). The work of this thesis shows the specificity of the circumstances in which state support for nanotechnology was secured in both the US and in Australia, and the form that this support took, and reveals how nanotechnology's meaning as a policy object was locally (re)constituted. In so doing it highlights sociopolitical contingency in the assumed 'centres of calculation' (Latour 1987) of global technoscience, and in the situated (re)enactment of ostensibly universal policy objects.

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[10] Neo-classical economic thinking privileges the role for 'the market' in new technology development, but typically recognises "externalities, sunk costs, asymmetric and imperfect knowledge and transaction costs... as sources of market failure" (Marsh and Edwards 2008, 9). 'Market failure' rationales for public policy therefore limit state initiatives to measures designed to redress these specific instances of 'failure' (but see, for example, Levidow, et al. 2012 on the opportunist use of 'market failure' rationales to justify measures designed to create new markets).

[11] Andrew Balmer and colleagues use the term 'situated' to emphasise that the production of objects and knowledge is located not only in particular contexts, but also in particular practices (cf. Mol 2002). On 'situated' knowledge see also Haraway (1988, 1991).

This thesis shows the role of the state in shaping technological futures to be at once greater, more diffusely organised, more characterised by sites of friction, and more reactive to the imaginaries and entrepreneurial efforts of the research sector and of science-policy intermediaries than is commonly recognised. This complicates previous representations of state-science relations as those of delegated power between principal and agent (eg Braun and Guston 2003; Guston 2000), but so too does it challenge the often assumed responsiveness of science and technology policy to the interests of capital. In common with previous STS scholars I observe an alliance between science and capital facilitated by the state which is transforming social relations. However I show that it was not simply the expansive potential of "lively capital" (Sunder Rajan 2006, 2012) that gave impetus to nanotechnology policy development, but rather the advocacy of elite science-policy intermediaries who had themselves internalised the need for publicly-funded research to support commercial imperatives (cf. Kleinman and Vallas 2001; Vallas and Kleinman 2008). Indeed, I show that in both Australia and the US, government policy to prioritise nanotechnology research and to spur its development was advocated by researchers and government bureaucrats in the absence of substantial industry engagement in the field. Predictions of nanotechnology's future economic impact did not (at least initially) reflect the activities and expectations of capital, but were rather a tactic of science-policy intermediaries to boost funding prospects for the physical sciences (Eisler 2013a, b). These efforts were broadly successful. Yet, in the subsequent development of Australian nanotechnology policy, appeals for government to foster the industrial development of a 'nanotechnology' sector achieved more ambiguous results. In the context of widely shared interpretations of the constraints on state activities posed by 'free market' commitments, nanotechnology policy was framed narrowly, and focused on activities that could be justified as both 'science-based' and addressing 'market failure'. The findings of this study will be of interest to promoters of more strategic interventionist innovation policy, but also to those who argue for more democratic participation, accountability, and public good commitments in science and technology oversight.

1.3. Analytic approach

In this thesis I employ and contribute to what has been termed the 'idiom' of co-production (Jasanoff 2004, 3). Co-productionist accounts reject as inadequate both socially and technologically determinist explanations of how knowledge is generated, circulated, challenged and stabilised, and insist that natural and social orders are produced together. As

Sheila Jasanoff (2004, 2-3) observes, how we know and represent 'reality' is not only inescapably intertwined with how we think it ought to be, but also constitutive of it. Similarly, Bruno Latour (1987) emphasises that when scientific activity and fact making is observed "in the making", there is no clear separation between 'natural' or 'scientific' and 'social' factors – the categories of both 'nature' and 'society' reflect the settlement of controversies, and not their cause (see also Latour 1993, 1999). Like Latour, Jasanoff (2004, 3) stresses the need to avoid allocating ontological primacy to either social or material dimensions of knowledge claims, or accepting the simplifications of social or technological determinism. However Jasanoff's approach foregrounds the mutually constitutive relationship between normative, epistemic and ontological dimensions of knowledge claims, emphasising the influence of durable relations of power, aspects of sociopolitical and moral choice, and the influence of imagination. Further, she extends the analytic reach of co-production beyond science and technology to the "cognitive and material bases of other powerful political and cultural configurations" (Jasanoff 2004, 274). This more expansive approach to co-production underpins my analysis of science and technology policy making, and my conceptualisation of science-state-market relations.

There are multiple theorisations of science-state-market relations in previous STS work. Science policy scholars have long regarded the state's role in sponsoring technological innovation as complicated – especially in political terms – by arguments for the proper autonomy of both science and markets from government 'interference' (Brooks 1986, 1996; Dodgson, et al. 2011; Greenberg 2001; Marsh and Edwards 2008).[12, 13] Nonetheless, recent study illustrates the extent to which – in sometimes unacknowledged ways – governments' backing is pivotal to nascent technological sectors' development (Block 2008; Block and Keller 2011; Weiss 2014). STS scholars have observed that states offer such backing not only in the pursuit of instrumental objectives, but also in broader projects of nation-building, in which imaginaries of the nation and what it stands for may be equally at stake (Jasanoff 2005a; Jasanoff and Kim 2009, 2013).[14] Somewhat differently, other work has highlighted the

[12] Such arguments suggest the ontologically prior and separate existence of both 'science' and 'markets' from government, which, consonant with long-standing STS critiques (for a review see Irwin 2008), my empirical work disproves throughout the thesis.

[13] In recent decades state-backed technological innovation has also been seen as complicated by the anxieties and resistances of disaffected publics (Felt, et al. 2007; Gottweis 1998; Jasanoff 2005a; Welsh and Wynne 2013; Wynne 2014) and by demands for greater social accountability in setting research agendas and in science and technology governance (Benjamin 2013; Epstein 1996; Frickel and Moore 2006).

[14] The concept of 'sociotechnical imaginaries' is elaborated in the Part A Introduction.

influence of markets and of 'market logics' in shaping both contemporary technoscience and systems of its valuation (Sunder Rajan 2006, 2012), the "asymmetric convergence" between academic and industrial research (Kleinman and Vallas 2001; Moore, et al. 2011; Vallas and Kleinman 2008), and the influence of neoliberalism[15] in science's "escalated and enhanced commercialization" (Mirowski 2011, 90; see also Mirowski and Sent 2008). Collapsing any distinction between understanding science as being directed by either the state or by capital, Robert Doubleday and Brian Wynne observe a "late-twentieth-century convergence" between the "state, science and global capital" (2011, 242; see also Wynne 2016). Yet despite the compelling insights of this literature there is a tendency within it to universalise the alliances between governments and capital-intensive emerging technologies, and between capital and new technology development, in ways that obscure both the contingency of these relations and periods in which their alliance has been more obviously fractured. Further, overlooking processes of co-production within science and technology policy making and in emerging technologies development, in some studies one is left with a somewhat determinist account of the influence of state-policy architectures or of the logics of contemporary forms of capital accumulation on the trajectory of new technology development. A common image across these accounts is that processes of technology development are the *result* of science policy decisions, research funding prioritisation or commercial strategies, rather than a more complex, situated and provisional accomplishment.

In this thesis, while I understand convergence between science, the state and capital as exerting a conditioning influence on the events and phenomena I investigate, I emphasise its unevenness in two key respects. Firstly, I stress that states' approaches to technological innovation are heterogeneous. Unlike much influential STS work (see above), I do not assume that governments' commitment to fostering emerging technologies' development is evenly distributed. Indeed, I find divergent views in the US and in Australia regarding both technology's economic value, and proper roles for government, scientists and markets in its

[15] In this thesis I understand 'neo-liberalism' as a heterogeneous (Birch and Siemiatycki 2016) and often internally incoherent ideology (Ryan 2015) that holds 'the market' to be the best arbiter of value, allocator of resources, and mechanism for achieving social order (Birch 2015). It nominally – albeit not practically (Ryan 2015; Weiss 2012) – restricts government's role to setting and policing the 'rules' within which 'the market' will operate, and responding to areas of identified 'market failure' (see above). Government's activities, along with "most other areas of economic and social life", are expected to conform to 'market-based' logics (Thurbon 2012, 278). In the context of technological innovation, 'neoliberal' or 'free market' policy settings presume 'the market' to be ontologically prior and accord the private sector a central role in technology development. Conversely 'developmentalist' policy paradigms grant the state a proactive role in facilitating techno-industrial transformation (Thurbon 2012; see also Part A Introduction).

development. And secondly, beyond observing, as Kelly Moore and colleagues do, that "neoliberal policies and programs have never appeared in a standard fashion across the globe, because in practice 'free markets' encounter cultures, histories, and geographies that make it difficult to implement" (2011, 509; see also Ong 2007), I emphasise the constructedness and situated meaning of even apparently universal ideologies such as neoliberalism. It is not only that a 'free market' imaginary encounters friction in practice, but that the very understanding of what 'free market' commitments mean – for example, for science policy – is locally (re)constituted. For example, it is the same deference to 'market logics' that underpins the Australian government's emphasis on public funding for commercially relevant science, which in the US ostensibly militates against it (see Part A Introduction). The specificity that I call attention to here underscores a wider argument and analytic commitment. That is, I observe that just as scientific knowledge and the products of technoscience are co-produced, so too are particular science-state-market relations and policy settlements.[16]

A co-productionist analysis underpins my examination of how work to construct new objects of technoscience and new innovation policy agendas reflected the interwoven influence of economic and political dynamics, technical developments, and beliefs about and aspirations for the future. In turn, the empirical and interpretative work of this thesis helps contribute to some of the 'why' and 'how' questions that remain largely unexplored in co-productionist accounts to date (cf. Jasanoff 2015a, 3). Specifically, my research questions support an investigation of *how*, *where* and *by whom* policy making was co-produced with imaginaries in which future prosperity is contingent on government backed, high-tech competitiveness, and the limited salience of such imaginaries to some political audiences. I use Annemarie Mol's (1999, 2002) concept of 'ontological politics'[17] and enactment[18] through sociomaterial practice

[16] There are parallels here to the 'internalist-externalist' debates surrounding sources of change in science (for a review see Shapin 1992). Similar to Latour's (1987) insistence that the categories of 'science' and 'society' should be understood as the consequence of the settlement of controversies, rather than used as explanatory resources, I highlight any demarcation between 'politics', 'science' and 'markets' as the contingent result of settlements, and not their cause (see also Bijker, et al. 2009; Gottweis 1998; Irwin 2008). Related arguments can be made regarding the provisional achievement of meaning for other concepts and categories in science policy, which should be subject to analytic inquiry, rather than understood as pre-existing their situated articulation (see also Part A Introduction).

[17] The term 'ontological politics' reflects an acknowledgment of multiplicity: the 'reality' of any category or object is underdetermined by its material 'truth'; alternative performances or 'enactments' of categories and objects are therefore possible, which hold differing stakes for the actors involved; and particular enactments are consequently of political consequence and analytic interest (Mol 1999, 2002). See also Part A Introduction.

[18] In her early writing on ontological politics (eg Mol 1999) Annemarie Mol uses the language of 'performance', which she subsequently eschews in favour of the (in her view) synonym 'enactment' (Mol 2002). Mol avoids 'performance' because of its associations with the dramaturgical metaphor

to help elucidate how proponents forged a 'reality' for nanotechnology and its economic promise that was underdetermined by any material 'truth' of the nascent field (for more detailed discussion of this concept and my employment of it in a co-productionist account see Part A Introduction). Yet unlike Mol I ask how particular enactments and policy making reflected, responded to and engaged with structural features of the policy environments in which they took place (cf. Klein and Kleinman 2002; Wright 1994), and how macro scientific, political and economic dynamics make clear the stakes of particular enactments. My employment of the concept of ontological politics in this study and my approach to reading Jasanoff and Mol together are elaborated in the Part A Introduction.

1.4. Methods

This thesis investigates the rise of nanotechnology as an object of innovation policy in the US (mid-1990s to 2003) and in Australia (2000-2005), and the subsequent design and implementation of Australian nanotechnology policy (2005-2013). In so doing, I employ and expand a technique developed in STS laboratory studies. In a variation of Latour's (1987) invocation to 'follow the actors', I 'follow' nanotechnology from its enactment as an object of innovation and as a research priority, through to the debates surrounding state support for commercialisation and the regulation of nano-products. Following Kaushik Sunder Rajan (2006, 97) my use of empirical sites in the two countries is not intended to support a symmetrical comparison, but rather to offer "situated juxtapositions" that highlight the specificities of history, political economy and science-state relations, and the contingency of the 'reality' that is made for and by 'nanotechnology' at each site (for the value of comparison see also Jasanoff 2005a, 13-41; Law 2017).

I take a broad view of 'policy' and policy making 'practice' as objects of study, informed by my interpretative methodological orientation. Interpretative approaches to policy analysis reject the possibility of 'rational' explanations of policy outcomes, and, relatedly, of positivist approaches to policy analysis (Fischer and Forester 1993; Fischer and Gottweis 2012; Hajer 1995; Yanow 2000).[19] Instead, they emphasise the "social construction of the normative – and

employed by Erving Goffman, and the implication that a 'real reality' may exist behind the performance. For the same reasons I will use the term 'enactment' in preference to 'performance'.

[19] The positioning of interpretative policy analysis in opposition to the realist tradition in political science resonates with that of STS towards positivist philosophies of science. There are some explicit intersections in these literatures (for an exemplar see Gottweis 1998), but, more broadly, much work in

often conflicting – policy frames of those who struggle over power and policy" (Fischer and Gottweis 2012, 3), and pay particular attention to the ways in which language, argumentation and ideas "are used to constitute social, economic, scientific, or political phenomena, to endow them with meaning, and to influence their operation" (Gottweis 1998, 3). These commitments imply an expansive view of policy making activities. Accordingly, I examine the formal policy statements released to support the NNI, the National Nanotechnology Strategy (NNS) and the National Enabling Technologies Strategy (NETS), but I also appraise press releases, bureaucratic advice, consultants' reports, parliamentary and congressional inquiries, internal government correspondence (Appendix B and C),[20] oral histories of key stakeholders recorded by other scholars, and 70 interviews I conducted for this research (Appendix A, see also below). I treat the state's documentation of its own activities, the public statements of its representatives, the internal correspondence of policy makers, stakeholders' ephemera (eg websites, submissions, public statements), and functionaries' recollection of their involvement in particular events as sites at which constitutive work, the production of epistemic claims, the expression of state thinking, and interactional struggles may be observed.[21] Evaluating this broad documentary base supports my analysis of how framing, discursive argumentation and narrative practices were variably employed in anticipation of particular audiences (cf. Mahony 2015; Wynne 2002, 2005). Additionally, in some instances this approach is required by the absence of detailed policy statements. Most notably in relation to the NNS, millions of dollars were allocated to a program for which a formal policy statement was never released. STS has long grappled with the expression of presence and absence; I bring this attention to the varying expression and form taken by science and technology policy.

STS employs interpretative methods (for a review of STS approaches to science and technology governance see Irwin 2008).

[20] I reviewed the public archives of internal correspondence, policy advice and public communications from the Clinton administration that relate to the NNI (see Appendix C). I also reviewed a large number of documents obtained under seven separate *Freedom of Information Act 1982* (FoI) requests to the Australian government and regulators. Six of these requests were made previously by other parties, and related documents were obtained either from government agencies subsequent to their listing on a public disclosure log or from the public domain. One new FoI application was made for the purposes of this research (see Appendix D).

[21] My approach to this analysis is informed by ethnographic studies in laboratories and other institutions that investigate the diverse social and material practices associated with constituting the objects of technoscience and particular epistemic cultures (eg Cohn 1987; Knorr Cetina 1999; Latour and Woolgar 1986 [1979]; Mol 2002; Traweek 1988). I am guided also by previous investigations of states' formulation of science and technology policy (eg Gottweis 1998; Jasanoff 2005a; Kleinman 1994, 1995), and the fates of particular research and development programs (eg Forman 1987; Mackenzie and Spinardi 1988a, b).

I conducted semi-structured interviews[22] with 49 Australian and 21 US nanotechnology policy stakeholders between September 2013 and December 2015. These were largely 'in-depth' interviews: a few lasted 30-45 minutes, with most taking approximately 90 minutes, and some longer.[23] In several instances interviewees also answered follow up questions via email. Participants included: a former Minister; Ministerial and Presidential advisors; public servants and agency officials; regulators; technical scientists, safety scientists and social scientists; technology analysts; and members of research councils, think tanks and foresight groups; industry representative associations; commercial companies; unions and NGOs. I used a purposive sampling technique: interviewees were selected because of their known contribution to nanotechnology policy development or debate, because of the professional position they occupied during such policy development and debate, because they were nominated by other interviewees as key to understanding particular periods, decisions or events, and/ or because I considered it likely that they may have knowledge or experience relevant to a question raised by my study.[24]

Despite the importance of interviews as a key data source for social research, there are disparate views regarding proper methods for their conduct and analysis, and also concerning what such interviews may reveal (Baker 2004; Holstein and Gubrium 2004; J. Miller and Glassner 2004). Consonant with my co-productionist commitments, I reject both positivist treatments of interview respondents as a "vessel of answers" from which, given the successful application of unbiased procedures, a mirror image of the pre-formed subject's already existing thoughts and feelings may emerge (Holstein and Gubrium 2004, 146), and also assertions that the only knowledge obtainable from an interview concerns the locally specific interaction. James Holstein and Jaber Gubrium suggest that active (non-standardised)

[22] UNSW Human Research Ethics Advisory Panel B approval numbers 14136 and 13095.

[23] Approximately three quarters of the interviews took place face-to-face, with the remainder via telephone or Skype audio. Interviews were digitally recorded and mostly professionally transcribed. In one instance, the recording failed and a written summary of the interview was approved by the interviewee.

[24] Interviewees were all offered anonymity (Appendix B), and any attributed quote, statement or information is presented in this thesis with explicit written permission. In order to safeguard anonymity within what particularly in Australia is a modest-sized professional community, I describe the professional role of interviewees in only general terms (eg lawyers, ethicists, sociologists and those engaged in foresighting work are all described as 'social scientists'). Further, some of my interviewees have occupied multiple professional roles over time, and because reference to any particular range of roles would compromise their anonymity I have cited only the primary role occupied by an interviewee in the period for which their interview is most relevant. A limitation of such measures is its removal of some specificity in the identification of interviewees' 'membership categories' (Baker 2004), and the obscuration of the exchange which occurs over time between individuals' professional categories (for example as someone identified as a 'technical scientist' for the purposes of our interview subsequently became an 'industry representative' or a 'regulator').

interviewing is always both interactional and constructive: interviews are "collaborative accomplishments" in which the objective is "to provide an environment conducive to the production of the range and complexity of meanings that might occur to all interview participants" (Holstein and Gubrium 2004, 141, 152). My approach to interviewing and its analysis is informed by this understanding, but in my evaluation of what interviews may reveal, I also follow Jody Miller and Barry Glassner (2004, 126) in the view that interviews: "may provide access to the meanings people attribute to their experiences and social worlds. While the interview is itself a symbolic interaction, this does not discount the possibility that knowledge of the social world beyond the interaction can be obtained". Similarly, I do not discount the possibility of obtaining information regarding events or activities from interviews; to the extent that I use content from interviews for empirical purposes, I have sought to triangulate this with other sources.

In-depth interviews aim to build rapport between interviewee and interviewer to create the space for respondents' reflections on their own actions, thinking or behaviour, or those of the membership categories of which they form part (J. Miller and Glassner 2004). One influence on the rapport that I built with some interviewees was our past professional relations in the context of my earlier work as a nanotechnology campaigner with Friends of the Earth Australia (FoEA, see Prologue). I had had some previous contact with approximately three quarters of my Australian interviewees, albeit very few of my US interviewees. While recognising my altered professional membership category (from community campaigner to student researcher), many interviewees addressed me collegially and appeared to identify me as a fellow former policy stakeholder. They evinced a willingness to share their own experiences and perspectives of activities we had sometimes both participated in, which for some included views regarding the merits or deficiencies of FoEA's activities or analysis.[25] A small number of other interviewees were noticeably guarded or defensive; some enjoined me to be mindful of my new responsibilities to present a 'balanced' analysis. No doubt both responses influenced particular interviews, despite my efforts to approach all interviews in a spirit of respect and open-mindedness, and to emphasise my responsibilities to research participants (for example in treating their insights and comments with strict confidentiality; Holstein and Gubrium 2004;

[25] This emphasises the range of dimensions at play in respondents' identification of interviewer's membership categories (cf. J. Miller and Glassner 2004) – that is, even non-community sector participants identified some commonality in membership category with me as a former policy stakeholder. This is not to say that the stories shared by even 'collegial' respondents were not affected by their perceptions of my own epistemic or normative commitments. It is interesting, for example, to observe that stronger criticism of Friends of the Earth Australia's activities appeared to be expressed by interviewees cited by Stephen McGrail (2011).

J. Miller and Glassner 2004). In analysing all interviews I sought to evaluate our "collaborative accomplishment" mindful of such dynamics.

My research also included observation of a consultative forum on nano-products' regulation conducted by the Australian Pesticides and Veterinary Medicines Authority. This was with the written permission of its organiser, and in accordance with 'Chatham House Rules', which governed participation in the event more broadly. This permitted me to take detailed notes, including of presentations, discussion and the interactions of participants, but with no recording of either individuals' names or their institutional affiliations.

Throughout my analysis of interviews, archival records and other observations, I am attentive to the interplay between "the political economy of science – the power relations that affect the direction and growth of research and that crystallize in government policy" (Wright 1994, 8; see also Birch 2013), and the micro-level actions, motivations and social worlds of individuals and groups. This analytic commitment is supported – even required – by my empirical investigation. The structural factors conditioning nanotechnology policy making, not least those of political economy and the extension of 'market logics' (variably interpreted) to the operations of both science and the state, were readily apparent and central to my investigation.[26] Yet at the same time, the extensive efforts of individuals in the research sector and in government to position nanotechnology for political patronage, to secure prioritised public funding for R&D, and to foster conditions thought favourable to its commercialisation, underscore the observation that: "technology is ... shaped not only by social structures and power relations, but also by the ingenuity and emotional commitment of individuals" (Bijker 1995, 4). There is also an important normative dimension of this approach. The recognition that "agents may act to change and modify structural constraints" (Wright 1994, 9), and 'open up' for consideration new or neglected policy pathways (Stirling 2008a), affirms the long-standing STS observation that world-making may always be done differently.

1.5. Contributions of this thesis

This thesis contributes to two areas that have been comparatively understudied by STS: how policy makers understand, justify and prosecute their role in the sponsorship and oversight of

[26] Past STS work has been criticised for having focused disproportionately on the micro-politics of knowledge production, probing questions of agency over enduring structural dynamics (see Birch 2013; Frickel and Moore 2006; Klein and Kleinman 2002; Mirowski and Sent 2008).

new technologies; and how particular imaginaries are instantiated in the objects, goals and implementation of science and technology policy. STS scholars have investigated science and technology policy as a site for nation-building, yet they have focused less on the vicissitudes of the state's sponsorship role, and have instead emphasised the subsequent *reception* of new technologies "into the political life" of nations, including via public debates regarding regulatory settings and the science that underpins them (Jasanoff 2005a, 290). Together with STS laboratory studies work, its investigation of 'knowledge controversies' within scientific communities (eg Collins 1981; Epstein 1996; Shapin and Schaffer 2011 [1985]) and among wider publics (eg Callon, et al. 2009; Epstein 1996; Gottweis 1998; Irwin and Wynne 1996; Jasanoff 1990, 2005a; Nelkin 1979; Wynne 1982) has "enabled the 'black box' of science to be at least partially opened" (Barry 2012, 326). Yet when it comes to government's science and technology *policy*, the 'black box' remains largely closed (Kearnes and Wienroth 2011a).[27] This elision of processes of co-production *within* states' sponsorship of technological innovation may inadvertently entrench assumptions of the state's technopositivity, and imply that politics lies *outside* science and technology policy making, rather than in the navigation by policy makers and political actors of continually branching sociotechnical development pathways (cf. Stirling 2009a, 2010a).

This thesis opens the 'black box' of nanotechnology policy making, expanding understanding of how it emerged as a policy object and gained the attention of policy makers, but revealing also the tensions that constrained state efforts to foster its development. Some previous accounts of the NNI's creation (eg McCray 2005, 2013; Motoyama, et al. 2011) recognise the influential alliance building and promissory work for the program of US government officials and academics, but leave instrumental rationales for the NNI's support by the state largely untroubled.**[28]** Others offer a more discursive (Gallo 2009) and openly sceptical (Eisler 2013a, b) analysis of nanotechnology's elevation as an object of public policy. However, while showing convincingly how work to forge the policy object 'nanotechnology' was responsive to political imperatives, this work does not further understanding of how the field was singled out for

[27] Sometimes this is the result of active work. For example, on efforts to keep shut the 'black box' of submarine-launched nuclear weapons development programmes see Donald Mackenzie and Graham Spinardi (1988b). Relatedly, the contribution and analytic orientation of STS to what Andrew Webster (2007) terms the "the policy room" has itself been the subject of debate (Nowotny 2007; Wynne 2007).

[28] Cyrus Mody's (2011) detailed account of the co-evolution of scanning probe microscopes and the community of scientists and technologists who used them is an exception. Mody shows how probe microscopists eventually – and with some hesitancy – adopted the 'nanotechnology' moniker for their work, and how this evolving "instrumental community" gave impetus to the NNI bid. Yet efforts to secure state support for the initiative, and their reception by the Clinton administration, are ancillary to his principal study.

priority attention in preference to similar framed fields. The origins of Australia's nanotechnology policy have received even less scholarly attention than that of the US. Earlier work has evaluated regulatory responses to nanomaterials' toxicity risks (Bowman and Ludlow 2012; Faunce, et al. 2008; Ludlow, et al. 2007), government-backed public awareness and engagement activities (Lyons and Whelan 2010, 2013; Marks and Russell 2015; Petersen and Bowman 2012; Russell 2013), and the rise and retreat of expectations for the field (McGrail 2011). Yet the only significant work investigating Australian nanotechnology *policy* (McGrail 2011) did not examine the circumstances of its creation, or how government's approach to policy making was constrained by long-standing tensions regarding the state's role as innovation sponsor. This thesis adds to this earlier work by investigating how, in what circumstances and with what consequences nanotechnology acquired ontological significance as an object of research and innovation policy (cf. Lynch 2013), the work and circumstances associated with proponents' successful efforts to attract the priority attention of government, and the specificity of the forms in which state support for its development was subsequently articulated.

1.6. Limitations of this thesis

The insights offered by this thesis are particular to certain times and policy environments. I do not claim that the findings of my case studies are transferrable to other periods, nor do I suggest that the experiences of Australia or the US are transferrable to other countries. In particular, the extent to which parallels exist between Australia's ambivalent sponsorship of technological innovation and that of other resource-rich, settler colonial states remains a question for future study. My findings are rendered more robust by the period of my investigation spanning government by different parties in both countries, and including the entire period within which nanotechnology rose and receded as an object of dedicated Australian policy. Yet I emphasise the temporal specificity of my case studies, even as comparison with other work points to the obduracy of certain structural features, imaginaries and institutional imperatives shaping science and innovation policy in each country. My focus in Part B of this thesis on Australia's implementation of national nanotechnology policy means that I do not explore the latter years of the NNI, which remains ongoing at the time of writing. Were my analysis to have focused on a later period of US nanotechnology policy, or on the activities and perspectives of nanoscientists, industry figures or publics rather than policy makers, a divergent if not necessarily contradictory account would no doubt have emerged.

There are some limits to the story I tell in this thesis that relate to my methodological commitment to 'following' nanotechnology through various sites of policy making. There is an ontological challenge associated with investigating a policy object whose metaphysical status is contested. As the chapters that follow make clear, my interviewees took quite different positions on whether 'nanotechnology' exists, and on whether we should conceive of it as a technology, a tool set, a platform, a new label for 'nanomaterials', or a brand to bring together divergent fields of nanoscale research and its applications. I use the concept of ontological politics and the language of enactment in part to emphasise the contingency of the versions of 'nanotechnology' that emerged as policy objects, and to highlight the stakes associated them (cf. Mol 1999). I have sought to establish critical distance (cf. Law 1991) from the milieus in which nanotechnology became a policy focus, and from the subject-object relations of particular stakeholders, in part by comparing political and policy responses to nanotechnology in the US and in Australia. Nonetheless, by 'following the object' and the engagement with it of policy and political actors in these countries, it is their categories, imaginaries and actions that I have investigated. While I argue that this extends our understanding of an under-studied range of subjects, I recognise that it neglects other subjects, particularly wider publics, whose responses to these objects and events may well be more sceptical (cf. Callon, et al. 2009; Dietrich and Schibeci 2003; Macnaghten, et al. 2015; Wynne 2016).

1.7. Thesis structure and chapter overview

The chapters of this thesis are in approximately chronological order, and divided in two parts (Table 1). Part A may be understood as asking how particular areas of technoscience come to achieved privileged attention from the state, and Part B as exploring the forms in which state support for their development is subsequently expressed.

Table 1: Thesis structure

Section	Chapter
A – Nanotechnology as innovation object	Part A Introduction
	2 - Creating the US NNI
	3 - Prioritising Australian nanotechnology research
	4 - Consolidating national nanotechnology policy
	Part A Conclusion
B – Implementing Australian nanotechnology policy	Part B Introduction
	5 – Tensions in Australian nanotechnology policy
	6 - Nano-sunscreen regulatory debates
	Part B Conclusion

The two-part structure to this thesis and the focus of each section recalls the conceptual distinction Harvey Brooks drew between "policy for science" and "science for policy" (Brooks 2001, 37). Brooks' model has been frequently invoked to license the study of science policy as a site of government activity, although it has also been recognised as problematic. Work in STS has repeatedly shown the constructedness and co-constitution of the categories of 'science' and of 'politics', and the entanglement of science and technology policy with "wider social, cultural and technical processes" (Irwin 2008, 584; see also Barry 2001; Jasanoff 2004; Kleinman 1995; Wright 1994). Consonant with such analyses, I explicitly locate US and Australian nanotechnology policy in the renegotiation of science-state-market relations that occurred in the early years of the 21st century, showing how such policy was underdetermined by technical developments in 'science'. Moreover, I emphasise that rather than the two-part structure of the thesis reflecting any taken for granted relationship between research and innovation policy ('policy for science') and regulatory policy ('science for policy'), my attention to regulatory policy in Part B mirrors the government's own policy focus. Rather than accepting as natural the focus of Australian nanotechnology policy on metrology, risk regulation and public engagement activities as the means to foster nanotechnology's commercial development, this is a topic for investigation and analysis. The two-part structure of this thesis affords a further advantage, as it enables me to compare co-production at two different sites, and to probe the different sets of science-state-market relations implied in the categories of 'innovation science'[29] and 'regulatory science'.

The chapters each pose a particular empirical question, taking a specific period and site of policy making to investigate. That is, rather than offering a strictly linear historical account, I offer a series of connected, detailed studies that respond collectively to my research questions. Individually and jointly the chapters contribute to the central argument of this thesis: state support for nanotechnology and the policy object 'nanotechnology' itself were situated achievements, reflecting the influence of structural features and circumstance, but also the extensive efforts of intermediaries.

Chapter 2 (mid 1990s – 2000) investigates the work by US agency officials, with support from White House staff and some entrepreneurial academics, to position nanotechnology as a compelling object for a new Presidential initiative. I explore NNI proponents' work to enact the then highly heterogeneous field of largely non-commercial research as an economically compelling, powerful new technology, and elucidate the political, economic and institutional imperatives to which this enactment responded. I show also the contingency of the NNI bid's success.

Chapter 3 (2000 – 2002) explores nanotechnology' nomination as an Australian research priority, and the central role in priority setting of science-policy intermediaries. In pursuit of greater funding security and institutional autonomy, research funding bodies backed nanotechnology to demonstrate their willingness to prioritise 'commercially relevant' research. Although nanotechnology's prioritisation gave the impression of strong state support for the field, it largely reflected intermediaries' responsiveness to keenly felt political pressures.

Chapter 4 (focus on the US in 2001-03, Australia 2005) compares efforts by proponents in the US and in Australia to consolidate national nanotechnology policy, and the means by which they sought to make persuasive to political audiences promissory claims for the field's future economic impact. US proponents deployed storylines that foregrounded the importance of state-funded science to US wealth, health and military might, helping to make predictions of

[29] This term is employed by Sheila Jasanoff (2005a, 108) to distinguish it from 'regulatory science'; she credits it without citation to Brian Wynne.

nanotechnology-based opportunity ‘sound credible’. Lacking these discursive resources, Australian proponents struggled to achieve credibility for promissory claims.

Chapter 5 (2005 – 2013) explores the design and implementation of Australian national nanotechnology policy. Constrained by disagreement regarding the state’s role in sponsoring innovation and limited political interest in nanotechnology itself, nanotechnology policy focused on initiatives that were ostensibly science-based and reactive to ‘market failure’ – metrology, risk regulation, and public awareness initiatives. Nonetheless, ‘political’ questions regarding the purpose and value of nanotechnology policy recurred internally to government, ultimately contributing to its discontinuation.

Chapter 6 (focus on 2012) investigates how the features of the policy environment identified in earlier chapters were articulated in regulatory debates surrounding nano-sunscreen. Australia has very high rates of skin cancer, and maintaining publics’ confidence in sunscreen safety is viewed as important by Australian policy makers. Yet the efforts of public servants from the industry department to propel the closure of these debates were shaped also by the constraints of ‘market failure’ rationales for nanotechnology policy, and the pursuit of innovation objectives via attempts to manage publics’ risk perceptions.

Part A: Nanotechnology as innovation object

Part A Introduction

How do particular areas of technoscience become singled out for priority public funding and political patronage? How do their proponents foster expectations that such fields are those most likely to deliver future prosperity – or at least near-term advantage for their backers? And how do governments' divergent responses to 'prospective techno-futures' (N. Brown, et al. 2000) reveal variation in the value attributed to technological innovation, and in views regarding the state's role in sponsoring it? Part A of this thesis explores such questions by probing the rise of nanotechnology as an object of innovation policy in the United States (US) and in Australia. In this Part A Introduction I offer some greater detail regarding the theoretical resources I employ in the subsequent three chapters and an introduction to the science policy contexts in which the events they investigate took place. I begin by providing an overview of how formative work in science and technology studies (STS) has conceptualised science-state relations as co-produced. I then trace shifting rationales for science and technology policy in the US and in Australia, and the different policy settlements that have emerged in each country. Finally, I discuss my treatment of imaginaries and 'sociotechnical imaginaries' (cf. Jasanoff and Kim 2009, 2013, 2015), and of 'ontological politics' (Mol 1999, 2002) which I explore as a site and a mechanism of co-production.

The co-production of science and political order

As elsewhere in this thesis, Part A employs a co-productionist analysis which foregrounds the "simultaneous production of knowledge and social order" (Jasanoff 1996, 393; 2004). As introduced in Chapter 1, past work in STS has shown the co-construction of science and social order at sites that bear directly on the central interests of this thesis. The production and classification of scientific knowledge reflects and reproduces normative judgments and social hierarchies (Bowker and Star 1999; Epstein 1996; Hacking 1999; Haraway 1989, 1997; Harding 1998; Jasanoff 2004; Latour 1987). The projects and the artefacts of technoscience embed and reinscribe political judgments (Gottweis 1998; Jasanoff 2005a; Kleinman 2005; Latour 1992; Stirling 2009a; Winner 1986; Wynne 2014). The epistemic authority of science has been central to the historic achievement and maintenance of political power in liberal democracies (Ezrahi 1990, 2004; Shapin and Schaffer 2011 [1985]). And, importantly, visions of desirable futures made possible by particular forms of social, scientific and technological relations play an animating role in the activities of scientists and politicians alike (Balmer, et al. 2016; Ezrahi 2012; Felt 2015; Jasanoff and Kim 2009, 2013, 2015; Kearnes, et al. 2006a; Welsh and Wynne

2013). Deploying the co-productionist 'idiom' (Jasanoff 2004, 3) suggests that studies of the interactions between science, technology, politics and policy are not simply "concerned with the interaction between two separate processes ('expertise' and 'power') but precisely the manner in which knowledge of the natural world and political action have been mutually embedded and co-constituted" (Irwin 2008, 586).

In theorising epistemic and political order as co-produced, two accounts of the interlinked emergence of Modern science with that of liberal democratic politics have proven particularly influential. Steven Shapin and Simon Schaffer (2011 [1985]) investigate the development of practices used to produce 'matters of fact' in seventeenth century Restoration England. They show that experimentalists' production of certified knowledge relied on its witnessing by 'gentlemen' whose own social status supported their claim to independent and trustworthy judgment. At the same time, legitimacy was achieved for the experimental method and political security for the new polity of natural philosophers in part by demonstrating science's instrumental value to the state and other economic, religious and cultural stakeholders. The experimental space was touted as a model polity from which and through whose work the Restoration settlement could be strengthened. Perhaps more importantly, the experimentalists were able to demonstrate the usefulness of the epistemic authority achieved by their method for the maintenance of political authority. Shapin and Schaffer conclude that "solutions to the problem of knowledge are solutions to the problem of social order" (2011 [1985], 332). Their findings regarding the social processes by which credibility is achieved for findings regarding the nature of 'reality' (see also Calvert 2010; Epstein 1996; Gieryn 1999; Kinchy and Kleinman 2003; Shapin 1995), the service of 'scientific' knowledge in maintaining particular kinds of sociopolitical order, and the importance of science's instrumental utility to the political status it is accorded, bear directly on the analytic interests of Part A.

In comparison to Shapin and Schaffer's investigation of the social and political contexts that shaped the development of modern experimentalist science, Yaron Ezrahi provides an analysis of the close interconnections between scientific forms of reason and practice and the contemporary projects of political liberalism. While sharing some of the same historic and conceptual ground, Ezrahi 's examination of the historic basis of relations between science and politics pays particular attention to the rise and retreat of the "specifically political and ideological role of science in upholding modern liberal-democratic conceptions of action, authority and accountability" (Ezrahi 1990, vii). Ezrahi emphasises the resources which scientific instrumentalism and systems of expertise have historically offered political elites. The ability of technical systems of appraisal and commitment to 'depoliticise' political action by making it appear objective and impersonal, and thereby to demonstrate to the citizenry the commitment of public authorities to acting in the public, rather than their own personal or institutional interest, has been particularly valuable. Yet, despite what Ezrahi describes as the late twentieth century's "unprecedented record of spectacular technological successes" (1990, 13), he observes diminishing public confidence in the 'truth' value of science.

Extensive STS work has shown that the latter decades of the twentieth century were not only a time of "spectacular technological successes" but also one of spectacular technological disasters and of controversy in science governance – in nuclear energy, chemicals pollution, bovine spongiform encephalopathy (BSE), genetically engineered crops and elsewhere (Beck 1992; Jasanoff 1990, 2003; Nelkin 1979; Szerszynski, et al. 1996; Wynne 1982, 2002). These public controversies and the growing recognition of the social and political choices inherent in technical systems and their oversight (Winner 1986) have contributed to the phenomena that Ezrahi describes:

> "*Science is no longer the resource it once was, with which policies and public choices could be legitimated as impersonal, objective and technical. It is no longer as important as it once was as a component of modern state authority. Consequently, scientists are much less in demand by politicians who seek to legitimate their positions and actions before an informed and sceptical public, and therefore politicians have on their part diminished incentives to 'buy' the cooperation of scientists by large allocations of public money to, and by public (political) endorsement of, basic research and the general goal of the advancement and the diffusion of knowledge*" (Ezrahi 2004, 273).

Such observations provide important context to Part A's investigation. In the same period in which 'basic' science's[1] economic value was increasingly called into question (see below), there were "diminished incentives" for politicians to fund basic research and discovery-oriented science for their legitimating potential. It was in these circumstances that advocates for nanotechnology – a field of highly heterogeneous, largely non-commercial research – sought

[1] The distinction between 'basic' and 'applied' science has been criticised as an inadequate and inaccurate reflection of actually existing research practice (Calvert 2006; see also Kleinman and Solovey 1995; Mirowski 2011; Nowotny, et al. 2001). The linear model of innovation, with which the distinction has been associated, has been similarly critiqued (Callon 2007; Godin 2006; Sarewitz 1996). In this thesis I employ the terms basic and applied science as heuristics, while recognising that they do not reflect actually existing categories of science.

to "link their funding futures to the objective of high-tech industry", as Daniel Kleinman (1995, 173) had more generally predicted some years previously. Nonetheless, the enduring, if fractured, influence of science in "upholding... conceptions of action, authority and accountability", and in legitimating public policies, is also apparent throughout this thesis and is explored in detail in Part B.

A particularly important site in consolidating relations between science and the state has been the development of research policy following World War II. In this period, research councils and other infrastructure were created to manage the allocation of newly boosted public funding, amidst debates regarding science's proper autonomy from, and accountability to, wider society. The following section explores evolving rationales for research policy in the US and in Australia, showing how in each country this has been a site of co-production and one in which assumed science-state-market relations are continually renegotiated.

Evolving rationales for research policy

US science and technology policy

There is now an expressed view in US politics that government's role is to fund basic rather than applied science – although, as elsewhere, the use of these categories is contingent and strategic (Calvert 2006). Yet, as Harvey Brooks (1986, 122) observes, prior to World War II the US government had little interest in supporting "science for its own sake, rather than for well defined special social purposes". Indeed, even in the post-war years, politicians preferred to support research "that promised quick and impressive returns on public investment" (Kleinman and Solovey 1995, 131). Nonetheless, in the post-war period science enjoyed new kudos thanks to its perceived contribution to the defeat of the Axis powers, and government funding for basic science – which was nonetheless closely intertwined with military and security objectives (Forman 1987) – grew dramatically.[2] Competing theories regarding whether the sources of scientific and technological change were 'internal' or 'external' (for a review see Shapin 1992) underpinned rival models for the new research policy that emerged at this time. Of particular significance were questions regarding the extent to which science could or should be managed to maximise its societal relevance, for example via priority setting, and the state's role in funding applied or industrially relevant research (see Brooks 1986; Brooks 1996; Dennis 2004, 2015; Guston 2000; Kleinman 1994, 1995).

[2] As it did to a lesser extent in other affluent countries including Australia (Aitkin 1991).

The director of the wartime Office of Scientific Research and Development, Vannevar Bush, advocated more generous public support for basic science, while giving scientists a high degree of autonomy in these funds' allocation (Kleinman 1994, 1995). The 'social contract' proposed by Bush has been characterised in the following terms: "Government promises to fund the basic science that peer reviewers find most worthy of support, and scientists promise that the research will be performed well and honestly and will provide a steady stream of discoveries that can be translated into new products, medicines or weapons" (Guston and Keniston 1994, 2). While Bush was successful in many respects, US scientists never fully enjoyed the autonomy that he and other elite scientists and their allies in research-based industry had envisaged (Brooks 1986, 1996; Dennis 2004, 2015; Kleinman 1995). Indeed, the "mythology of autonomy" (Calvert 2006, 202) has proven more a resource in cultural and political leverage than a reflection of actually existing science-state relations (Jasanoff 1996, 2003, 2005a; Kleinman and Solovey 1995).[3]

In the 1970s, as declining US economic competitiveness, high inflation and high unemployment were attributed to inadequate technological innovation, demands grew for US science to demonstrate greater responsiveness to sociopolitical aims, particularly those of restoring industrial growth and employment (Brooks 1986, 1996; Wright 1994; see also Calvert 2006). Cold War competition amplified the growing focus on industrial technology, as maintaining technological primacy was increasingly seen as vital to geopolitical interests (Kleinman and Solovey 1995; Weiss 2014). From the 1970s onwards, US governments sought to promote technological innovation through tax incentives and new patent policy to foster the commercialisation of government-funded research, agency-sponsored programs to support university-industry collaboration, 'public capital' programs to aid early stage commercialisation, and prioritised agency funding for basic research deemed to be strategically useful for future industrial application or defence (Block 2008; Weiss 2014; Wright 1994; see also Brooks 1996; Guston 2000; Jasanoff 2005a; Vallas, et al. 2011). Through the 1980s and early 1990s a series of initiatives also sought to boost coordination and planning in

[3] In particular, see Paul Forman (1987) on the strength of military interests in shaping physical sciences research in the post-war years, including in the development of the electronics industry.

the state's approach to science and technology policy, although these often met with limited success (Greenberg 2001; Kleinman 1995).[4]

State-backed efforts to promote technological innovation exist in perennial friction with the discursive commitments of US political actors to 'free market' policy settings (Block 2008; Keller and Block 2015). Government funding for basic science, including that anticipated to be of future industrial relevance but whose high risk means that it would likely go unfunded by the private sector (also known as 'strategic' science, van Lente and Rip 1998), has been broadly supported on both 'market failure' and 'public good' grounds (Brooks 1986, 1996). Yet applied research, understood to be more directly relevant to near-term commercial application, has been cast as properly conducted by the private sector (on the strategic self-interest of research-conducting industry in lobbying for this post-war settlement see Kleinman 1994, 1995). There is bipartisan backing for the state's decentralised but active role in directing military R&D and related procurement programs.[5] Yet outside defence, government-backed initiatives to sponsor technology development have been derided by self-described fiscal conservatives as corporate welfare that distorts the 'free market' (Fleury and Iachello 2006; Greenberg 2001). The adoption of selective-strategic policy measures to foster the development of particular sectors (otherwise known as industry policy or industrial policy)[6] has become "a virtual taboo" (Keller and Block 2015). In this, tensions are apparent between the declaratory statements of policy makers, and the actually existing practices of the state. Indeed, some analysts identify a "hidden developmental state" (Block 2008; Block and Keller 2011), where *de facto* US industry policy operates to finance and foster the commercialisation of new technologies via favourable tax policy and industry-supportive legislation (Vallas, et al. 2011), and by initiatives such as the Small Business Innovation Research program, the Small Business Technology Transfer program, and government procurement policies (Connell 2006; Weiss and Thurbon 2006).

[4] Daniel Kleinman (1995, 173) observes that the limited success of efforts to create coordinated science and technology policy was not simply a product of ideology, but also the "permeable and fragmented character of the state and the nonprogrammatic, undisciplined character of American political parties".
[5] Although even in defence there are limits to the extent that developmental activities may be openly pursued (Block 2008).
[6] A more comprehensive definition of industry policy is offered in an OECD report: "*any type of intervention* or government policy that attempts *to improve the business environment* or to alter the structure of *economic activity* towards sectors, *technologies or tasks* that are expected to offer better prospects for economic growth or *societal welfare* than would occur in the absence of any such intervention" (Warwick 2013, 16, emphases in original).

Australian science and technology policy

The approach to science and technology policy in Australia's commodities and services-dominated economy has differed from that of the US. The "distinctive Australian industry structure" is characterised by a high proportion of businesses that conduct limited research, beyond the few large firms in the mining and energy sectors (Marsh and Edwards 2008, 13; see also Dodgson, et al. 2011; Gregory 1993).[7] Yet despite the key role of the Australian government in supporting research, and perhaps more pertinently, despite the importance of science-based technological innovation to the country's economically important resources sector (Cutler 2008; Office of the Chief Economist 2015), research has traditionally been seen as marginally relevant to improving national economic competitiveness, and to Australian politics in general (Aitkin 1996). Whereas the Australian Research Council (ARC) was modelled on the US National Science Foundation (NSF), the terms of the Australian social contract between science and the state were never clearly articulated (Aitkin 1991, 1996). Australia lacks the US drive for geopolitical primacy that underpins the latter's emphasis on maintaining technological leadership and military dominance.[8] And, while notionally sharing with their US counterparts a discursive commitment to 'free market' policy settings and to embedding 'market logics' in the structures of the state, a different set of assumed science-state-market relations has shaped Australian research policy.

Like the US, Australia struggled with stagflation and recession in the 1970s. In the US these conditions led to a new emphasis on technological innovation as the means to economic renewal, and attention to how government could better promote the commercial application of research findings (Wright 1994; see also above). Conversely, Australian policy and political responses focused on improving the competiveness of previously highly protected Australian manufacturing firms through a program of state-led tariff reductions (Bell 1992; see also Conley and van Acker 2011). Rather than being seen as a resource that could be exploited to

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[7] Firms conducting little research include a large number of small and medium-sized enterprises, but also more sizeable manufacturing firms which are "primarily market-seeking subsidiaries" of multi-national corporations (Marsh and Edwards 2008, 13). Australia's innovation system has been described by Robert Gregory (1993, 324) as exhibiting: "a low level of science and technology expenditure, a high level of government involvement in financing and undertaking research, a low level of private sector research and development and exceptionally high dependence on foreign technology". That is, Australian businesses have historically invested comparatively little in either research or research-based technology development. In the period examined by this study Mark Dodgson and colleagues (2011, 1149) observe that many of the characteristics identified by Gregory "remain apposite".

[8] Indeed, as a medium-ranked economy of modest population, Australian diplomatic thinking has commonly posited strong strategic alliances as key to the nation's defence, initially with the United Kingdom and after WWII with the United States.

regain economic competitiveness, Australian research held limited significance for political actors at this time.[9]

Australian research policy did not attract significant interest from government until the 1980s (Aitkin 1996, 1997). When it did, the view that publicly funded researchers were not delivering a sufficient return on investment promoted a greater emphasis on applied science of more direct relevance to industry. As early as 1977 Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), was encouraged to shift its research "from longer term, fundamental research toward strategic-mission orientated research" and to foster "the greater involvement of end-users in the allocation of research funding" (Upstill and Spurling 2008, 144). In subsequent decades the imposition by government on CSIRO of an external earnings target further shifted its focus to applied research of near-term commercial relevance (Dodgson, et al. 2011; Upstill and Spurling 2008).[10] In parallel, publicly funded scientists at universities were exhorted to pursue industrially-relevant research, resulting in a pronounced overall decline in the proportion of funding allocated to basic rather than applied science (Group of Eight Australia 2014). That is, in contrast to the 'free market' policy settlement that emerged in the US, in Australia public funding was increasingly expected not to support 'high-risk' basic science, but rather research of near-term commercial value. In the context of Australian science policy, 'market logics' were understood to require the minimisation of government outlays and the maximisation of commercial returns: industry partners were expected to contribute financially to collaboratively undertaken research, and researchers to demonstrate commercial applications of their work.

Perhaps surprisingly, given the expectation for publicly funded researchers to pursue commercially relevant research, Australian policy makers have proven even more ambivalent than their US counterparts towards an active state role in technological innovation. There is episodic recognition that Australia must diversify its economic base to reduce its reliance on

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[9] A former member of the then Australian Research Grants Committee (ARGC), the principal body for supporting university-based research, recollects that the ARGC was not: "seen by the Whitlam Labor Government in 1972 as an instrument that might help to change Australia, and it was almost wiped out, apparently by oversight, in that government's last Budget, that for 1975/76. It was saved by the action of the universities, which produced the necessary money as a short-term loan when the Government admitted its error" (Aitkin 1996, 183).

[10] Debates regarding the proper role of CSIRO in the national research system, particularly the extent to which it should focus on commercially-relevant research, and rely on the earnings of contract work, were influential in the events I investigate (see especially Chapter 3) and are ongoing.

and exposure to the vicissitudes of mineral exports (eg Batterham 2000; Bell 1992; Hampson 2012). Yet despite experimentation with strategic interventions to support techno-industrial transformation, such efforts have largely reflected the personal efforts of individual political actors and have been vulnerable to their own political fortunes (Thurbon 2012). In the central government agencies of Treasury and Finance, targeted sectoral initiatives are often viewed as compromising 'free market' principles and associated with the broad-based protectionist measures of the past (Bell 1992; Conley and van Acker 2011; Hampson 2012). Unlike the US, Australia lacks a coordinated co-investment program designed to nurture small business innovation, and, amidst concerns to safeguard 'free trade' principles, it does not have a clear government procurement policy (Thurbon 2012, 2015). Even as US policy makers declare their country the bastion of 'free market' ideology, their Australian counterparts espouse a stricter interpretation of neo-classical economics in technology and innovation policy – albeit one routinely compromised by the pragmatic pursuit of electoral advantage (Bell 1992; Conley and van Acker 2011; Thurbon 2012).

Situated science policy settlements

This brief outline of post-war science policy in the US and in Australia has highlighted some striking discrepancies in the political rationalities that underpin the two countries' research policies, the extent to which science and technology are understood as relevant to economic competitiveness or defence, the ways in which 'market logics' are interpreted and applied to government's oversight of publicly funded research, and the assumed character of the science-state-market relations that drive technological innovation. My work differs from that of influential STS scholars who observe the eager competition of states in a new, 'knowledge society', and whose study assumes the existence of "protechnology state policies" (Jasanoff 2005a, 8).[11] I do not find unequivocal technopositivity within the state, and nor do I identify ubiquitous attention to fostering or managing technological innovation. Instead, I emphasise that the science policy settlements that have emerged in each country are situated, and that state commitments to nurture new technology development are uneven. The nominally similar 'free market' commitments espoused by US and Australian policy makers are also shown to possess unexpected 'interpretative flexibility' (Pinch and Bijker 1984). Despite the

[11] Sheila Jasanoff, for example, observes: "knowledge has become the primary wealth of nations, displacing natural resources... State policies, correspondingly, are geared more and more toward nurturing and exploiting knowledge, with scientific knowledge and technical expertise commanding the highest premiums" (Jasanoff 2005a, 4).

'coordination work' (Mol 2002) performed by the similar use of 'free market' discourse, the assumed meaning of such commitments for science policy is divergent – a product of situated co-production and the strategic efforts of intermediaries. This observation extends an argument made in Chapter 1 regarding the inconsistence and heterogeneity of neo-liberalism as ideology (cf. Birch 2015; Birch and Siemiatycki 2016; Ryan 2015; Weiss 2012). In the context of science policy, it can hold within in it both the impulse for state withdrawal and also intense state investment to realise speculative potential.

Sites of internal tension and conflict are apparent in the approach of both the US and of Australia to science and technology policy outlined here, which will be explored in greater detail in subsequent chapters. These observations provide the context for Part A's investigation of nanotechnology's emergence as an object of innovation policy, and the policy imperatives in the US and in Australia that conditioned nanotechnology proponents' promissory and constitutive work, and which affected their success. They also bear on the more detailed exploration of the design and implementation of Australian nanotechnology policy that is undertaken in Part B.

The politics of 'reality' and the power of imagination

In Part A of this thesis, as I ask how nanotechnology achieved priority status as a new object of innovation policy, I explore how proponents' constitutive and promissory work responded to the imperatives of their respective policy environments, and also to shared imaginations of 'the future'. Before I elaborate my conceptualisation of co-production in such world-making activities, I make some brief comments on my treatment of imaginaries. Earlier work has shown the generative power that the sociocultural and technoscientific visions and aspirations of individual scientists, investors or industrialists can exert (eg Fujimura 2003). In this thesis I distinguish between such individually held visions and imaginaries which I treat as shared. For example, when I refer to imaginaries of nanotechnology-based prosperity made possible by state sponsorship, I mean that this was a vision discernible among groups of nanotechnology's champions. In other places, following Sheila Jasanoff and Sang-Hyun Kim (2009, 2013, 2015), I use the terminology of 'sociotechnical imaginaries'. Jasanoff (2015a, 4) defines these as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology". The concept recognises that "scientific and technological ideas" are "produced together with ideas about science and technology" (Jasanoff 2015b, 333), and about their relations with sociopolitical systems: in this way sociotechnical imaginaries both reflect and reinscribe processes of co-production.[12] The key distinction that I make in using the language of sociotechnical imaginaries is that such imaginaries are not only "collectively held", but also "institutionally stabilized" – that is, they have been embedded within the architectures of the state or other institutions, where they are "publicly performed" and continually (re)enacted (cf. Mol 2002). Sociotechnical imaginaries are widely familiar, possess durability, and may themselves act as resources in the articulation of newer visions and imaginaries.[13]

In my conceptualisation of co-production as the joint production of social and scientific order, as elaborated earlier, I employ and complicate vocabulary developed by Jasanoff. Jasanoff identifies two streams of co-productionist work, constitutive and interactional, that investigate respectively "the way the world is and how we find out about it" (Jasanoff 2004, 274). Constitutive co-production encompasses ontological questions regarding the "*emergence and stabilization* of new objects or phenomena" (Jasanoff 2004, 5, emphasis in original); it "speaks to the creation of fundamental ordering devices and categories" (Jasanoff 2004, 274). Conversely, interactional co-production focuses on questions of epistemology germane to the framing and resolution of controversy, "deal[ing] with the conflicts and accommodations that arise when competing natural and social orders are brought into confrontation" (Jasanoff 2004, 274). In Part A, as outlined in Chapter 1, I aim to open up the 'black box' of science policy by drawing upon archival and observational work and interviews with key stakeholders to investigate the "emergence and stabilization" of nanotechnology as a new policy object. In observing that the form in which the policy object 'nanotechnology' was enacted in each country was responsive to the tensions and opportunities of its policy environment, I reach a somewhat surprising conclusion: the co-production of nanotechnology as a policy object took

[12] There is a resonance between 'sociotechnical imaginaries' and the "future-oriented abstractions" that are explored in the sociology of expectations literature (Borup, et al. 2006, 285; N. Brown and Michael 2003; see also N. Brown, et al. 2000; Pollock and Williams 2010). In this thesis, I do not draw any sharp distinction between imaginaries and expectations. Nonetheless, I recognise that many expectations take a more specific form, centring on particular outcomes or developments; as "'bids' about what the future might be like" they may play a mediating role amongst contending larger-scale visions of sociotechnical change (cf. Berkhout 2006, 301).

[13] This is not suggest that sociotechnical imaginaries are "static or tightly bounded belief systems", or that there are "unique imaginaries guiding the production of knowledge or knowledge-based technologies in the contested spaces of democratic policymaking" (Jasanoff and Kim 2009, 123). Indeed, sociotechnical imaginaries may exist in conflict with one another. Nonetheless, "of the multiple contending sociotechnical imaginations at play in any society, some tend to be more durable" (Jasanoff and Kim 2009, 123), and therefore influential, for example in policy making.

place within the co-production of wider science-state relations. That is, I argue that interactional co-production, and attempts to "deal with the conflicts and accommodations" associated with science policy more broadly, was present at the heart of constitutive work. To help me elaborate this argument, I draw on Annemarie Mol's (1999, 2002) concept of ontological politics.

"Ontology" is concerned with "'reality'… what is or isn't out there in the real world", or put differently, "with what there *is* and what there could be" (Law 2004, 23, emphasis in original). The creation of scientific knowledge, objects and categories is underdetermined by their material correlates. Indeed, in any particular situation, multiple versions of objects and categories are possible (Mol 1999, 2002). Material 'truth' is always a constraint on the enactment of 'reality' and recognising multiplicity is not to say that 'anything goes' (Law 2004). Nonetheless, as 'reality' is produced through both social and material practices, "'truth' is not and cannot be the only arbiter" of the 'real' (Law 2004, 66) – classification and the world-making with which it is engaged could always "have been otherwise" (Hacking 1999, 111). Whether it regards race, sexuality, geography, ecology, or disease, historically and culturally situated judgments play an influential role in category making (Bowker and Star 1999). This co-constitution of science and social order can have profound consequences, as postcolonial and feminist work in STS has shown (W. Anderson 2002a; W. Anderson and Adams 2007; Haraway 1989, 1991; Harding 1998, 2009; Seth 2009; Verran 1998). The concept of ontological politics draws together these observations: alternative enactments of categories and objects are possible, and these hold differing stakes for the actors involved. The privileging of particular 'realities' while others are denied is a site at which normative choices and political judgments are inscribed, sometimes to violent effect (Bawaka Country including Sarah Wright, et al. 2016). As Donna Haraway (1988, 588) observes: "what counts as an object is precisely what history turns out to be about".

In this thesis I make no general philosophical claim regarding the nature of the world "out there" (cf. Law 2004; see also Lynch 2013). I do not locate the ontological politics at the centre of my investigation in a general cosmology or world view (cf. Bawaka Country including Sarah Wright, et al. 2016; Law 2004; Muir, et al. 2010; Verran 1998). Nor do I adopt a "realist tenor" that treats reality's production as a material consequence of our interventions in and investigations of the world around us (cf. Barad 1996, 164; 2007). Following Mol (1999, 2002) my interest lies in the performative (rather than the material) constitution of particular realities, and the normative choices and political consequences associated with this. Put differently, I investigate the world-making accomplished by the enactment of certain objects and categories in science and technology policy making, and by stories told about them, probing the stakes associated with privileging particular versions of reality over others. In so doing, I approach the ontological politics surrounding nanotechnology as a site at which long-standing normative questions asked by STS of science-state relations may be pursued.

In the two countries' innovation policy investigated in Part A, and in the design and implementation of Australian nanotechnology policy investigated in Part B, I explore how, in what context, and with what effects the highly heterogeneous field of nanoscience and its products acquired ontological significance (cf. Lynch 2013). I elucidate how proponents' constitutive work strategically allied the policy object 'nanotechnology' with the interests and aspirations of influential stakeholders, and enabled them to leverage "historically resonant discourses" (cf. Kinchy and Kleinman 2003, 872) as resources in claims making. By tracing how this foreclosed potential avenues of epistemic or normative challenge, favourably positioning nanotechnology for priority attention, I show how this work was not only *ontological* but also *political*. This approach is consonant with calls from Michael Lynch (2013, 444) for a deflationary "ontography" that posits 'ontology' as a topic of empirical inquiry, involving "historical and ethnographic investigations of particular world-making and world-sustaining practices that do not begin by assuming a general picture of the world". Lynch criticises authors – implicitly including Mol – whose "attempt to describe 'ontologies' *in* the world must revert to an ontology *of* the world" (2013, 453; see also Woolgar and Lezaun 2013; Woolgar and Lezaun 2015). Nonetheless I suggest that Mol's ontological politics offer one means to pursue the 'ontographic' work Lynch calls for (for other investigations of how ontologies are brought into being, which could be described as 'ontographic', see Balmer, et al. 2016; Balmer and Molyneux-Hodgson 2013; Calvert and Joly 2011).

The term ontological politics has featured in the work of both Mol (1999, 2002) and Jasanoff (2011b), and there are similarities and differences in their use of it: Mol's keener attention is to 'ontology', Jasanoff's to 'politics'.[14] Mol emphasises the multiplicity of the 'real', in which particular versions of reality may overlap, or even be performed with a semblance of singularity, but not necessarily. Her work explores how different versions of an object "hang together", and how the multiple does not become fragmented or plural. Mol emphasises the

[14] I am grateful to Zara Mirmalek for this observation.

dependence of any particular reality on repeated enactment for constant renewal: "*ontologies* are brought into being, sustained, or allowed to wither away in common, day-to-day, sociomaterial practices" (Mol 2002, 6, emphasis in original). I return to this insight throughout the thesis. Yet in her invitation to praxiography and ethnography, Mol offers little guidance on how to understand the influence of structural features – political, economic or discursive – in shaping the versions of reality that are enacted. Conversely, Jasanoff (2005b) emphasises "ontological uncertainty" and her treatment of multiplicity is ambiguous. Jasanoff investigates "national practices of ontological boundary-drawing, focusing on the intersection of classification, ethics, and regulatory policy" (Jasanoff 2011, 61). In this way, her work locates the acts of biological, ethical and legal classification which she investigates in culturally and historically situated institutions and practices of "sense making" or "civic epistemologies" (Jasanoff 2005a). Unlike Mol, for Jasanoff ontological boundary-drawing cannot be understood only by a study of (scientific) practice. That is, ontological politics must be understood within the idiom of co-production, and in the context of the broader political struggles of late modernity. For Jasanoff, ontological politics, for example in a sector such as biotechnology, is connected with "more or less" self-conscious projects of reimagining nationhood and political identity, the state's ongoing quest for political legitimacy, and the dynamic articulation of the "three-cornered" relationship between science, society and the state (Jasanoff 2005a).

There are tensions apparent in drawing upon the approaches of Jasanoff and Mol together, but read in dialogue they offer helpful insights and explanatory power to this study. Following Mol, I recognise multiplicity and the importance of recurring practice in (re)enacting the 'real' in science and innovation policy; I am attentive to the dynamic and always incomplete performative achievement of 'reality'. In my exploration of how ontological politics were imbricated in broader social, political and economic struggles, I draw on Jasanoff's elaboration of co-production. I emphasise that these approaches are interlinked. Indeed, in tracing how constitutive work responded to wider epistemic and political conflicts, I show that it cannot be understood only through metaphysical or praxiographic inquiry but demands that we account for its location in and engagement with the skirmishes that characterise political life. By exploring the shifting forms in which nanotechnology was enacted as an object of innovation and regulatory policy, the stakes associated with alternative enactments, and the structural features and resources that conditioned constitutive work, I show how interactional co-production was present within constitutive co-production. This is an argument that runs through the chapters of Part A.

Chapter 2: Creating the US National Nanotechnology Initiative

The question of why and how states seek to sponsor technological innovation remains under-examined in science and technology studies (STS). As discussed in Chapter 1, the field has often assumed the state's technopositivity without interrogating contingency and indeterminacy within science and technology policy, or the means by which particular fields of technoscience are singled out for priority support. The United States (US) National Nanotechnology Initiative (NNI), launched by President Bill Clinton in January 2000, is a case in point. Despite US government investment in it of nearly US$24 billion[1] to date (NSTC 2016) and the initiative's international influence, the circumstances of its creation have attracted limited scholarly investigation. Some of the studies that have been undertaken recognise the influential promissory work[2] and alliance building of US government officials in support of the NNI, but tend to imply instrumental rationales for its adoption by the state (eg McCray 2005, 2013; Motoyama, et al. 2011). The effect of this is to more or less accept proponents' claims that nanotechnology would be critical to future US economic and geopolitical standing, and to understand this as the basis of the support and funding the NNI received. Other studies take a more sceptical view, treating nanotechnology as a discursive construct particularly suited to a period in US science policy in which political actors demanded a greater technological dividend from the public investment in 'basic'[3] science (Eisler 2013a, b; Gallo 2009). Yet these studies do not investigate the circumstances in which the proposed initiative achieved backing from the Clinton administration and Congress, leaving unanswered the question of how nanotechnology achieved support over fields that were similarly framed and were in direct competition for resources. This chapter adds to earlier work by showing that we cannot understand the NNI's creation without recognising not only proponents' work to enact a version of nanotechnology (cf. Mol 1999, 2002) that was responsive to the imperatives of its policy environment, but also the particularly favourable political and fiscal conditions in which their efforts succeeded. It highlights also the element of chance that accompanied nanotechnology's winning a White House-led competition for a new science and technology initiative, emphasising that its success was far from predetermined.

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[1] All figures in this chapter are United States (US) dollars.

[2] For earlier science and technology studies (STS) analysis of promissory work in technoscience see, for example: Mike Fortun (2008); John Gardner and colleagues (2017); Adam Hedgecoe (2003); Alan Petersen and Ivan Krisjansen (2015); and Neil Pollock and Robin Williams (2010).

[3] On the flexible and strategic use of this term see Jane Calvert (2006); for my qualified use of it and the political dimensions in the US context of the basic/ applied distinction, see Part A Introduction.

As outlined in Chapter 1, in each chapter of this thesis I investigate a different question, using a particular period or event. This chapter asks how the Clinton administration decided to support the NNI, and Congress to fund it. More broadly, it responds to my thesis research question of how late-modern, capitalist states understand, justify and prosecute their role in creating, fostering and overseeing new technoscientific fields and industries. I show that to understand the NNI's creation we must explore the ontological politics (cf. Mol 1999, 2002; see also Part A Introduction) associated with forging the policy object 'nanotechnology' and the 'prospective techno-futures' (cf. N. Brown, et al. 2000) with which it was associated. I trace how proponents' efforts to name, define and story the policy object 'nanotechnology' helped them to navigate the "conflicts and accommodations" of contemporary US politics and science policy debates (cf. Jasanoff 2004, 274), and to favourably position their proposed initiative for political support. Indeed, I argue that this constitutive work was a necessary – if insufficient – component of the backing the NNI achieved.

The chapter is structured in three parts. I begin with an explication of the unusual receptivity of the White House and Congress in 1999 to a major new science and technology policy. Next, I probe the efforts of NNI proponents to name, define and story 'nanotechnology', then a diverse field of largely non-commercial research, to position it for such an initiative. In the final section, I investigate the means by which the NNI proposal achieved success, winning a White House-led internal competition for Clinton's 'legacy' initiative, and securing support from Congress as a growing array of scientific and political actors identified their own interests and those of their constituents as aligned with it. My analysis focuses on the years leading up to the NNI's announcement and funding – the mid-1990s to 2000. Archival work and semi-structured interviews with nanotechnology policy stakeholders were conducted as described in Chapter 1.

2.1 Millennial USA

I begin the chapter by elucidating the political and economic conditions and science and technology policy debates that preceded the NNI proposal, and by which proponents' constitutive and promissory work was shaped. I provide a brief overview of the turbulent years of Clinton's first term, and contrast this with his second term in which a newly achieved budget surplus made it a particularly promising time for a proposed new science and technology initiative. I finish the section by showing how Clinton's quest for a legacy initiative that would also carve out a point of political differentiation in the 2000 elections led to the competition in which the NNI was formally proposed.

2.1.1 An unusually receptive Congress

The role for the state in sponsoring technological innovation was a point of particular contention through Clinton's tumultuous first term. Amidst significant budget deficits, Clinton and Vice-President Al Gore favoured a strong government role in fostering new technology development as a means to economic recovery (Clinton and Gore 1993). Attracting the ire of Republicans, Clinton and Gore singled out the Advanced Technology Program (ATP) for rapid budget growth, in which industry and government shared the costs of early-stage commercialisation activities. Despite a wider commitment to austerity, the administration planned to increase the ATP's annual budget from $67.9 million in 1993 to a billion dollars by the late 1990s (Greenberg 2001, 427). This was rejected by fiscal conservatives as an inappropriate incursion on the 'free market' (on the declared rationale for this position see Part A Introduction; attacks on the ATP were also a partisan political tactic, see Block 2008). At the same time, given the perceived disinterest of the Clinton administration in basic science and its emphasis on industrially relevant research (Greenberg 2001; Kleinman 1995), basic scientists grew fearful of cuts to their own budgets. Their concerns were compounded in November 1994, when Republicans won control of both Congress and the Senate for the first time in forty years, promising a 'Republican Revolution' that would eliminate the budget deficit by 2000 (Greenberg 2001).

The new Republican House Speaker Newt Gingrich and his close friend House Science Committee Chairman Robert Walker, while "self-described 'techno-nut[s]'" (R.M. Jones 1998, unpaged), took a dim view of government involvement in technology development. The ATP attracted their criticism and budget cuts, although it survived until President George W. Bush abolished it (Block 2008; Greenberg 2001).[4] Walker declared his intention to "protect" "fundamental science and basic research" from aggressive budget cuts, but announced plans to reduce overall research and development (R&D) spending from $27 billion in 1995 to $21 billion by fiscal year 2000 (Suplee 1995, A11). The proposed cuts led to an unprecedented mobilisation by both Fortune 500 high-tech companies and scientists, who insisted on the importance of maintaining research funding for the nation's future prosperity (Bromley and

[4] The Small Business Innovation Research fund survived intact in these years, perhaps largely by chance (Greenberg 2001).

Lubell 2003; Greenberg 2001). The campaign to protect the research budget was largely successful; Gingrich's personal support for basic science was also seen as having helped shield it from more dramatic cuts at this time (R.M. Jones 1998).

With the achievement of budget balance in 1998, science and technology policy entered a more benign era. At the Speaker's request, the House Committee on Science prepared a report that sought to lay out a new rationale and direction for post-Cold War US science policy. The report was compiled by physicist and Science Committee Vice Chairman Vernon Ehlers (Republican, Michigan). Consonant with contemporary inquiries (for an analysis of ten such studies see Boesman 1997) it emphasised that, although a military threat to the US remained, geopolitical competition would increasingly be economic with technology playing a central role (Committee on Science 1998). The committee's report, which was backed by the House, called for an expanded research investment particularly in basic science, technology, engineering and mathematics (STEM) research – a position favoured by fiscal conservatives.

The political atmosphere in 1999-2000 was highly receptive to a major new science and technology initiative. This was in large part due to the newly achieved budget surplus, to which the Clinton administration credited US success in information technology (IT) and biotechnology (eg Clinton 2000a). After the long years of budget conflict, Congress proved willing to accommodate expanding requests for R&D funding. Even Gingrich, no longer in the House but a fellow at the American Enterprise Institute, called for Congress to break the caps on government spending established in previous years and to "double the federal budget for scientific research" with the promise that "no other federal expenditure would create more jobs and wealth" (Gingrich 1999, A19). He singled out nanotechnology as an area of particular potential.[5] Amidst a palpable sense of millennial optimism, the Clinton administration could afford to be convinced that nanotechnology was a 'revolutionary' field in which its investment was essential, Gingrich encouraged them in this view, and for fiscal year 2001 the Republican-controlled Congress was ultimately willing to make R&D appropriations that exceeded even the President's budget request (Long 2001; Shaki Trimble 2000).

[5] Newt Gingrich went on to become one of nanotechnology's high profile champions, even serving as Honorary Co-Chairman of the US NanoBusiness Alliance (Wolfe 2003).

2.1.2 Technology's centrality for Clinton

With a newly supportive Congress, the Clinton administration could advance its long-standing desire to more actively sponsor technological innovation. From the beginning of their first term Clinton and Gore had positioned technology as offering the basis for "high-skill, high-wage jobs for American workers", "a cleaner environment", maintaining US "leadership in critical world markets", improving national security, and boosting the "very quality of life" (Clinton and Gore 1993, 1).[6] Arguments that knowledge and innovation are the source of inelastic wealth creation and the foundation of the 'new economy' (Romer 1990, 1994) were highly influential within the administration. Covered extensively in internal policy briefings (eg Brock 1995; PPI 1998), public statements by the administration's leadership also repeatedly touted the promise of the 'new economy' (eg Gore 1997, 1998). In Clinton's second term, the dot-com boom appeared to offer material testament to these ideas: the President's Science Advisor Neal Lane observed that IT accounted for 80% of US stock market capitalisation (APS 1999). As the dot-com bubble grew, the administration's enthusiasm for the wealth-creating "potent power" of the high-tech sector's "intangible" assets (Gore 1997, unpaged) even surpassed that of some senior industry figures.[7] In time, the eagerness of Clinton and Gore to support cutting edge new technology, amplified by the dot-com boom, proved a vital asset to nanotechnology proponents.

The approach to nanotechnology of key White House advisors was informed by their earlier success with internet-based policy. Indeed, the Next Generation Internet (NGI) initiative provided a template for the NNI bid. Thomas (Tom) Kalil, Deputy Assistant to the President for Technology and Economic Policy and Deputy Director of the National Economic Council (NEC), was the White House 'point person' on the NGI and a key champion of the NNI. In an oral history recorded by W. Patrick McCray, Kalil credits the success of the NGI in part to its formulation as a targeted program with strategic goals that could be used to generate popular enthusiasm and to marshal political support: "The NGI was successful. We got most of the money we asked for from the Congress. The President featured the NGI in his State of the Union address... For me, this became a model to pursue as opposed to saying that 'Agency X should get a 7% [R&D] increase this year'" (Kalil 2006, 19). Kalil also recollects that "I started

[6] Indeed, as occurred under the United Kingdom's 'New Labour', Clinton looked to cutting-edge technology as a vehicle for his 'third way' politics. Technology was touted as the means to achieve economic and social objectives but also used to signal his government's own progressive, visionary qualities (eg Clinton 1999, 2000b), a function underscored by Clinton's repeated emphasis on building "a bridge to the 21st century" (Clinton 1996, 2000a).

[7] For example the president of Microsoft Corporation warned a technology conference of the "absurd" "overvaluation of technology stocks" (as quoted in Eselgrowth 1999, unpaged).

looking around for the 'next new thing' after the Internet. That's when I stumbled across nanotechnology" (Kalil 2006, 20).[8] Even before nanotechnology became the object of the proto-NNI bid, White House advisors were convinced of the merits of using a 'strategic initiative' approach in search of R&D funding (see Greiner and Lane 2009), motivated by the recent success of internet policy, and, in newly favourable fiscal conditions, "looking around for 'the next new thing'".

There was another important dynamic at play in Clinton's willingness to back a new technology initiative: the political fortunes of he and Gore were increasingly intertwined with those of the high-tech industry, and there was a federal election imminent. The sector had become an important source of campaign donations and political validation for 'centrist' (market-leaning) Democrats (Dreyfuss 2001). In turn, the Clinton administration backed trade, law and policy initiatives for which high-tech firms lobbied, including the restoration of 'permanent normal' trade relations with China, the moratorium on taxing internet sales, cutting capital gains tax, favourable treatment for employee stock options, and lifting restrictions on the employment of foreign workers (BAD Undated; Schnitzler 2000). The administration also pursued the interests of the IT (The White House Undated-a) and biotechnology industries in the World Trade Organization (WTO) and through bi-lateral trade agreements (The White House Undated-b).[9] The announcement of a major new science and technology initiative in the lead up to the 2000 Presidential elections offered a further means to demonstrate the administration's commitment to pursuing the sector's interests. The political and fundraising opportunities for the Democrats associated with the NNI were noted by the science press, for example in *Nature* reportage of the initiative's announcement (Dalton 2000).

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[8] Neal Lane, the National Science Foundation (NSF) Director and later Presidential Science Advisor to Clinton, was supportive of this "strategic initiative" approach as a vehicle to secure funds for "excellent basic research" (Greiner and Lane 2009, 35). Lane attributed the strategy to President George H. W. Bush's Science Advisor D. Allan Bromley, whose Materials Science and Processing Initiative ten years earlier is viewed by some (Murday 2007, 51; Rudd 2009, 106-7) as the progenitor to the National Nanotechnology Initiative (NNI). James Murday later remarked of the NNI's positioning as a Presidential 'strategic initiative': "this was not new. It is an option that's explored, sort of routinely" (Murday 2007, 51).

[9] For example it used the WTO to prosecute European countries whose rejection of US companies' genetically engineered (GE) crops the administration deemed to be 'unscientific'. Gore personally telephoned French Prime Minister Lionel Jospin regarding France's reticence to authorize the use of GE corn, prompting the French approval ten days later of two GE corn products (Kohlenberger 1998).

2.1.3 The quest for a legacy initiative

In the 2000 elections, Clinton and Gore sought to use science and technology to carve out a point of political differentiation. The administration was looking for a program that it could "trumpet as part of Clinton's rhetoric and policy about creating the 'bridge to the 21st century' and creating a 'new economy'" (House Committee on Science staff member, Interview 26, May 2014). Polling and messaging advice provided to the President on the eve of his last State of the Union address emphasised the need to bring together a coherent narrative about how the US had benefited economically and socially under his administration, and to articulate a compelling vision for ongoing transformation and success (Penn Schoen Berland Associates 1999). The advice urged that the number one message be that "this is a nation that is prepared for the 21st century", indeed that the US was prospering in a time of rapid technological change (Penn Schoen Berland Associates 1999, unpaged). It suggested Clinton argue that under his government, rather than costing jobs, technology now supported "one in three jobs" while creating "whole new industries" (Penn Schoen Berland Associates 1999, unpaged). A strong new science and technology initiative would exemplify this story of Democrat-created, forward-looking opportunity. It was in this context that the White House Office of Science and Technology Policy (OSTP) decided to hold a competition to decide on a legacy initiative for Clinton – a competition ultimately won by the NNI proposal (Karn and Schottel 2016; Roco 2007). Having shown why 1999-2000 offered a particularly favourable constellation of political and fiscal circumstances for a new Presidential science and technology initiative, the next section explores how 'nanotechnology' emerged as its leading contender.

2.2 Ontological politics and the NNI

In the years prior to the NNI proposal, federal agency and White House staff, in collaboration with a smaller number of university academics and private sector representatives, worked hard to forge a politically salient identity, story and research agenda for 'nanotechnology'. In this section I trace how these proponents strove to enact a version of nanotechnology that would maximise its appeal to the Clinton administration, Congress, their scientific peers, and ultimately wider publics. In responding to the political and economic imperatives of its policy environment, this constitutive and promissory work consciously maximised the opportunities for nanotechnology proponents to successfully navigate the "Washington policy machine" (see below). Recent STS work on technoscience field formation refers to such efforts as "definitional work" (Kearnes 2013; Kearnes and Wienroth 2011a). Yet given that proponents sought not only to create shared technical definitions and nomenclature that could usefully bound and distinguish their field (see below), but also to create politically salient identity and meaning for nanotechnology, "definitional work" appears an inadequate descriptor.[10] Instead, I regard this as a site of ontological politics, and my investigation of it and the stakes with which it was associated (cf. Mol 1999) as an example of 'ontographic' study (cf. Lynch 2013; see Part A Introduction).[11]

2.2.1 Introducing the intermediaries

It was the federal agencies that took the lead in building political support for the NNI. As a former senior member of the House Committee on Science put it, the key factor in the bid was not high-level political or industry interest – "it wasn't really on the political radar screen" – but rather "the working level in the agencies and the scientific community gets focused and there's no reason not to do it" (House Committee on Science staff member, Interview 26, May 2014). Similarly, another interviewee observed: "I don't mean this in a pejorative way, but the technocrats are in charge here with no push back" (Regulator, Interview 4, February 2014). The central role of federal agency program managers and White House advisors in nurturing interest in nanotechnology and in championing the NNI bid has been identified in earlier work (Eisler 2013a, b; Gallo 2009; McCray 2005, 2013; Mody 2011; Motoyama, et al. 2011). This chapter adds to existing studies by investigating the interplay between these actors' constitutive and promissory work and their brokering efforts (cf. Meyer 2010) in support of the NNI. I describe those individuals who intermediate between the "social worlds of politics and science" (Guston 2001, 401), or, more accurately, "between the worlds of science, policy and the market" (Meyer and Kearnes 2013, 424), as science-policy intermediaries.[12] In so doing I

[10] The "profoundly social" character of 'definitional work' is emphasised by these authors, who employ the term to encompass such activities as research agenda and priority setting "to define the social, economic and political ambitions of new and emerging fields of scientific and technological development" (Kearnes and Wienroth 2011a, 8). I am informed by these authors' demonstration of the co-constitution of new fields of technoscience with salient 'societal challenges' and application pathways, but I consider describing this as "definitional work" unnecessarily reductive.

[11] For a somewhat similar approach to study in synthetic biology see work by Andrew Balmer, Katie Bulpin and Susan Molyneux-Hodgson (Balmer, et al. 2016; Balmer and Molyneux-Hodgson 2013).

[12] The work of intermediaries at the science-policy interface has been the subject of considerable STS inquiry. Sheila Jasanoff (1990) has shown the influence of science advisors in the formulation of regulatory policy and the assessment of regulatory science. Daniel Kleinman has shown their role in developing the post-war US research policy architecture, for example attributing Vannevar Bush's influence to his "day-to-day actions and interactions occur[ing] at the boundaries between elites from several social sectors, including science, business, government, and the military" (Kleinman 1994, 268; see also Kleinman 1995). My conceptualisation of intermediaries' role in science policy is explored in greater detail in Chapter 3.

recognise the "complex" "territorial landscape" of contemporary public policy making (Meyer and Kearnes 2013, 424) and the influence of 'market logics' in science and science policy even in the absence of capital's direct involvement (cf. Kleinman and Vallas 2001; Vallas and Kleinman 2008). Chapter 3 offers a more detailed conceptualisation and investigation of intermediaries' roles and functions.

The National Science Foundation (NSF), the primary federal grant-making body for non-biomedical basic research in the US, was characterised by many interviewees as a "driver" of the NNI. One senior interviewee remarked that: "the primary reason that the NNI got started was because of NSF" (NNCO staff member, Interview 12, February 2014; see also NRC 2002, 19). The bid was widely popular in the agency because virtually every part would benefit from new funding associated with it (NSF staff member, Interview 49, May 2014; see also Gallo 2009). But the agency's interest in nanotechnology also reflected the belief of key individuals in its 'revolutionary' and disruptive potential. This included Neal Lane who was NSF Director from October 1993-August 1998, before becoming Science Advisor to Clinton (Assistant to the President for Science and Technology) and OSTP Director (Lane 1998, 2001; Lane and Kalil 2005). It also included Joseph (Joe) Bordogna, who was NSF Deputy Director from June 1999 – 2005 (see Bordogna 2003a, b), and who in 1990 hired Mihail (Mike) Roco, who would go on to play one of the most high profile roles in the NNI bid.

Roco is recognised as one of the key architects of the NNI, and a populariser of the claim that nanotechnology would "spawn the next industrial revolution" (Roco 1999b, 435). Roco has written that from 1990 to 1999 he worked to build "a chorus to support nanotechnology" (Roco 2007, 3.6).[13] He dates the genesis of the NNI proposal to 1996, when he organised "a small group of researchers and experts from government including Stan Williams (Hewlett Packard), Paul Alivisatos (University of California, Berkeley) and Jim Murday (Naval Research Laboratory), and we started to do our homework in setting a vision for nanotechnology" (Roco 2004, 2). The self-consciously performative nature of this recollection is striking – the group actively sought to bring into being an as-yet non-existent but wished-for nanotechnology, and to "set a vision" for it. As their work progressed the status of the group grew, along with its official connection to the White House. With Kalil's assistance, in October 1998 the Interagency Working Group on Nanoscience, Engineering and Technology (IWGN) was created,

[13] In this period, Roco was responsible for the first federal agency program devoted to nanoscience and engineering, after winning a 1990 competition at NSF with a proposal for "nanoparticles synthesis and processing at high rates" (Roco 2007, 3.6).

as part of the cabinet-level National Science and Technology Council's (NSTC) Committee on Technology. Roco became its Chair, Kalil its White House Co-Chair, and Murday its Executive Secretary. The effort to build support for nanotechnology had been elevated from what Kalil (2006, 20) later recalled as "a grassroots group of program managers" to a working group that reported to the White House. In 1999 it was the IWGN that made the formal NNI proposal.

Despite reluctance within DOD in the early 1990s to sponsor nano R&D (Murday 2007), the defence agencies eventually played a core role in the NNI bid. Murday has dated his and DOD's interest in nanoscience to the early 1980s (Committee on Commerce 2003). In a parallel with views then expressed at NSF, in an oral history recorded by Cyrus Mody Murday recalled that by the early 1990s he was advising his military superiors that: "'There's this freight train coming down. It's still very much in the science. We're not going to hand you revolutionary technologies in the next two years, but there are going to be some dramatic impacts'" (Murday 2007, 48). Murday argued that DOD needed to fund nanotechnology to maintain US technological advantage, including in the next generation of electronics.[14] He introduced himself to Roco in the mid-1990s, offering to bring DOD support for the proto-NNI bid and proposing that the two "join forces" (Murday 2007, 46). Murday ultimately became Roco's "junior partner" in the NNI's creation (Mody 2011); when the formal proposal for the NNI was made, the two were co-authors (Committee on Science 1999).[15] Some interviewees attributed state support for the NNI to DOD's commitment to the initiative. Complicating this view, and again emphasising that it was the agencies' "working level" that drove the NNI proposal, DOD leadership's reservations about participating in a collaborative, inter-agency initiative delayed its signing the NNI Memorandum of Understanding until "literally... the last day of the Clinton administration" when Duncan Moore, head of the Technology Division of the White House OSTP "got [the deputy director for research and engineering] to sign that document" (Murday 2007, 54). This underscores the active work required from intermediaries in both DOD and the White House to secure the agency's eventual participation in the NNI.

The other key site of the intermediaries' effort was in the White House where Kalil played a vital role as the 'point person'. He both helped shape the NNI bid and built support for it, recalling that: "I helped to identify several long-term ambitious but not wildly unrealistic goals

[14] On the Department of Defense's (DOD) historically important role in developing electronics see Paul Forman (2014); on electronics' particular strategic value in the 1990s see Linda Weiss (2014).
[15] After the NNI was established, Murday was appointed as the first Director of the National Nanotechnology Coordination Office (NNCO) which oversaw it.

for the NNI that were understandable. I got senior White House staff, and ultimately the President and the Vice President, to support the budget request. Also, I made sure that the President announced it" (Kalil 2006, 24). Murday emphasised the centrality of Kalil's work to the NNI proponents' efforts to build credibility for their proposal: "Having somebody out of the White House saying, 'This is an economic engine for the future', separate from the scientists saying, 'Give me more money', was very useful. Kalil played a major role... His persistence and political savvy were very important" (Murday 2007, 47-48). Widely regarded as a broker by interviewees for this research, one described Kalil as possessing the political nous that together with Lane's navigated the NNI through the "Washington policy machine" (NSF staff member, Interview 49, May 2014). In the following sections I trace the work of these intermediaries to forge a politically compelling policy object 'nanotechnology' from what was in the late 1990s a highly disparate field of research from which few applications had been commercialised.

2.2.2 Nanoscale R&D prior to the NNI

Prior to the NNI bid, the sprawling field of nanoscience attracted both scientific excitement and scepticism, and many researchers who worked at the nanoscale did "not normally consider (or in some cases, want) their scientific efforts to be labelled as 'nanoscale'" (Siegel, et al. 1999, 65). The 1980s had seen the development of scanning tunnelling microscopes, atomic force microscopes, and near-field microscopes that provided new technical capacity for nanoscale measurement and manipulation, and the emergence of "instrumental communities" associated with them (Mody 2011). Yet even probe microscopists, whose work was later identified as foundational to 'nanotechnology', showed some initial reluctance to identify with that label (Mody 2011). Nanoscale research grew during the 1990s within disciplines including physics, chemistry, engineering, materials and surface science, and to a lesser extent biology (Siegel, et al. 1999). Murday (2007, 45) later described the growing sense of expectation surrounding the field at that time: "by the time we got into the '90s everybody and their grandma began to realize, 'Oh my god! This thing's starting to take off'.‖ A lot of [scientific] societies started to pay attention to it". Yet despite such enthusiasm, at the time of the NNI bid even nanotechnology's most ardent champions recognised that "the investigative tools and level of understanding of basic nanoscale phenomena are now only rudimentary" (Roco, et al. 1999, ix). In a later interview, Lane recollected that in the late 1990s, "only a few companies were involved with nano" such as Hewlett Packard and IBM (as quoted in

Motoyama, et al. 2011, 114). Moreover, the field continued to struggle with scientific credibility issues and debates surrounding what should and should not be considered as ‘nanotechnology’ (see below).

In 1999-2000 very few products intentionally exploited nano-features or devices. Iconic IBM physicist Don Eigler observed to a *Nature* writer that "nanotechnology doesn't yet exist" (as quoted in Ball 2000, 904), while John Seely Brown, Chief Scientist at Xerox Corporation, suggested that “the technology is still almost wholly on the drawing board” (J.S. Brown 2001, 41). Some of the early ‘nano-products’ identified by NNI proponents included sunscreens and cosmetics that used metal oxides in nano-form for their novel transparency, clothing treated to give it stain-repellence, and nanomaterial-reinforced polymers for use in cars (Roco 1999b, see also Chapters 4, 6). But the most economically valuable and prominently cited application of nanoscale phenomena was the IT industry’s use of giant magnetoresistance (GMR) to boost the density of magnetic disk information (eg IWGN 2000). Indeed, the argument that nanoscale breakthroughs were essential in the near-term to enable the US to maximise competitiveness in the “second silicon revolution” — and thereby to maintain ongoing fulfilment of Moore’s Law[16] — formed a key component of the NNI pitch (eg Committee on Science 1999, 5, 59-68). The application of GMR, and the predicted value of further nano-scale breakthroughs for IT, enabled proponents to put a high dollar value on anticipated market returns of investment in what was still largely an area of non-commercial research (eg Roco and Bainbridge 2001).

It was only in the late 1990s that the term ‘nanotechnology’ began to be more consistently applied to nanoscale R&D. This reflected not only what Nobel laureate chemist and prominent nano-advocate Richard (Rick) Smalley described to a Senate roundtable as the scientific “buzz” surrounding nanoscale work (as quoted in Schulz 2000), but also the work of the intermediaries who championed the NNI.

[16] ‘Moore’s Law’ is a prediction that the number of transistors in an integrated circuit will double every two years, supporting accelerating miniaturisation and processing capacity in microchips. On the performative nature of Moore’s Law, and its use to mobilise resources sufficient to maintain its realisation, see Neil Pollock and Robin Williams (2010).

2.2.3 Nanotechnology category making

Categories of various kinds do not result straightforwardly from distinctions between material properties but embed normative and aesthetic judgments,[17] sometimes serving explicitly political purposes (Bowker and Star 1999; Hacking 1999; Haraway 1989; 1991; see also Section A Introduction). The 'category work' by which intermediaries sought to produce the policy object 'nanotechnology' was no different. Their efforts to cohere divergent areas of research and a small number of commercial applications, to distinguish this from work in established scientific disciplines, and to articulate an ambitious research agenda which could underpin their appeals for priority funding and political support, were purposive. In their exploration of the often invisible political work of classification, Geoffrey Bowker and Susan Leigh Starr (1999, 10) define classification as a "segmentation of the world" based on "unique classificatory principles". They identify categories as "clearly demarcated bins, into which any object addressed by the [classification] system will neatly and uniquely fit" (Bowker and Star 1999, 10). Bowker and Starr emphasise that this is an ideal type, and that no "real-world working classification system" is likely to meet the attributes they specify (Bowker and Star 1999, 11). Nonetheless, their model is useful in the present analysis. The nanotechnology category reflected a process of segmentation based on a series of "classificatory principles" that were articulated in the definition NSF developed for the field, as we will see. The material basis of such segmentation and whether or not the nanotechnology category could ever be "clearly demarcated" are contested. Indeed, it could be argued that a great deal of nanotechnology category making was achieved not through classificatory infrastructures but rather by discursive work and motivational stories (Eisler 2013a, b; Gallo 2009). Yet this illustrates one of Bowker and Starr's central arguments: classification and category making is never purely technical but is necessarily also sociopolitical.

The motivations of NNI proponents in this category work were somewhat divergent. Agency officials such as Roco and Murday were specifically focused on promoting research they predicted would drive "the next industrial revolution". White House advisors, while enthusiastic about nanotechnology, were additionally both in search of a legacy initiative for the President, and also keen to use the NNI as a vehicle to secure funding for the physical sciences more broadly. The latter goal was shared by its advocates in the research sector, including the federal agencies (Eisler 2013a). All were eager to ensure that the proposed bid could successfully navigate a Congress insistent on a greater dividend from the public research

[17] For example Donna Haraway (1991) emphasises the "non-innocence" of gender categories and the normative and political judgments inherent in the inclusions and exclusions they support.

investment, yet hostile to government-backed industrial technology development. The nanotechnology category was carefully fashioned to accommodate all these needs.

White House staff and science advisors saw nanotechnology as a promising vehicle to demonstrate to Congress the economic and social value of publicly funded STEM research. In 1998 a House Science Committee report observed that: “Without the backdrop of the Soviet military threat or the race to conquer outer space, convincing and often-used justifications for federal research funding became less compelling” (Committee on Science 1998, 10).[18] In the period investigated by this chapter the funding gap between STEM and biomedical sciences (AAAS 2014) was poised to widen further given bipartisan support for doubling the National Institutes of Health (NIH) budget (OLPA Undated). There was scepticism in Congress regarding the contribution of basic science to economic outcomes (Eisler 2013a, b) and a perception that research sponsored by agencies such as the DOE and NSF was ‘out of touch’ with the nation’s needs (Gallo 2009; Greenberg 2001).[19] Such criticism had led to the introduction of a new “broader impacts” criterion for NSF grant applications (Holbrook 2005). Now, nanotechnology was identified by White House staff as a means to renew the basis for physical science’s ‘social contract’ with the state (cf. Guston and Keniston 1994; Kleinman 1995; see also Part A Introduction). The NNI Implementation Plan’s identification of “Grand Challenges” to which nanotechnology would respond (NSTC 2000) followed this logic, and the example of the NGI before it, by identifying tangible, if hypothetical, social, economic and even environmental outcomes from the nanotechnology investment.[20] In this way, the formulation of ‘grand challenges’ was at once a site at which the policy object ‘nanotechnology’ was co-produced with its ‘prospective techno-futures’, and a strategy for proponents to demonstrate the societal relevance of STEM research more broadly.

The Clinton administration’s strong support for technology policy, and its resistance to “open-ended appeals” for increases in basic science funding (Etzkowitz 2001, 123), was related to its

[18] As one American Physical Society official put it: “When the Berlin Wall came crashing down a decade ago, Beltway science advocates began to search for rationales to replace national defense as the umbrella for Federal investments in research. Biology found disease and everyone else found the economy” (Lubell 1999, unpaged). In practice, there was some crossover between these strategies: biomedical research was touted as supporting new industries and job creation, while the physical sciences argued for their contribution to new medical devices, diagnostics and drugs.
[19] Indeed, in the dramatic budget confrontations of 1995, the Republicans even proposed abolishing the Department of Energy (DOE) altogether (Suplee 1995).
[20] On the growing prominence of 'grand challenges' in 21st century science policy see Jane Calvert (2013). For the earlier articulation of 'grand challenges' in an internal pitch for the NNI see Thomas Kalil (1999; see also Lane and Kalil 2005).

conviction in the former's more "concrete outcomes" (see Kalil 2006, 18). Alongside the political work the nanotechnology category performed in Congress, in the White House it offered a way for intermediaries to link basic STEM research to the President's key priority of sponsoring technological innovation. That is, the nanotechnology category enabled White House staff who supported increasing funding for the physical sciences to align this with pursuit of "the president's top priorities" (Lane and Matthews 2009, 849).

After the NNI's announcement, Kalil openly told a *Science* writer that the STEM budget had been "stagnant" and "we see [nanotechnology] as a way [of] increasing support for physical science and engineering" (as quoted in Service 2000, 1525).[21] Yet, underscoring this chapter's argument regarding the uncertainty of nanotechnology's eventual prioritisation, the field was never the only candidate to play that role – archival documents show that Kalil's interest in using an "exciting new area" to leverage greater STEM funding preceded the NNI proposal (NEC Staff 1997). In a 1997 memo to the NEC Director, Kalil argued for boosting funding for NSF and DOD compared to that of NIH, noting that NSF would use a "substantial proportion" of its increase to fund Presidential priorities, such as next-generation technologies (NEC Staff 1997). The memo goes on to suggest two "exciting new areas" which could form the focus of such funding boosts, naming both "functional genomics" and "nanotechnology" which it explains as "manufacturing at the molecular level" (NEC Staff 1997, 8). Two years later, when the NNI bid had gained momentum, its capacity to help achieve greater "balance" for STEM research funding became one of the primary arguments made for it by the NEC Director to Clinton's chief of staff (Sperling 1999), and by Lane to the President (Lane 1999).

The nanotechnology category mobilised support for basic STEM research that interviewees consider would have been otherwise impossible. Yet the underdetermination of the 'reality' of the category by the material 'truth' of the then field (cf. Law 2004; see also Part A Introduction) was recognised by some its greatest champions. One interviewee recalled that their first response was to see the nanotechnology category as a "scam":

> "*When I first saw it I was like 'this is the biggest scam in the world' because here are these basic researchers in chemistry and engineering and all the rest. If I went up to The Hill and tried to get the House Science Committee to look at making a bigger investment in those areas, they would have laughed at me at the time. If you went up*

[21] A similar rationale for the NNI was acknowledged by Duncan Moore, associate director for technology in the OSTP: "You need to come up with new, exciting, cutting-edge, at-the-frontier things in order to convince the budget and policy-making apparatus to give you more money" (Stix 2001, 32).

to The Hill and you said 'nanotechnology is the future, it's what's going to keep this country number one economically in the 21st Century and you've got to invest in it, and by the way it means that we have to make a big investment in all these areas of education and basic research at an enhanced level', as long as you put that nano label on it, it was golden" (NSF staff member, Interview 49, May 2014).

This recollection highlights the performativity of the "golden" nanotechnology category. Its name and the stories told about it helped to establish a common identity among disparate physical sciences research and to link it with economic goals that were widely shared in Congress. It also enabled proponents to employ "historically resonant discourses" (cf. Kinchy and Kleinman 2003, 872) about the power of technology to drive progress and growth (see also Kleinman 2005; Sarewitz 1996; Stirling 2009a, 2010a).[22]

Importantly, the 'interpretative flexibility' (Pinch and Bijker 1984) of the nanotechnology category allowed for context-specific responsiveness to the competing epistemic and political preferences of different audiences (McCray 2005; see also Bowker and Star 1999). Nanotechnology was variously enacted as aligning with: the basic science preferred by fiscal conservatives; the more goal-directed but still politically uncontroversial arena of "strategic [basic] science" (cf. van Lente and Rip 1998; see also Calvert 2006); and the unapologetically instrumental and politically contested aim of using federal government investment to foster industrial technology development, as favoured by Clinton and Gore. In an interesting and under-remarked function of the nanotechnology category (but see Eisler 2013b), its interpretative flexibility enabled proponents not only to assert the industrial relevance of NNI-funded science, but also to deny it. Alfred Nordmann and Astrid Schwarz (2010, 260) suggest "the power of nanotechnology... does not reside in what it can or will do but in [its] very indeterminacy and emptiness". I extend their observation by emphasising that the indeterminacy of the nanotechnology category was not an "empty" property, but one crafted and deployed strategically by NNI proponents in response to the multiple imperatives of their policy environment.

[22] For a more detailed exploration of this discursive strategy see Chapter 4.

2.2.4 Naming nanotechnology

Just as category making sought to unify a disparate field of academic research and a limited number of commercial products, naming played a pivotal role in its identity building for 'nanotechnology'. The importance of naming in technoscientific field formation is well-recognised (Graham 2013; Hedgecoe 2003; J. Martin 2015; A. Powell, et al. 2007). It "delimits, renders more visible, more powerful, and increases the potential to attract funding for, certain forms of work" (Molyneux-Hodgson and Meyer 2009, 136), although it is by no means essential for such work to take place (Toumey 2010). The stakes associated with naming both the proposed NNI and the policy object at its heart were readily apparent to its proponents and to other research sector stakeholders (cf. B. Martin 2010).[23] One science writer reported reservations among researchers that the name mischaracterised the field, suggesting that "nanotechnology is still in its infancy – and really should be called nanoscience" (Lawler 2000, 558). Somewhat differently, several professional scientific societies and committees expressed concern, possibly regarding the funding implications, of not having the word 'science' in the NNI's title: Roco later described explaining to them "that we selected a simple name to show its relevance to society" (Roco 2007, 3.7). The IWGN carefully considered the strategic dimensions of the initiative's name, as Murday (2007, 53) recalled: "is it going to be called 'science'‖ or is it going to be called 'technology'? Everybody agreed, roughly, that this is more science opportunity for the short-term, but you aren't going to sell a national initiative on, 'Let's do good science'.‖ You can sell a national initiative on, 'We're going to have good technology'". That is, proponents recognised that the initiative's appeal to widespread political enthusiasm for technological innovation, and ability to demonstrate "relevance to society", rested in part on their enacting, and naming, the NNI as a technology policy (Gallo 2009, 203 describes this as "playing an excellent game of Washington semantics").[24]

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[23] Ben Martin describes the adverse consequences of a poorly chosen name on an emergent field's prospects. In 1983 Martin and his British colleagues titled a new book *Foresight in Science: Picking the Winners*. As the authors later realised, this subtitle was antithetical to the ideological commitments of Margaret Thatcher's government: "doom[ing] whatever faint hopes we might have previously entertained of persuading the UK Government to launch a pilot foresight exercise. It took another eight years, and a change in Primer [sic] Minister (to John Major) and in political philosophy, before the UK Government was willing to even consider the possibility of adopting foresight as a means of identifying scientific and technological priorities" (B. Martin 2010, 1442).

[24] Conversely, Matthew Eisler (2013b; see also Eisler 2013a) notes reservations within the Clinton administration regarding naming the NNI a 'technology' initiative, anticipating opposition from fiscal conservatives in Congress: "In late 1999, an official in the Office of Management and Budget warned... that the agency was more interested in supporting a science initiative than a technological one. He felt the NNI would run afoul of legislators in February and wished it could be renamed" (Eisler 2013b, 29).

Even after the IWGN had decided on the initiative's name and the formal NNI proposal had been made, the President's Council of Advisors on Science and Technology (PCAST) revisited the decision. In an interview for this research Lane recalled a conversation with Smalley regarding PCAST's official review of the NNI bid (Neal Lane, Interview March 2015). The committee, of which Smalley formed part, discussed whether the technology label was appropriate:

> "*Rick Smalley told me that he thought 'nanotechnology' was a good choice, even though this was not yet a technology, this was a research field. But he thought by coupling, by putting 'nano' on the front end that would signal that this is really kind of forward looking, we're not there yet, this is a far out goal, but by adding technology at the back end, it also signalled that this could have enormous potential in terms of technological innovation*" (Neal Lane, Interview March 2015).

Indeed, at a meeting of the American Association for the Advancement of Science (AAAS) in February 2001 Lane made a similar argument for the communications value of the 'nanotechnology' name:

> "*So, what about the word 'nanotechnology'. On the one hand, it is risky to raise the profile of a technology that really isn't there yet... On the other hand, by deliberately using the term 'nanotechnology' we can much more easily convey to the public that the research is likely to lead to something useful, that will improve their lives. That helps us gain public support not just for nanoscale science engineering but for all the physical and mathematical sciences and engineering*" (Lane 2001, 96).

In a symmetrical move, leveraging claims regarding 'nanotechnology's' political value to appeal to his AAAS audience, even as claims regarding its scientific and technological value were leveraged to appeal to politicians and policy makers, Lane added that "President Clinton also likes the word" (Lane 2001, 96). In this way, the very naming of 'nanotechnology' was a site where interactional co-production was prominent in constitutive work (cf. Jasanoff 2004), and the political stakes of alternate enactments of the policy object clearly visible (cf. Mol 1999, 2002).

The name 'nanotechnology' was also useful to the NNI proponents because of its familiarity in scientific and some policy circles, and its currency in science fiction where it was associated with visions of miniaturisation. The word "nano-technology" was coined by Japanese researcher Noricho Taniguchi in 1974,[25] and popularised a decade later by K. Eric Drexler (1986), who at the time was unfamiliar with Taniguchi's work (McCray 2013). Drexler brought a new level of scientific and popular attention to nanotechnology through his writing and advocacy for atomically precise manufacturing, or molecular manufacturing, made possible through protein machines. In searching for a term that would best capture its own vision, Roco told me that the NSF kept Taniguchi's name "because it was the most readable, like it had to be a simple name" while recognising that "it's not exactly his concept" (Mihail Roco, Interview May 2014). Taniguchi's contribution is recognised in the histories of nanotechnology development published by the NNI, although Drexler's contribution is not (eg Amato 1999; on the significance of strategic absences in a scientific community's textual self-representation see Hodgson 2006).

2.2.5 Defining nanotechnology

Along with nanotechnology's name, the definition developed for it by NSF was important to the field's identity making, and to proponents' quest to distinguish 'nanotechnology' from the traditional disciplines (cf. Kearnes 2013; Kearnes and Wienroth 2011a). An early NSF definition was: "the construction and utilization of functional structures with at least one characteristic dimension measured in nanometers" (Roco, et al. 1999, vii). Both the length scale of particular interest, approximately 1-100nm, and the existence of novel nanoscale physical, chemical and biological properties were emphasised. Like the name, this definition was contested. Molecular manufacturing proponent and Xerox Research Scientist Ralph Merkle argued that a similar definition was wholly inappropriate for nanotechnology, which he suggested should rather be: "a manufacturing technology able to inexpensively fabricate, with molecular precision, most structures consistent with physical law" (Merkle 1996, unpaged). Merkle observed a "turf-war" playing out in the mid-1990s, as "many researchers" sought to profit from the excitement that Drexler had created around molecular manufacturing, while "wish[ing] to adopt a definition of 'nanotechnology' that includes their own work" (Merkle 1996, unpaged). In the years preceding the NNI bid, its proponents obtained a clear advantage in the "turf-war", which nevertheless continued after the NNI was created (see McCray 2013).

[25] Taniguchi used the term in a paper presented at an industrial conference to describe highly precise surface machining, semiconductor processes and ion beam milling, although he did not subsequently publish using this term.

Roco (2011) credits the NSF definition as critical to the nanotechnology endeavour's success. In an interview for this research, he described the "unifying definition" based on "control of matter at the nanoscale where unique phenomena enable novel applications" as "transformative", adding that "without this new definition nano had no chance, it was just a curiosity for some people in physics or other disciplines" (Mihail Roco, Interview May 2014). Roco's comments in our interview and in his written work (eg Roco 2007; Roco 2011)[26] make clear that he saw this "unifying definition" as actively constructing both a field and its constituent research community (cf. Molyneux-Hodgson and Meyer 2009; A. Powell, et al. 2007).[27] Yet even after the NNI's announcement, there were concerns that in their efforts to encompass such a wide range of potential techniques, applications and disciplinary paradigms, proponents had over-reached. The former Vice President of Science & Technology at IBM observed archly that: "I find that the very term 'nanotechnology' — although wonderfully suited to the description of a welcome and significant funding initiative — is at too high a level of abstraction... which 'nanotechnology' are we supposed to be talking about?" (Armstrong 2001, 35). Nonetheless, the NSF definition, in conjunction with the name, helped to play a coordinating role, patching together – albeit imperfectly – a seemingly singular nanotechnology from among its multiples (cf. Mol 2002). Moreover, the breadth and interpretative flexibility of the NNI definition may in part explain its success (McCray 2005). As efforts grew to build a policy object that would attract wide support, the definition accommodated a diversity of actors, interests and disciplinary practices, and supported varying enactments of nanotechnology's content and meaning – just as Merkle observed.

The size range specified in the definition was not materially arbitrary, yet it was underdetermined by the novelty of nano-specific physicochemical properties, and ultimately reflected aesthetic as well as practical considerations. Nano-phenomena do not occur neatly bounded within 1-100nm. In the manufacture of nano-devices and electronics, the size range

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[26] Mihail Roco (2011, 427, 428) wrote: "...only in 1998–2000 were fragmented fields of nanoscale science and engineering brought together under an unified science-based definition and a 10-year R&D vision for nanotechnology... It has become clear after about 60 countries developed nanotechnology activities by 2004 that without this definition and corresponding long-term vision, nanotechnology would have not been developed on the same accelerated, conceptually unifying and transforming path".

[27] Of course, the NSF definition was neither sufficient to achieve 'unity' in enactments of nanotechnology, nor necessary to underpin work in nanoscience. In the years following the NSF definition's release, multiple divergent definitions of nanotechnology and nanomaterials were released internationally (eg European Commission 2011; NICNAS 2010; US EPA 2009). Moreover, as noted by James Murday (2007, 51): "I think Mike [Roco] oversells the U.S., it's as though nobody started anything until the U.S. had the initiative, and that's not true. Germany had a program that was put together and was funded at a lower level. Japan did. UK did. Other nations had pieces". In corroboration of this view, see also Angela Hullmann (2006).

of interest may be 0.1-50nm (Siegel, et al. 1999, 67-92), yet elsewhere novel nano-specific properties may be observed in structures that are a few hundred nm or even sub-micron in size (Roco 1999a, b). Interviewees for this research described the 1-100nm size range as a "brand":

> "*Scientifically there's nothing particularly special about it. But it's a powerful brand and if you're going to choose a size range what would you choose? You're going to go with powers of ten because otherwise it's messy. One to 1000 it's too broad. One to 10 it's too small. I think 1 to 100 is just right. But scientifically it makes relatively little sense*" (Safety scientist, Interview 25, March 2014).

In his recollections of the IWGN discussions regarding definitions, Murday made a similar point, describing the 1-100nm definition they agreed on as "artificial", but saying that: "People like round numbers. You could argue whether it should be two hundred nanometers instead, but come on guys. It's just round numbers. [Laugh]" (Murday 2007, 58, 53).

Somewhat more pragmatically, Lane emphasised that the size-based definition also reflected the practical needs of the agencies and funding bodies who needed to distinguish between nanoscience and nanomaterials and existing disciplines and materials, as discussed above:[28]

> "*It had to have error bars on it because nobody really knew. But they had to – we really had to get a definition that would allow the federal agencies to look around what they were doing and identify what projects were going to be nanotechnology and which ones weren't. And of course chemists have worked with molecules forever, and they're much smaller than 200 nanometres.*[29] *So there had to be a way to draw a distinction between business as usual in materials science and chemistry and physics, and what's new here, and that's what gave rise to that definition*" (Neal Lane, Interview March 2015).

Lane's statement emphasised both the logistical and institutional exigencies that shaped the definition, and also the definition's performative nature. By assigning a particular range of numbers, policymakers could "identify what projects *were going to be nanotechnology* and which ones weren't".

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[28] Later this size range became the focus for defining nanoparticles and nanomaterials for regulatory purposes, developments which will be explored in Chapter 6.

[29] It is interesting that additional to Murday and Lane, the 200nm figure was cited by two other US interviewees for this research.

2.2.6 Storying nanotechnology

Stories that built expectations of nanotechnology's necessity to future US wealth, health and security were prominent in proponents' efforts to marshal support for the field (cf. Borup, et al. 2006; N. Brown and Michael 2003; N. Brown, et al. 2000; Pollock and Williams 2010; Sunder Rajan 2006). As one interviewee described it, the vision of a nanotechnology-supported future articulated by the NNI's proponents was the basis to "get the funding, to get the politicians to line up, and to get the public to also tag along" (Director R&D consortium, Interview 43, March 2014).[30] Indeed, the crafting and telling of the 'story' of nanotechnology's future economic value and disruptive potential must be understood as interwoven with its enactment as a policy object (on the strategic co-construction of technoscience objects, research agendas and communities identified with them, and the societal challenges they are posited to solve, see Balmer, et al. 2016; Calvert 2013; Kearnes and Wienroth 2011a; see also Molyneux-Hodgson and Meyer 2009). Yet just as was true of nanotechnology's categorisation, name and definition, the stories told about nanotechnology were underdetermined by the field's material 'truth', and also responsive to the broader political debates and imperatives of the policy environment.

A story in which the US faced falling behind in a (nano)technologically-dominated 21st century was prominent in efforts to secure support for the NNI bid. A brochure released to communicate nanotechnology's potential to the public offers the cautionary observation that major competitors "Japan and Europe are making similar investments. Whoever becomes most knowledgeable and skilled on these nanoscopic scales probably will find themselves well positioned in the ever more technologically-based and globalized economy of the 21st century" (Amato 1999, 2). Similar statements were made at the 1999 Congressional hearings into nanotechnology (Committee on Science 1999). Yet complicating this storyline of a nanotechnology 'race'[31] is the work by the NNI's proponents to build the field internationally and to encourage other nations' investment in it. Even as Roco argued that US nanotechnology was insufficiently competitive in this 'race',[32] he proactively encouraged other countries to commence nanotechnology programs. Between 1996 and 1998 Roco led an eight person working group to visit twenty countries; the findings were published in September 1999 by the

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[30] On the importance of narrative in the creation of 'policy myths' that frame, justify and give impetus to the actions of policy makers see Herbert Gottweis (1998), see also Chapter 4.

[31] As an example of how entrenched the discourse of a nanotechnology 'race' became, see Hullmann (2006).

[32] For academic Evelyn Hu's critical response to this conclusion of Roco's, which she saw as pre-emptive, see interview comments quoted in W. Patrick McCray (2005, 197).

IWGN and the NSTC (Siegel, et al. 1999). The declared purpose of the study was not only to assess extant international activities but to nurture new activity in nanotechnology (Siegel, et al. 1999, xvii-xviii). Indeed, Roco later recalled that the tour was critical to building credibility for the nascent field: "The visits performed in that time interval were essential in developing an international acceptance of nanotechnology, and defining its place among existing disciplines" (Anonymous 2006, unpaged). In an interview for this research Roco observed that subsequent to the international survey and the workshops the working group held in association with it: "many countries started programs in '98/ '99 at an exploratory level including China and Germany in addition to the United States" (Mihail Roco, Interview May 2014). This suggests that rather than pre-existing the bid for the NNI, the nano 'race' can be seen as in part a desired outcome of the outreach efforts of its proponents (see also Chapter 4).

Stories regarding the 'miraculous' properties of nanomaterials and their power to drive wealth creation while also "dramatically" "improv[ing] the quality of life" and even "promoting a cleaner environment" were also prominent in advocacy for the NNI (NSTC 2000, 14; see also Committee on Science 1999; Kalil 1999).[33] The IWGN-NSTC report hailed "the beginning of a revolutionary new age in our ability to manipulate materials for the good of humanity..." (Siegel, et al. 1999, xviii). A public brochure predicted that "nanoscience and nanoengineering will become as socially transforming as the development of running water, electricity, antibiotics, and microelectronics" (Amato 1999, 1). And the terminally ill Rick Smalley testified to Congress regarding his conviction that "a new exquisite nanotechnology" would within twenty years cure cancer: "I may not live to see it, but, with your help, I am confident it will happen and cancer, at least the type that I have, will be a thing of the past" (Committee on Science 1999, 8). Peter Redfield (2002) observes that throughout history, colonial quests for 'gold' have been justified by their civilising impulses. And indeed, the articulation of nanotechnology promissory claims in a discourse of salvation (cf. Sunder Rajan 2006), and the emissary role of the much-revered and cancer-stricken Smalley, were tactics of whose power proponents were well aware (eg see Admin 2005). Yet these actions were not necessarily cynical: many interviewees for this research appeared convinced of nanotechnology's ability to solve long-standing social, economic and environmental problems, which they understood in

[33] The touting of new 'miracle' materials has a long history, for example in relation to Tupperware (Clarke 1999) and Bakelite (Bijker 1995). For the critical response to nano-sunscreens and the 'miracle' materials they contained see Chapter 6.

technical terms (cf. Calvert 2013).[34] Nonetheless, the formulation of "noble goals" and "'grand challenges'" for the NNI was also a direct response to Congressional demands for research sponsored by agencies such as NSF to demonstrate greater social relevance (Lane 2001, 91).

2.2.7 Overcoming scientific scepticism

The push for recognition of a field called 'nanotechnology', and the efforts of agency officials and White House staff to develop shared language and definitions for it, initially encountered resistance among other scientists. James Heath, a Caltech chemist and Smalley's graduate student during the Nobel-winning discovery of fullerenes ('buckyballs'), told a *Nature* writer that in 2010 that in the years before the NNI was announced "I couldn't even convince people that nano was a real field" (as quoted in Lok 2010, 19). In the quest for scientific credibility, nanotechnology proponents faced difficulties in persuading the research sector that novel quantum phenomena, molecular self-assembling, surface recognition and other specific phenomena observed at particular sites could be generalised, or systematically controlled (Mihail Roco, Interview May 2014). Indeed, in an interview for this research Roco suggested that in the mid-1990s nanotechnology "was not a good word in academia" (Mihail Roco, Interview May 2014). Roco told me that nanotechnology faced scepticism because it was not well understood, and because it was labelled as "technology" and so not viewed as credible by the scientific establishment (Mihail Roco, Interview May 2014). Yet some scientists were also sceptical about 'nanotechnology' because of its association with Drexler's vision for molecular manufacturing. Indeed, McCray's (2013) archival work has shown that Roco himself was deeply concerned about being associated with Drexler, and collaborated with Smalley in efforts to discredit Drexler's work and to distinguish the NNI from it.[35]

By the time of the NNI's launch, Drexler had been marginalised from elite nano policy circles (McCray 2013). As Drexler (2004) insisted, his conception of nanotechnology differed significantly from that of the NNI. Although he welcomed developments in the manufacturing of nanomaterials such as fullerenes and nanotubes as a sign of the field's incremental maturation, Drexler did not consider this to be 'real' nanotechnology (Drexler 2004). In turn,

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[34] On the power in US policy circles of expectations that complex societal problems may be addressed by technological solutions see Kleinman (2005) and Daniel Sarewitz (1996), and on technological determinism in nanotechnology's 'non-presentism' see Cyrus Mody (2006).

[35] On Smalley's publics debates with Drexler see Otávio Bueno (2006), W. Patrick McCray (2013) and Cynthia Selin (2007); on the selective deployment of Drexlerian claims or rhetoric by Smalley and others see also Eisler (2013a, b), McCray (2005) and Mody (2006, 2011).

the NNI's chief proponents and other prominent scientists sought to distinguish their own work as based in empirical experimentation and development. A *Science* article observed that: "many researchers at the cutting edge of dealing with matter on the near-atomic scale have become aggressively matter of-fact, squirming at the suggestion of cornucopian nanofactories or even humbler mass-produced nanodevices" (Service 2000, 1524). In response to a question asked by Christopher Toumey, Hewlett-Packard's Stan Williams, who played a key supportive role in the NNI bid, was blunt about the desire to distinguish his own work from Drexler's:

> "*I have had to spend a huge amount of my energy over the past 15 years or so putting distance between myself and Drexler so that what I do is not associated with him. In fact, when I founded my research group at Hewlett-Packard, we called it 'Quantum Science Research' to avoid any connection with the negative connotations of 'nanotechnology.' Eventually, because the word had found such widespread use in the public, we in the field essentially had to adopt it*" (as quoted in Toumey 2008, 149).

Williams' comments underscore the boundary work (Gieryn 1999) performed by scientists as they sought to align or to distinguish their own research from 'nanotechnology', including through naming. It also highlights the sometimes reluctant adoption of the 'nanotechnology' moniker by practitioners as its public profile grew – a profile that was actively nurtured by NNI proponents such as Roco, including by using the work of industry figures such as Williams to corroborate their own vision for the field (eg Roco, et al. 1999).

As they sought support for the NNI bid, proponents strove to restrain public display of their sometimes bitter ontological disputes. The determinedly civil disagreements between Smalley and Merkle at the June 1999 Congressional hearings offer a striking example (Committee on Science 1999). Yet the critical development in obtaining the broader support of scientists for 'nanotechnology' was arguably the NNI's announcement by Clinton. With the prospect of hundreds of millions of dollars in research funding, thousands of members of the key scientific societies mobilised in support of Congressional appropriations for the NNI, helping to secure its success (see below).

2.3 The formal NNI bid

In the final section of this chapter, having illuminated the circumstances in which conditions in Congress were unusually receptive to a new science and technology initiative, and traced the efforts of NNI proponents to name, define and story nanotechnology to position it as a compelling contender for such patronage, I explore the bid itself showing how its advocates shepherded its eventual success.

2.3.1 A step-shift in momentum

The breakthrough opportunity for NNI proponents came when Lane took up the position of OSTP Director and Presidential Science Advisor at the White House in August 1998. Lane was enthusiastic about nanotechnology's potential. Indeed the transcript from one of the last House Appropriations Committee hearings that he attended as NSF Director recorded him as saying: "If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering, often called simply 'nanotechnology'" (Lane 1998, unpaged). This statement became very widely cited by NNI proponents in support of their bid (eg Amato 1999; IWGN 2000; Kalil 1999; Roco, et al. 1999). Yet intriguingly, in an interview for this research Lane recalled that:

> "*...it was just a flip answer, it wasn't that I didn't believe it, it was just that it wasn't part of the script and I had never thought through, still had not thought through that maybe we should have a government-led initiative. I didn't get into that until I got to the White House...I might have said genetic engineering, who knows what I would have said... but I actually believed it and clearly it was in my head,*[36] *I had been thinking about it, but at that time I had not thought about an initiative, although other people had*" (Neal Lane, Interview March 2015).

Lane's statement highlights the contingency of his much-cited backing of nanotechnology as the field "most likely [to] produce the breakthroughs of tomorrow". It underscores the element of chance in nanotechnology's emergence as "the next big thing" (Schulz 2000). Nonetheless, within a month of taking up his OSTP post, Lane was able to elevate the IWGN which in his estimation had been a "fairly below the radar" working group to the President's attention (Neal Lane, Interview March 2015). Within a month of his appointment Lane established a President's Review Directive to explore nanotechnology's potential, which marked a step shift in momentum for the NNI bid (Neal Lane, Interview March 2015). When Clinton decided to hold a competition to decide his legacy initiative some five months later, it

[36] Eisler (2013a, 240) cites an unpublished working paper in claiming that this testimony was "swayed by Roco".

was in the context of their roles as Presidential assistants that Lane and Kalil invited Roco to present a formal bid for the NNI (Karn and Schottel 2016).

2.3.2 Making the pitch

The NNI was proposed by Roco on behalf of the IWGN[37] on 10 March 1999 (Committee on Science 1999, 59-68). In the Indian Hall at the OSTP's White House offices, Roco was given 10 minutes to pitch to the OSTP and NEC (Roco 2007, 2011). There were over two dozen rival bids in the competition, and on the day that Roco was "competing" two other proposals were made: the Deputy Director of the CIA proposed $30 million for a program to protect the national facilities, and a representative from the National Academy of Engineering proposed $30 million to improve the heating and insulation of buildings (Mihail Roco, Interview May 2014). Conversely, reflecting his evaluation of the needs associated with fostering a new general purpose science and technology, and wishing to make a bold rather than a modest proposal, Roco bid for half a billion dollars (Mihail Roco, Interview May 2014). He later recollected that "nanotechnology captured the imagination of those present and discussions reverberated for about two hours" (Roco 2007, 3.7). According to Roco (2007) it was considered improbable that the NNI would "win" the OSTP competition. However, this marked the first time that its proponents were able pitch the proposed initiative to a high-level audience.

The latter part of 1999 was a time of "intense activity" for the IWGN (Roco 2007). Members sought to shore up the commitments of the 6 proposing agencies to list nanotechnology as a top budget priority – which in the cases of at least DOD (Murday 2007) and DOE (Eisler 2013a) was uncertain – and to build support within the Clinton administration and the wider Congress for a little known field (Roco 2007). On 12 May the IWGN coordinated an informal hearing by the Senate Subcommittee on Science, Technology, and Space at which nanotechnology was discussed (NSTC 1999). On 22 June, the IWGN assisted with a more formal hearing into nanotechnology hosted by the House Subcommittee on Basic Research of the Committee on Science (NSTC 1999). These hearings enabled NNI proponents to expose highly receptive members of Congress to their star supporters, including Smalley who testified at both the Senate (Anonymous 1999) and House hearings (Committee on Science 1999) at Roco's invitation (Lane 2010). Amidst the dot-com boom and a budget surplus, NNI proponents found

[37] The participating agencies were NSF, DOD, DOE, NASA, NIH NIST.

sympathetic audiences. As a result of the 1999 hearings, the Chairman of the House Subcommittee on Basic Research Nick Smith (Republican, Michigan) and Senators George Allen (Republican, Virginia) and Ron Wyden (Democrat, Oregon) became champions for the NNI, identifying new opportunities for their home states in the funding it promised (Allen 2005; Committee on Commerce 2002; N. Smith Undated).[38] Indeed, Allen and Wyden went on to be co-sponsors of the *21st Century Nanotechnology Research & Development Act* which in 2003 was signed in to law by President George W. Bush, as explored in Chapter 4.

By the end of September 1999 the list of candidates for OSTP priority funding had been reduced to three. Intriguingly, the other two finalists were tissue engineering and electronic communications (Karn and Schottel 2016). Tissue engineering's presence in this list appears to suggest that, while powerful, the high-tech discourses by which efforts to name, define and story the policy object 'nanotechnology' had been shaped were not uniquely compelling in science policy at this time (cf. Eisler 2013a; Eisler 2013b; Gallo 2009).[39] Nonetheless, in November 1999, the Office of Management and Budget, whose favourable view of nanotechnology had been cultivated by Kalil (Kalil 2006), recommended it as the only new R&D initiative for financial year 2001 (Roco 2007). PCAST was enthusiastic. Normally requiring 12 months to review a proposal, a PCAST sub-committee headed by MIT President Charles Vest and including Smalley (now in the role of independent science advisor) reviewed the NNI bid in two months. In its endorsement, sent to Clinton on 14 December, PCAST observed: "The United States cannot afford to be in second place in this endeavor. The country that leads in discovery and implementation of nanotechnology will have great advantage in the economic and military scene for many decades to come" (PCAST 1999, 2). Yet emphasising the uncertainty even then of White House support for the NNI, Lane later recalled that through December "Clinton held internal White House meetings in which he grilled several of us on competing initiatives" (Lane 2010, 3). Finally, with the backing of champions in the IWGN, NEC, OSTP, PCAST, Congress and the Senate, nanotechnology won the competition – in January 2000 Clinton publicly announced his commitment to the NNI (Clinton 2000b).

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[38] On the US political appeal of decentralised science and technology initiatives that support the wide distribution of resources, jobs and infrastructure see Daniel Greenberg (2001); on the conservative Cato Institute's accusations that the NNI was an instance of 'pork barrelling' see Clyde Crews Jr. (2003).

[39] A fascinating counter-factual would be to ask what difference tissue engineering's success in this competition may have made to our understanding of dynamics within late-1990s US science policy.

2.3.3 *Securing the budget*

The scientific sector had equivocated before offering support for the NNI, yet ultimately its advocacy was vital to securing Congressional support for the initiative's budget. Clinton announced the NNI in January 2000; appropriations to support $423 of the $495 million the administration requested were approved by Congress in November that year (Shaki Trimble 2000). In addition to nanotechnology's scientific credibility issues, some professional societies had been concerned about the NNI's budgetary implications for their own constituents. The American Physical Society (APS) was initially sceptical, fearing that physics would necessarily lose out (Mihail Roco, Interview May 2014).[40] Nonetheless, the prospect of hundreds of millions of dollars of funding for STEM research affected a marked shift by the professional societies. In the months following the NNI announcement the APS, the American Chemical Society and others hurried to familiarise their members with the new opportunities it promised, and to lobby Congress for budgetary support (Chodos 2000, 2001; Schulz 2000). The APS provided Roco with not one but two statements endorsing the initiative – one from the APS President, and one from the Chairs of the Divisions of Materials Physics and Condensed Matter Physics (NSF Undated). Perhaps suggesting heightened expectations among materials scientists for new funding opportunities associated with the NNI, the other scientific societies to endorse the proposed initiative were the Materials Research Society, The American Ceramic Society, and The Minerals, Metals and Materials Society (NSF Undated).[41]

Within Congress, nanotechnology's champions also organised to lobby their peers. In April the bipartisan Senate Science & Technology Caucus organised a "roundtable discussion" on nanotechnology that featured presentations from high profile industry and academic scientists including IBM scientist Don Eigler and the ubiquitous Rick Smalley (Schulz 2000). Kalil secured endorsements for the NNI from prominent Republicans, including former House Speaker Gingrich, and former science advisor to Bush Snr and past president of both AAAS and APS Allan Bromley (Kalil 2006; NSF Undated). Through the summer of 2000, Senator Barbara Mikulski (Democrat, Maryland), once a critic of NSF's disconnection from the nation's needs (Greenberg 2001), co-wrote with Senator Christopher ('Kit') Bond (Republican, Missouri) a letter to the Senate's leadership, co-signed by more than 40 of their colleagues, urging a doubling of the agency's budget (R.M. Jones 2002a). Their efforts benefited the NNI by making the argument for greater funding of basic STEM research and for the agency charged with its

[40] See also communications of APS to DOE cited in Eisler (2013a).
[41] On the ontological politics surrounding materials science and condensed matter physics, and their relation to nanotechnology, see Eisler (2013a) and Joseph Martin (2015).

lead. Further, in a June 2000 lecture delivered at the NASA headquarters, Mikulski threw her weight directly behind the NNI, hailing it as "the science and technology that will drive the future" and arguing that "the time is right to establish Nanotechnology as an urgent national priority" (cited in Roco and Bainbridge 2001, 349).

Despite early rejections of the bulk of NSF and DOE's NNI budget requests, by November 2000 the NNI funding had emerged largely intact from the appropriations process (Shaki Trimble 2000). NSF's allocated nanotechnology budget of $150 million fell considerably short of the $216.7 million requested for it by Clinton. Reservations were expressed about the agency's capacity to manage two multi-agency long-term initiatives (it was already leading the Information Technology Research initiative). It also faced the perennial challenge of competing claims on its subcommittee's allocations from the electorally sensitive areas of veterans' affairs, housing and urban development (Shaki Trimble 2000; see also Greenberg 2001). Nonetheless, the 54% increase for NSF's nanotechnology work helped contribute to the agency's $529 million increase, its largest ever, which NSF Director Rita Colwell hailed as "put[ting] us on the path toward doubling the NSF budget in five years" (Long 2001, 22).

The success of the NNI bid, and its funding by Congress, was anything but certain. One report cited a White House staff member as saying of its funding that: "The important thing was getting the science community out to support it...That made the difference" (Shaki Trimble 2000, unpaged). Nonetheless, its passage from proposal to funded initiative must be understood also in the context of wider R&D largesse[42] made possible by the budget surplus, technological optimism associated with the then-booming high-tech industry, the efforts over many years of "working level" science-policy intermediaries, the responsiveness of their constitutive and advocacy work to the imperatives of the US policy environment, and some element of chance in the competition for a legacy initiative. In turn, the creation of the NNI had reverberating consequences for the broader success of nanotechnology, the 'reality' enacted for it by its proponents, and the emergence of what Eisler (2013a, 230) has termed "'nanotechnology liturgy'".

[42] According to AAAS figures, federal government support for R&D in fiscal year 2001 grew 9% to $90.9 billion, exceeding the Clinton administration's request of $85.4 billion (Long 2001).

2.3.4 The absence of industry

Perhaps surprisingly, industry had limited involvement in developing the NNI bid or in advocating for it. Workshops and reports produced by the IWGN always included representatives from major companies such as IBM, Hewlett Packard, Exxon, Bell Labs, Dow, Motorola and Eastman Kodak (eg Roco, et al. 1999; Siegel, et al. 1999). Indeed, the authors of such reports were always careful to present them as the result of the "almost equally distributed [participation] between academe, industry and government" (Roco 2004, 3), reflecting the "chorus of support" that Roco had sought to build for the field (Roco 2007). Nonetheless, there is no doubt that the initiative was government driven. Kalil later recalled that even among the semiconductor and IT industries there were few advocates for a nanotechnology initiative: "they were interested in it and wanted to figure out how to work with the government. But there was no one in industry who was actively lobbying me for an initiative in nanotechnology. Once [the NNI] had been launched, there were a number of people in industry who were happy to endorse it and support it" (Kalil 2006, 26). Such observations highlight the pivotal role in creating the NNI of science-policy intermediaries, particularly agency officials and White House staff.

The inadequacy of private sector investment in nanotechnology formed a key component of proponents' pitch for the NNI (eg Committee on Science 1999; Kalil 1999), and PCAST's (1999) rationale for supporting them. This posited government investment in the field as necessary both because the field offered long-term strategic value and because the private sector deemed it too high risk and, at 10-20 years, too far from market to justify its own investment. That is, both public good and market failure rationales were used to justify calls for public investment. This "'dialectics of promise'" (van Lente and Rip 1998, 223) was particularly well-suited to the US political environment. It enabled the NNI, while crafted to appeal particularly to the Clinton administration, to be simultaneously presented to fiscal conservatives as wholly consonant with the principles of those who would see federal funding limited to non-commercial research.

Previous analysts have pointed to the NNI as the "culmination" of a new, commercially oriented and utilitarian US science policy (Johnson 2004), that may be in part explained by "industry's influence" in policy making (Rudd 2009, 126). Others have characterised it as a form of industry policy (Block 2008), albeit one with questionable efficacy given its focus on basic science (Applebaum, et al. 2013; Motoyama, et al. 2011). In this chapter I make a slightly different argument: the rationale and public justification offered for the NNI was utilitarian and commercial, but rather than this reflecting the influence of industry or indeed the expectation of its government champions for near-term commercial outcomes, it is another site at which we can observe responsiveness to interactional dimensions in intermediaries' constitutive work. Key NNI proponents acknowledged that the "technology... really isn't there yet" (Lane 2001, 96). Yet in search of new funding streams for the physical sciences they enacted what was then a heterogeneous field of largely non-commercial research as an economically compelling, geopolitically important new technology, whose backing was consonant with commercially oriented and utilitarian science policy. That is, positioning nanotechnology as 'commercially relevant' was a tactic adopted by intermediaries who sought more generous research funding, including for basic science.[43] Steven Vallas and Daniel Kleinman have shown the influence of "a logic of commerce and capital accumulation" within academic science (2008, 11; see also Kleinman and Vallas 2001). Relatedly, I find the influence of 'market logics' – or at least the felt need to demonstrate conformance with them to political audiences – in the administration of federal science policy. Put differently, at the time of its creation, the "industry influence" on the NNI reflected the work of federal agency officials, White House staff and entrepreneurial scientists as they sought to "sell a national initiative" to the Clinton administration and to Congress (cf. Murday 2007, 53).[44] The generative power in science policy of political preferences and market logics *as apprehended* by science-policy intermediaries is explored further in Chapter 3.

2.4 Conclusion

Challenging impressions of the inevitability of state support for nanotechnology, this chapter has shown that state support for the NNI, and the form assumed by the policy object at its heart, were situated achievements. That is, they were enabled by and responsive to a particular set of scientific, political, and economic conditions, and enacted through science-policy intermediaries' active work – their achievement must be understood *in situ* (cf. Balmer,

[43] For a similar argument see Eisler (2013b). On the long-standing challenge for NSF to demonstrate socioeconomic 'relevance' in the research it funded see Kleinman and Mark Solovey (1995).

[44] This provides a somewhat different and messier picture of the means by which 'industry influence' is exerted on US science policy making from that of some earlier work. In Kleinman's analysis of policy making in the post-war years, he points to "the overlap between scientist elites and business" and their "dense web of interlocking social connections" as enabling the indirect influence on policy making of industry perspectives and interests (1995, 142). Yet here, largely in the absence of such "overlap", I find science-policy intermediaries actively advocating for the interests of industry – even in the absence of industry's identification with these interests – as a tactic to boost their funding prospects.

et al. 2016). Efforts to position the NNI for support by both the Clinton administration and Congress were shaped by epistemic and political conflicts in the wider policy environment, including regarding the state's role in sponsoring technological innovation and the economic value of STEM research. Intermediaries' efforts to name, define, and story the policy object 'nanotechnology' reflected and responded to these sometimes competing imperatives, illustrating how interactional co-production was present within constitutive work (see also Part A Conclusion). Early work to prepare the NNI proposal took place amidst "unprecedented discord in federal science" (Eisler 2013b, 24), and yet the NNI achieved political backing in unusually favourable circumstances. The Clinton administration's willingness to back a new science and technology initiative, and that of Congress to fund it, was boosted in large part by the extant budget surplus and the dot-com boom for which it was credited. Nonetheless, the identification of nanotechnology as the object of such new policy and the NNI's funding by Congress were never assured: they reflected intermediaries' extensive advocacy, but also an element of chance.

The NNI achieved political backing in a specific set of political and fiscal conditions. The Clinton administration's receptivity to the NNI bid was boosted by its embrace of economic theory that anticipated wealth-creating opportunities in nascent STEM fields, its belief in technology as the means to pursue both economic and social goals, the material success of the dot-com boom, the growing ties between market-leaning Democrats and the high-tech industry, and its quest for a point of political differentiation in the upcoming federal election. The desire of White House staff to use an "exciting new area" to rejuvenate funding for the physical sciences and Clinton's desire for a 'legacy initiative' predated the NNI proposal. Nanotechnology's selection to play these roles reflected the "buzz" surrounding the field, years of preparatory work by the federal agencies, the championing of key White House staff, and also chance. However the NNI ultimately benefited from broader bipartisan support for federal funding of basic research seen to underpin the nation's technological competitiveness, Congressional willingness to break the budget caps given a new budget surplus, and the growing array of scientific, political and to a lesser extent commercial actors who identified their own interests and that of their constituencies as aligned with its success.

This chapter contributes to Part A's exploration of the question of why states seek to sponsor technological innovation, and how particular areas of technoscience are singled out for political patronage. In the words of Neal Lane (2001, 101) "nanotechnology was the right initiative at the right time". Indeed, the policy object 'nanotechnology' was carefully crafted to maximise the opportunities offered by the unusually favourable political and fiscal circumstances of 1999-2000. In making this point, I differ from some earlier work (see especially Eisler 2013a; Eisler 2013b) which emphasises nanotechnology's responsiveness to the mid-1990s research funding crisis and anxiety over the basis for science policy. Nanotechnology was clearly a vehicle for physical scientists to claim industrial relevance. Yet I show that the NNI's creation was enabled not by crisis, but by a brief period of political detente amidst fiscal abundance and surging confidence in the 'new economy', in which a President's wish for a legacy initiative coincided with Congress's willingness to fund it. Moreover, I argue that even with such propitious conditions, the success of the NNI bid was never predetermined, but reflected significant work, mainly undertaken by agency officials and White House staff. Despite the NNI winning the 1999 competition for priority funding, the competition's broad field, the President's continuing exploration of alternatives in the month before the NNI's announcement, the early difficulties of the NNI's passage through Congressional appropriations, and the finalisation of DOD support for the NNI on the single last day of the Clinton administration, collectively underscore the possibility of the bid's rejection and the uncertainty of its eventual success.

The next chapter investigates in greater detail the role of science-policy intermediaries in the Australian decision to prioritise nanotechnology in public research funding, and their instantiation of apprehended 'market logics' and political preferences in the process of research policy making.

Chapter 3: Prioritising Australia nanotechnology research

In contrast to the new focus on nanotechnology in Washington DC, at the Sydney launch of *Backing Australia's Ability: An Innovation Action Plan for the Future* in January 2001, the field went unmentioned (Commonwealth of Australia 2001). Nonetheless, just 12 months later, nanomaterials research was identified by Prime Minister John Howard's Coalition government as one of four priorities towards which it directed the Australian Research Council (ARC)[1] to allocate at least 33% of its competitive grants. Given the nascent state of Australian nanoscience and mixed views regarding its commercial prospects (Ernst & Young 2002), this direction surprised, even "shocked" many in the research sector (Illing 2002, 31). It prompted accusations of political interference and suggestions that processes properly controlled by scientists had been compromised (Jackson 2002 a,b). Yet nanotechnology's prioritisation was not a sign of the strength of state support for the field, nor of overt government interference in the activities of the ARC, nor even of undue industry influence, as some Labor politicians suspected (eg Senate Employment 2002, EWRE187). Instead, I show that it reflected the pivotal role in priority setting of intermediaries acting between the spheres of science, policy and politics (cf. Meyer and Kearnes 2013), including the government's Chief Scientist, the senior management of the ARC, and that of the national science agency the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Following Chapter 2's investigation of the ontological politics (Mol 1999, 2002) associated with the successful bid for the United States (US) National Nanotechnology Initiative (NNI), this chapter undertakes a more detailed exploration of the role of intermediaries in the development of Australian research priorities. In so doing it responds to the first and second research questions of the thesis, illuminating a site at which the imaginaries of technoscience proponents, and political preferences and 'market logics' as *apprehended* by science-policy intermediaries, were transmitted to and embedded within science policy.

It is over twenty five years since Sheila Jasanoff wrote that: "Scientific advisory bodies occupy a curiously sheltered position in the landscape of American regulatory politics. In an era of bitter ideological confrontation, their role in policymaking has gone largely unobserved and unchallenged... and their impact on policy decisions is difficult to understand or evaluate" (1990, 1). The work and influence of intermediaries at the science-policy interface has subsequently received much attention from science and technology studies (STS) scholars (eg

[1] The Australian Research Council (ARC) provides the majority of public funding for non-biomedical, university-based research through its competitive grants scheme. It is modelled on the United States (US) National Science Foundation (NSF, Aitkin 1991).

Bijker, et al. 2009; Gottweis 1998; Guston 2000; Jasanoff 2005a; Kleinman 1994, 1995). An early and influential branch of such scholarship employed principal-agent theory in a series of studies that investigated relationships between the state, researchers and funding agencies (Braun 1993; Braun and Guston 2003; Guston 2000). Dietmar Braun and David Guston conceptualised relations between these three constituents as involving a form of double delegation, in which authority and resources were delegated from the state to research funding bodies, and from funding bodies in turn to the research community. In this context they characterised science policy in largely contractual terms, as the means through which the political 'principal' seeks to ensure the integrity and productivity of the work undertaken by its scientist 'agents'. This conceptual paradigm has informed understandings of how interactions between science and politics are organised, including via 'boundary organisations' such as research councils (Guston 2001). Yet principal-agent theory, grounded in rational choice theory, elides discursive and ideational influences on research policy, and insufficiently explains "the cumulative, social and institutional consequences of the relationships it describes" (Shove 2003, 381). More recent work has emphasised the performativity of intermediaries' practices in the definition or constitution of new technoscientific fields (Kearnes 2013; Kearnes and Wienroth 2011a),[2] the creation of expectations-based markets (Pollock and Williams 2010; see also Callon 2007; Mirowski and Nik-Khah 2007), and in reframing the value and meanings of science in public life (Kearnes and Wienroth 2011b). Yet despite this considerable body of STS work, it remains accurate to observe that, to paraphrase Jasanoff, intermediaries' role in research priority setting has gone largely unexamined, and remains difficult to understand or evaluate.[3] In illuminating how science-policy intermediaries shaped Australian research priority setting, in the absence of direct political or industry involvement although influenced by cues regarding political expectations, I contribute to addressing this lacuna.

The focus of this chapter is the period 2000-2002. I begin by investigating the political, economic and ideational environment in which a new policy focus on 'innovation' and a process of research priority setting emerged. I then explore the imperatives that conditioned the 2001 process of priority setting, as apprehended by its participants. Finally, I investigate the events that led to the 2002 declaration of the ARC Research Priorities, analysing the central

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[2] See also the special section of the journal *Science and Public Policy,* edited by Morgan Meyer and Matthew Kearnes.

[3] However on the influential role of intermediaries in establishing research policy architectures that permit prioritisation to greater or lesser degrees see Daniel Kleinman (1994, 1995).

roles played by elite science-policy intermediaries including the senior management of the ARC and CSIRO and Australia's Chief Scientist. Archival work and semi-structured interviews were conducted as described in Chapter 1.

3.1 Millennial Australia

3.1.1 A new focus on innovation

The millennial focus by the Australian government on 'innovation' was not unusual given contemporary international preoccupations with the pursuit of a 'new economy' (Romer 1990, 1994) or 'knowledge economy' (W. Powell and Snellman 2004; K. Smith 2004),[4] such as explored in Chapter 2. The Minister for Communications, Information Technology and the Arts Senator Richard Alston was also passionate about boosting Australia's capacity to participate in a knowledge economy (Ministerial advisor, Interview 46, December 2015). However, the new attention to innovation was also a more direct response to criticism of the conservative government's earlier aggressive cuts to research and development (R&D) funding. When the Coalition came to power in 1996, it brought with it a declared ideological commitment to small government and to 'free markets'.[5] Budget cuts and policy measures were introduced to force Australian researchers to better conform to 'market logics' as understood by government (see Part A Introduction). Cuts were made to university funding and to the CSIRO, in line with the Howard government's view that research should derive a greater proportion of its funding from industry. At the same time, the industry R&D tax concession was reduced from 150% to 125%, reportedly at the urging of Treasury (Anonymous 2000). Commonwealth expenditure on R&D fell 6.88% between 1996-1997 and 1998-99 (ABS 2006). Pressure from big business in response to the cuts is credited by some policy analysts for the government's new emphasis on innovation in 1999-2001 (Conley and van Acker 2011; Marsh and Edwards 2008, 2009). The threat by the opposition Labor party to make science and innovation a 2001 election issue, including via its 'Knowledge Nation' proposals (Beazley 2001; Chifley Research Centre 2001), also prompted the Coalition to offer policy differentiation.

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[4] On the origins of 'knowledge economy' discourse and its relationship to that of the 'new economy', the rhetorical use of both frameworks, and the dubious use of statistics to substantiate their claims, see Benoît Godin (2009). The terms were used interchangeably by many actors to denote an economy driven strongly by technological innovation, although in Australia 'knowledge economy' discourse was more prominent.

[5] In practice, as with all Australian governments, John Howard's was guided by political pragmatism as well as ideology. Once a budget surplus had been achieved, it initiated a "massive spending programme" (Thurbon 2012, 289) which was critiqued for its emphasis on 'middle-class welfare' (see Wanna 2011).

Howard's turn to innovation produced a number of reports and a National Innovation Summit (Miles 2000), which was jointly organised by the federal government and the Business Council of Australia (Marsh and Edwards 2008). In 1999-2000 the Chief Scientist Professor Robin Batterham carried out a review of the research system and Australia's science, technology, engineering and mathematics (STEM) capacity. The tenor of Batterham's report is encapsulated in its title: *The chance to change*. Warning that Australia was too heavily reliant on "'old economy'" industries such as mining (Batterham 2000, 27), the report noted that government support for industry R&D was only a quarter of the OECD average, having declined the most among OECD countries in the period 1990-1999. In a move familiar to STS and innovation scholars (Callon 2007; Calvert 2006; Godin 2006), Batterham positioned greater public funding for science as the means to building an innovative economy, and a 'science push' approach (Dodgson, et al. 2011; Marsh and Edwards 2008, 2009) as key to supporting techno-industrial transformation. In this, he appealed to a latent 'techno-nationalism' (Edgerton 2007), and implicitly leveraged the "foundational premise" – one increasingly critiqued by STS work – "that national programs of basic research beg[e]t national economic growth" (cf. Eisler 2013a, 241; see also Mirowski and Sent 2008). The Chief Scientist argued that only with greater public funding for STEM could Australia "be a vibrant economy with a range of knowledge-based industries, attract major international investment and further benefit from solid participation in the knowledge economy" (Batterham 2000, 27). In turn, such thinking informed the Howard government's innovation policy.

3.1.2 'Backing Australia's Ability'

Backing Australia's Ability (BAA, Commonwealth of Australia 2001; Howard 2001) was released by the Prime Minister on 29 January 2001 as the centrepiece of the government's new innovation policy. BAA committed an additional AUD$2.9 billion[6] over five years to research funding, research infrastructure, incentives for private sector R&D, and new initiatives in emerging technologies deemed to be of commercial promise, namely information and communications technology (ICT) and biotechnology. In subsequent comments ARC Chief Executive Officer (CEO) Professor Vicki Sara (2001, 1) described BAA as: "a very significant step in setting Australia on its path to becoming a knowledge based economy... This is the beginning of the turnaround which will boost Australia's global competitiveness both as a creator and a transmitter of knowledge". The symbolic and material victory for the academic

[6] All dollar figures cited in this chapter are for Australian dollars.

research sector was the $736 million BAA provided to double the ARC budget, contingent on its grants scheme emphasising “areas in which Australia enjoys, or wants to build, a competitive advantage” (Commonwealth of Australia 2001, 15).

Some viewed BAA as a necessary political retreat for the Coalition from its aggressive research funding cuts, and “amount[ing] to an apology for an ideology gone terribly wrong” (Kingston 2001, 22). Indeed by April 2000, in a speech focused on economic reform for the 21st century, even the Prime Minister acknowledged that initiatives taken by his government had “swung back a little too far ... we believed that every problem could be solved by the unrestrained operation of market behaviour and some naive notion that trickle down economics from that unrestrained operation would solve every problem. That’s not realistic” (Howard 2000, 3). Nonetheless, it would be misleading to view BAA as an unmitigated apology for an overzealous application of ‘free market’ principles to Australian research. Instead, BAA was also the means to support funding redistribution, in line with the Coalition’s broader aim to promote research commercialisation.

3.1.3 “Driving commercial outcomes”

Backing Australia’s Ability cited a primary objective as “driv[ing] commercial outcomes” from research (Commonwealth of Australia 2001, 7). Indeed BAA was framed as a ‘solution’ to the ‘problem’ that Australian researchers were failing to “translate knowledge into wealth” (cf. Batterham 2000, 9). This criticism was neither new, nor uncontested (eg ARC, et al. 2002; Senate Employment 2000, see especially p19). A 1993-1994 budget statement from the previous Labor government led by Paul Keating had observed that despite the “excellence” achieved in public sector research, there was a “weakness in our ability to exploit our R&D in many fields” (Schacht 1993, 3-4). Under Howard such criticism intensified, and rather than attributing any “weakness” in research commercialisation to demand-side dimensions associated with Australia’s industry structure (see Part A Introduction), researchers were held responsible. Divergent with the declared rationales for publicly funded science in the US (see Part A Introduction and Chapter 2), the Howard government demanded that scientists demonstrate greater responsiveness to the near-term needs of industry. The research fields which BAA identified as holding particular commercial promise, and rewarded with greater funding, were those of emerging technologies. Biotechnology and ICT were heralded as “key enabling technologies” and “an engine for growth” (Commonwealth of Australia 2001, 20).

BAA committed $176 million to the establishment of a Centre of Excellence for biotechnology and one for ICT, and an additional $20 million to double the government's existing Biotechnology Innovation Fund (Howard 2001). Conversely, BAA provided no dedicated funding for the arts, humanities or social science, or for ecological research. BAA's boost to research funding thereby reflected and entrenched a narrow view of what kinds of knowledge had value or relevance to 'innovation' or a 'knowledge economy' (cf. K. Smith 2004; Stirling 2009b), and merited public funding on this basis.

In addition to being a site for funding redistribution, BAA also signalled to the national science agency that it needed to realign its "game plan" with that of the government's. Despite its emphasis on commercially relevant science, BAA did not provide further funds for the CSIRO whose mandate most directly relates to 'applied' research.[7] In an interview the former Chief Scientist Robin Batterham observed of BAA: "...you look at [it] and say, 'I think there's a message here' because CSIRO at the time were on a game plan of their own" (Robin Batterham, Interview April 2015). Indeed CSIRO's vexed relationships with government (Senate Employment 2002) and its "cash-strapped" state (Johnson 2001) was noted more widely. When new CEO Geoff Garrett was appointed in January 2001, coincident with BAA's announcement, reconfiguring CSIRO's institutional identity and its relations with government and seeking a more secure footing for future funding were high priorities. This prompted a far-going review of CSIRO's strategic objectives that would in turn influence the process of developing ARC Research Priorities.

3.1.4 CSIRO's growing commitment to nanotechnology

As occurred internationally (see previous chapters), interest in nanoscience grew sporadically in the Australian research sector through the 1980s and 1990s, and was often not labelled 'nano'. Much early R&D took place at CSIRO, culminating in the successful commercialisation of a small number of nano-products (for summaries of early Australian nanoscience see ASTEC 1993; PMSEIC 1999). Labor Prime Minister Keating was supportive of the ambitions of the budding nanoscience sector, and contributed funding to establish the National Nanofabrication Facility in 1994. Two months before the NNI's announcement, Australian proponents made a report to the Prime Minister's Science, Engineering and Innovation Council

[7] On the flexible and strategic use of this term see Jane Calvert (2006); on my qualified use of it see Part A Introduction.

(PMSEIC, the Australian counterpart of PCAST),[8] now reporting to Coalition Prime Minister John Howard, seeking further funding to establish research infrastructure (PMSEIC 1999). The report achieved little direct impact, although it helped to build the familiarity with the field of Howard and his senior scientific advisors.

The institutional commitment of CSIRO to nanoscience expanded in 2000 and 2001. The field's profile grew rapidly at this time, following the creation of the US NNI and shortly thereafter of national nanotechnology programs in Japan and Korea (see Roco 2011). However, CSIRO's increasing focus on nanotechnology was due also to the internal advocacy of its researchers, and influenced by the arrival of new CEO Geoff Garrett. As one interviewee recollected: "...it was around about 2000 was when it really took off in CSIRO anyway, and we started taking notice of it... That was when Vijoleta Braach-Maksvytis sort of came and... she was pushing really hard on nanotech" (Technical scientist, Interview 11, December 2013). Senior nanotechnology researcher Braach-Maksvytis remembers putting a lot of effort into building support for the field within CSIRO at this time:

> "*It didn't exist before. Actually, it was when Geoff Garrett came, and I remember sending him an email saying 'CSIRO has to be the best in this field, because we have everything, we're multidisciplinary, I already knew all the scientists'... Geoff responded to that and was very supportive of initiatives that I was taking and also that helped, I became the head of CSIRO's emerging science strategy area, and so rallying around nano*" (Vijoleta Braach-Maksvytis, Interview June 2015).

In this way, a key argument made within CSIRO for a greater focus on nanotechnology was, consonant with the exhortation of BAA, the competitive advantage the institution already enjoyed in this area.[9] A more focused nanotechnology effort could potentially result in some visible, 'commercially relevant' successes, helping the national science agency to rebuild its relations with government and make its funding base more secure.

The success of nanotechnology advocates within CSIRO in developing its commitment to the field was apparent in the organisation's strategic planning processes of 2001. CSIRO undertook a series of internal reviews, producing a strategic action plan and also 2025 scenario planning

[8] PMSEIC has been described as "the Australian Government's principal source of independent advice on issues in science, engineering and innovation and relevant aspects of education and training" (DIS Undated-a, unpaged).

[9] On CSIRO's contemporary work in nanoscience see Vijoleta Braach-Maksvytis (2002).

around “national ‘thematic’ priorities” (Senate Employment 2002, EWRE261). The organisation identified five ‘emerging science areas’ in which it would concentrate effort: biotechnology, complex systems science, ICT, nanotechnology, and social and economic integration (DEST 2003). The strong similarity of these areas to those subsequently identified as ARC Research Priorities was conceded by Garrett at a Senates Estimates hearing, as discussed later in the chapter.

3.1.5 Researchers as “nanotechnology activists”

The advocacy for nanotechnology of CSIRO researchers expanded throughout 2001, as they sought to build support for an Australian counterpart to the NNI. Braach-Maksvytis persuaded sympathetic officials within the bureaucracy to fund an international nanotechnology conference held jointly by the CSIRO and Department of Industry, Science and Resources (DISR) in March 2001 (DISR 2001; Vijoleta Braach-Maksvytis, Interview June 2015). Braach-Maksvytis recalled the importance of the workshop within a broader context of lobbying for the field: “Behind the scenes, I was pulling it together, and it was me going round to convincing scientists, policy makers, industry bodies, that you know we need to get in early, at this stage. And so the sort of the leg work behind that. And that conference pulled it all together” (Vijoleta Braach-Maksvytis, Interview June 2015). The physicality evoked in Braach-Maksvytis’ description of her ‘brokering’ activities (cf. Meyer 2010; Meyer and Kearnes 2013) as “leg work” is evocative. Her recollection highlights the central role played by intermediaries in building the identity and membership of the nascent Australian nanotechnology ‘community’ as they sought support for a national nanotechnology program.[10]

As Braach-Maksvytis emphasised, the 2001 CSIRO-DIISR conference helped to build Australian momentum for nanotechnology. It was a site at which nanotechnology proponents sought to enrol (cf. Callon 1986; Latour 1987) diverse sectoral groups – “scientists, policy makers, industry bodies” – in their imaginary of future, nanotechnology-enabled prosperity conditional only on the sufficiency of state support, and to urge these groups to lobby government for resources to support the field’s expansion. The conference report was frank about the barriers to nanotechnology’s development in Australia, stressing the nascent state of nanoscience, the practical challenges to its commercial application, and the lack of both industry and political awareness of the field (DISR 2001). It noted that building support for a national

[10] On the strategic importance of 'community making' in emergent fields of technoscience see Susan Molyneux-Hodgson and Morgan Meyer (2009).

nanotechnology program would require the active work of "champions", with conference participants acting as "nanotechnology activists" prepared to "nurture[e] a second generation of activists" (DISR 2001, 28). This language is striking. Scientists were clearly planning to engage in a political and industrial campaign for an Australian nanotechnology initiative, adopting the lexicon and strategic planning toolkits of social movement activists. This offers a counterpoint to the suggestion by British physicist Richard A.L. Jones (2011a, 13) that "we should consider [nanotechnology] as a socio-political project, less created by the scientific community, than imposed on it by a combination of political and cultural forces". Instead, we see here scientists working to build support for a national nanotechnology program not only in *response* to "political and cultural forces", for example as has been shown convincingly in earlier US work (Eisler 2013a, b; Gallo 2009), but by actively seeking to marshal and to reshape those forces to better position their own research agendas. This under-recognised agency of science-policy intermediaries, and the influential work of key individuals and institutions in (re)shaping both research policy agendas and debates regarding the value of publicly funded research, is a theme to which I return throughout the chapter.

In this period, Australian science-policy intermediaries routinely leveraged the NNI to legitimise their promissory claims for nanotechnology's future impact (see also Chapter 4). Speculative, technologically determinist claims regarding nanotechnology's centrality to future US economic interests had helped to mobilise political support for the initiative (McCray 2005, 2013; Mody 2006). Yet, highlighting the performative achievement of the NNI's creation (cf. Callon 2007; Gibson-Graham 2008; Petersen and Krisjansen 2015; Pollock and Williams 2010), such claims were in turn given credence by its launch. Rather than being seen as the contingent winner of a competition for a new science and technology initiative (Chapter 2), the NNI was understood by many Australian researchers as an expression of state commitment to nanotechnology's development, based on expectations of its becoming a key technology of industry (eg AAS 2002c).

Australian researchers also used the NNI's representatives to bolster the credibility of their own contributions to the field. Braach-Maksvytis organised for the NNI's Mihail (Mike) Roco (Chapter 2) to give a keynote talk at the CSIRO-DISR conference, along with guest speakers from Japan and the United Kingdom. She stressed the importance of "having him come, with his status of association with the US President's office, and give that – hear the same things that I'd be saying [about the achievements of Australian nanoscience] but actually hear it from an outside view... That was sort of the final catalyst... it really was the starting point" (Vijoleta Braach-Maksvytis, Interview June 2015). As an "outside[r]" enjoying the "status of association with the US President's office", Roco's testimony helped boost both the self-confidence of Australian nanotechnology researchers, and their standing in the eyes of policy makers. During his 2001 visit, Braach-Maksvytis organised for Roco to lobby key political and scientific advisors: "that was very important, because I arranged and went with him obviously to a series of meetings in Canberra. Not just the Department of Industry but also the Prime Minister's office and the Prime Minister's Science and Research Council" (Vijoleta Braach-Maksvytis, Interview June 2015). In this way, as they sought to mobilise priority funding and political support for their field, intermediaries drew on the NNI and its representatives to nurture expectations among Australian political actors and influential bureaucrats of nanotechnology's future scientific and economic importance (cf. Borup, et al. 2006; N. Brown and Michael 2003; Hedgecoe and Martin 2003), and the competitive capabilities of Australian nanoscientists.

This section has provided a brief overview of the economic and political debates that shaped Australia's millennial focus on innovation, and the growing commitment of CSIRO to nanotechnology. Having provided this broad introduction to the context in which research priorities were developed, in the remainder of this chapter, I pay particular attention to the role of science-policy intermediaries in the process of priority setting. I first explore the imperatives that shaped the "deadly serious" business of research priority setting, as apprehended by the intermediaries who participated in it. Then in the final section, I offer a detailed investigation of the process that culminated in the nomination of nanotechnology, a field unmentioned in any of the BAA documents or speeches in January 2001, in January 2002 becoming one of four priority areas to which the Howard government directed the ARC to allocate 33% of its competitive grants allocation.

3.2 The "deadly serious" business of priority setting

3.2.1 Apprehending political preference

Science-policy intermediaries were keen to ensure the political salience of ARC priorities. And yet, it is a key argument of this chapter that the political preferences which were apprehended by them, and then mobilised in priority setting, were largely not explicitly communicated by government. Nonetheless, the desire of key Ministers for a greater 'focus' in the research investment was readily apparent – as was the Howard government's preference for STEM research that could have an industrial application, over arts, humanities, social sciences or ecological research. In a context in which most Cabinet members were disengaged from science and technology policy discussions, the Minister for Communications, Information Technology and the Arts, Richard Alston, exerted an "outsized influence" on research policy deliberations (Ministerial advisor, Interview 46, December 2015).[11] Alston was "horrified to discover that CSIRO had missed the dot-com boom" (Ministerial advisor, Interview 46, December 2015).[12] Concerned that Australia would miss out on "the technological revolution happening in other parts of the world" because it wasn't applying sufficient "focus" to the research effort, Alston had insisted that the BAA funding be prioritised (Ministerial advisor, Interview 46, December 2015). Whereas the US bid to prioritise nanotechnology emerged in the midst of the dot-com boom and sought to build on its success, the Australian push for research prioritisation was in this way spurred by a sense of missed opportunities. The view that a mid-sized economy such as Australia needed to "focus" its research effort to secure greater impact was one shared by the Chief Scientist Robin Batterham, the CSIRO CEO Geoff Garrett, and with qualifications by ARC CEO Vicki Sara (see below). Less clear was the degree to which such "focus" should be applied – that is, the quantum of research funding that would be dedicated to specific priorities – and the STEM fields that would be deemed to offer "competitive advantage".

The period in which the ARC Research Priorities were developed was one in which the senior management of the ARC and the CSIRO felt particularly vulnerable to political interference. CSIRO was in the midst of internal restructuring and strategic planning, and hoping to re-establish positive relations with government. The ARC was acquiring statutory independence from government for the first time, and its autonomy from Ministerial direction remained uncertain (eg Senate Employment 2000). BAA had made clear that the government wanted

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[11] An interviewee observed: "[Minister Alston] was actually a genuine believer in the importance of technology and innovation. So he was really passionate about it. And he thought [research prioritisation] was the right thing to do. Right – and passion is influential. Because you have a whole lot of other people who aren't passionate. They want to talk about tax policy. So they're in the Cabinet, and they've moved on from national security which is *this* person's favourite topic, and they've gone from tax policy which six people are *really desperately* interested in, and then we're on to science and innovation, and you know most people in the room, they want to do the right thing, but they don't really know what the right thing is. And so they think 'well you know we will treat [this] seriously, but you know with only 2% of government spending, it's only going to get 2% of our headspace, it's not our personal area of interest, here's a fellow who's actually really interested in it', then that person will have an outsized influence. I think [Labor Senator] Kim Carr had the same thing" (Ministerial advisor, Interview 46, December 2015, emphases in original).

[12] This response was itself emblematic of Australian politicians' tendency to attribute responsibility for technology development to the research sector (see Chapters 4-5).

researchers – and research funders – to target areas (seen by government to be) of commercial promise. To obtain greater security for their constituencies, the intermediaries involved in priority setting sought to demonstrate a greater degree of 'focus' and commercial relevance in the research they supported. That is, they understood that their responsiveness to extra-scientific logics would be vital to safeguarding both institutional autonomy and future funding. Demonstrating responsiveness to these keenly felt political imperatives whilst safeguarding the integrity of their core work presented significant challenges. Political, epistemic and strategic disagreements took place regarding the appropriate role for corporate-style management and "market oriented processes" in science, particularly within CSIRO (eg CEO Forum Group 2005, unpaged). The extent to which short or even long-term commercial prospects should be the basis on which research value was judged was a topic of recurring debate (eg Chifley Research Centre 2001, 53).

Research priorities necessarily reflect and reinscribe judgments regarding social and scientific value (Calvert 2013); they are always "thoroughly political" (Aitkin 1997, 184). As Daniel Kleinman has observed, "how and what research priorities are set has a dramatic impact on the contours of a society and, indeed, says a good deal about the society's broader values and priorities" (1995, 5). Research priorities can support the flourishing, or result in the withering, of whole fields of technoscience (Forman 1987). Yet processes of priority setting are often opaque, and the terms of their judgments implicit (Cozzens 2003), as was the case with the process of setting ARC Research Priorities.

Although its political stakes were well recognised by participants in the process, the identification of candidate areas for ARC prioritisation took place with little direct political involvement. When asked whether there was "much interest from government in the process of ARC priorities", Sara replied: "No, no, no. When you say, 'was there much interest', it was only if something was in the headlines in the daily paper – that was the interest" (Vicki Sara, Interview September 2015). Nonetheless, despite little *explicit* political engagement in its activities, Sara emphasised the attentiveness of the working group to its political context: "We were all fairly aware of what you had to do in a political situation" (Vicki Sara, Interview September 2015). Batterham made a similar point. Rather than experiencing any overt political direction, he recalled that the PMSEIC working group and the Office of the Chief Scientist were responsive to the *anticipated* priorities and constraints of government:

> "*PMSEIC and its working groups as well as my own activity always steered a fine line between total independence and simply following what the government of the time expected or wanted. PMSEIC and its working groups were always quite independent. That said, I had the privilege often of suggesting what might be politically doable and weaving such possibilities into the consciousness of the working groups. This is very different to simply following the whim of a particular government*" (Robin Batterham, Written comments, September 2015).

Batterham depicts the work of intermediaries as "steer[ing] a fine line" between developing "total[ly] independen[t]" science policy and ensuring its political support. This intuition, translation and instantiation of what was "politically doable" – a form of active intermediation between the assumed interests of the state and those of the research sector (cf. Meyer and Kearnes 2013) – was central to the PMSEIC working group's oversight of the ARC Research Priorities development. The priorities' eventual focus on emerging technologies may be understood to reflect the mobilisation of political preferences and commercial relevance as *apprehended* by the science-policy intermediaries who developed them, given 'cues' such as the precedent established by BAA and the known predilections of key Ministers such as Richard Alston. Largely unrecognised by the intermediaries, their actions in turn contributed to (re)shaping the research policy landscape as we will see.

3.2.2 Priorities as "packaging"

The stated purposes served by research priorities and the rationales given by interviewees for supporting prioritisation are heterogeneous. In 2002 Batterham argued that establishing research priorities would offer both material and discursive benefits. He suggested that concentrating the research effort could help "bridge the current credibility gap" plaguing Australian research by increasing the likelihood of its demonstrable impact, while also supporting more effective public and political communication regarding its goals and public value (AAS 2002a, unpaged; see also comments by Joanne Daly, AAS 2002c). Sara made similar public arguments. She observed that research prioritisation would shift funding resources and concentrate the R&D effort (Sara 2001), enabling Australian researchers to achieve and to demonstrate "excellence", while exciting both "the Cabinet" and "kids in school" (AAS 2002a, 27).[13] Somewhat differently, and consonant with the emphasis in recent STS work on nanotechnology as a discursive construct responsive to sociopolitical needs (Eisler 2013a, b; Gallo 2009; see also Wienroth and Kearnes 2010), in an interview for this research Sara emphasised the discursive role of priority setting and characterised emerging technologies priorities as "packaging".

Echoing the arguments of her US counterparts (Chapter 2), Sara described how the pursuit of funding for "fundamental research" required intermediaries to tell politically persuasive stories about the future gains such R&D investment would support, and the value of emerging technologies as "packaging" in this 'promissory' work (cf. Fortun 2008; Gardner, et al. 2017; Hedgecoe 2003; Pollock and Williams 2010):

> "*The role of the packaging is to convince the politicians of the need for investment. And it's much more exciting, and business understands much better, if you can package that in certain areas which will have a technology and commercial outcome. Very difficult for fundamental research, but without that you won't get anywhere... I think that that's why research or science bureaucrats play such a very important role. Because they kind of are able to be the middle person between the scientist and the politician, to be able to convince the politician to put the money into the science*" (Vicki Sara, Interview September 2015).

Rather than simply negotiating mechanisms to ensure the integrity and productivity of research (cf. Braun 1993; Braun and Guston 2003; Guston 2000), Sara's statement highlights intermediaries' influence in shaping the trajectories of research policy. In the context of priority setting, intermediaries undertook intertwined constitutive, promissory and knowledge brokering work. This included: evaluating the epistemic and normative preferences of research funders; forging technoscience objects and their 'prospective techno-futures' (N. Brown, et al.

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[13] Wider publics are notably missing from most of the debates and activities investigated in this chapter. In their intense focus on firstly, cultivating the favour of their political benefactors, and secondly, maintaining the confidence of their research constituency, for the science-policy intermediaries engaged in developing the ARC Research Priorities, publics were largely absent, even as "ghosts" (cf. Wynne 2016). Yet in the wake of the controversy that greeted the ARC Research Priorities' announcement, many academic participants in the subsequent consultations for the National Research Priorities argued that priorities should be salient to wider publics. Several academics invoked the judgment of hypothetical taxi drivers, and many observed that the ARC Research Priorities lacked 'public' appeal. One argued that: "It will be very important to bring Mr and Mrs Canterbury-Bankstown on board, and I don't think you will do that by talking nanotechnology. So that's an issue that needs to be carefully thought about" (AAS 2002a, 7). This contrasts with US interviewees' view of the strong communications value of the nanotechnology 'story' for US politicians and publics (Chapter 2).

2000) in response to these apprehended preferences;[14] deploying this "package" in search of research funding, and seeking to "convince the politician to put the money into the science"; and acting as authoritative witnesses to priorities' socioeconomic potential (cf. Shapin and Schaffer 2011 [1985]). That is, they participated in the active translation and transformation of objects and resources flowing in both directions between politics and science. Interactional co-production is clearly apparent in this high stakes constitutive and promissory work (cf. Jasanoff 2004; see also Part A Introduction). Indeed, in written comments subsequent to our interview, Sara emphasised that such work "was deadly serious as the future of our best researchers and leading research areas depended on government being convinced that investment in these areas would benefit the nation" (Vicki Sara, Written comments, July 2016).[15]

A strategy of mobilising expectations for technological innovation as a means to secure ARC funding would never benefit all research sectors equally. Some interviewees observed that nominating nanotechnology as a research priority had significantly shifted the research effort.[16] Others expressed uncertainty regarding how much work had simply been rebadged. The 'interpretative flexibility' (cf. Pinch and Bijker 1984) of research priorities was emphasised by Sara: "Probably, if I went back, I could have said to you or the Minister of the time, that the biological sciences grants that went out, 90% of those were related to biotechnology. It depends what that 'related to' means... in my view, [it] can also be the underpinnings of [the priority area]" (Vicki Sara, Interview September 2015). That is, prioritising 'industry relevant biotechnology' could serve to marshal funding for "fundamental research" in biological sciences. This echoes the strategy employed by the NNI's proponents to use nanotechnology to boost funding for the physical sciences more broadly (Chapter 2). It is also consonant with Jane Calvert (2006)'s findings regarding the rearticulation of "basic" (here "fundamental")

[14] On work to position emergent fields of technoscience as responsive to politically salient societal or 'grand challenges', see for example: Andrew Balmer and colleagues (2016); Jane Calvert (2013); and Matthew Kearnes and Matthias Wienroth (2011a).

[15] Sara emphasised the importance of safeguarding ARC support for basic research: "The issue of priority setting needs to be examined in terms of the whole research system...this is very important. The ARC focus is, and was, on excellence in fundamental research. This is the primary role of universities and I believe to be the basis for any successful national research system. Other components, ie through innovation, R&D, commercial, or research organisations like CSIRO, AGS etc fulfil different roles and receive support to achieve different outcomes. Whilst there must be coordination across the system it is critical in my view to have a strong and broad based basic research foundation based upon excellence" (Vicki Sara, Written comments, July 2016).

[16] One interviewee described government's role in priority setting as that of the "Pied Piper": "...where it was most critical of course was [nanotechnology] was made a priority item in ARC. As soon as it's one of those you could, you know, have beetroot growing or something or other made a priority, you'd find a lot of people would follow it" (Industry member, Interview 63, April 2015).

science in the context of policy demands for commercial or societal application. Nevertheless, interpretative flexibility was not unlimited.

Social sciences funding was reduced in this period, especially for the humanities which struggled to demonstrate commercial value and whose contribution to public life was repeatedly contested during the Howard years' 'culture wars' (Alexander 2007; Haigh 2006). As Sara stated:

> "*The real problem coming out of all of that was the humanities, and social sciences. We tried very much, I mean, we being I guess mainly the ARC and the people working with the ARC and the universities, to ensure that the social sciences were included in those [priority] areas, which they should have been, I think they should have been, and in some cases they were, but the humanities suffered very badly I think… And at the time we were under a lot of criticism from people like [right-wing journalist] Andrew Bolt for 'what do we Icelandic poetry studies for', etc*" (Vicki Sara, Interview September 2015).

The ARC worked hard to shield the social sciences and humanities from recurring political attacks that branded certain fields of research as irrelevant. Yet the expectations fostered by intermediaries of "technology and commercial outcome[s]" from the research investment had generative effects that were at odds with these efforts. Such expectations reinforced the conflation of research's societal value with its (perceived) commercial value, and the association of innovation and the quest for a knowledge economy with STEM research. This undermined the case for other disciplines' funding at a time when Ministers were sensitive to attacks from right-wing journalists on the legitimacy, relevance and public value of academic work, particularly that of the humanities (Alexander 2007; Haigh 2006).[17] In this way, intermediaries' emphasis on emerging technologies to "package" funding requests reflected and furthered normative and political judgments – apprehended and explicit – in preferencing particular kinds of knowledge-making (cf. Jasanoff 2004).

The use of emerging technologies as priorities to marshal greater funding for R&D was broadly successful for the ARC. Nonetheless, Sara's comments underscored the vulnerability the ARC and other research bodies felt towards their political funders who: "actually can do whatever

[17] Attacks on public funding for the humanities and social sciences are neither unprecedented nor unique to Australia (eg see Kleinman and Solovey 1995). Under President Ronald Reagan, NSF was prohibited from funding work in social science, prompting administrators to relabel "several economic databases and some of the databases from sociology... as physics databases so that we could maintain the funding to at least keep the databases intact and current" (Good 2006, 39).

they want with your budget". Sara emphasised the importance of ensuring that Ministers "feel *confident* when they talk to their colleagues, that 'we're doing something for the future of Australia'. So that's what the head of the ARC should be doing all the time, convincing people about that" (Vicki Sara, Interview September 2015, emphasis in original). To safeguard future research budgets, senior science-policy intermediaries were highly conscious of their responsibility to "convince" relevant Ministers that "we're doing something for the future of Australia". In this they were accountable not only to their primary dual constituencies – in politics and research – but to contested measures of national and public value, increasingly framed through the prism of economic impact and "packaged" in storylines of technology-driven wealth creation.

3.2.3 An incomplete contract

Priority setting was a site at which Australian research's implicit 'social contract' was renegotiated. The ARC modelled itself on the US National Science Foundation (Aitkin 1991), and sought to borrow also the model for science-state relations most commonly associated with Vannevar Bush (Guston and Keniston 1994; Kleinman 1995). The ARC championed state support for investigator-driven research that is accountable only to peer-determined 'excellence', on the principle that this would serendipitously produce outcomes of social worth (Aitkin 1996, 1997). Yet, while Bush's model was never wholly instantiated in the US, it achieved considerably less traction in the Australian research policy landscape, where the political value accorded basic science and even technology has historically been low (see Part A Introduction, see also Chapters 4-5). The Howard government sought to respecify the reciprocal responsibilities of researchers and the state, asking the former to respond to a new (albeit nebulous) set of political, economic and cultural metrics. In 2001, it appears that senior science-policy intermediaries were either sympathetic to these demands, or were pursuing a policy of appeasement.[18] In either case, the Chief Scientist and the senior management of the

[18] In the years subsequent to this investigation relations between the Minister for Education, Science and Training Brendan Nelson and the ARC degenerated further. In an unprecedented breach of the ARC's autonomy, in 2004 and 2005 Nelson responded to accusations by right-wing journalists that the ARC was funding research of dubious public value by personally vetoing up to 11 approved grants, and by establishing non-academic committees to advise the ARC on whether particular applications were in the national interest (Alexander 2007; Haigh 2006). This was reported to have had a "chilling effect" on researchers, leading them to alter project titles to remove politically sensitive words (Alexander 2007), and to exert "self-censorship", shying away from whole research areas (Haigh 2006). For analysis of the "chilling effect" of controversies in health research see Joanna Kempner (2008).

ARC and the CSIRO publicly supported calls for a change in Australian research culture and a new basis to conceptualise and measure its public value.

At the keynote forum of the August 20-21 2001 Science Meets Parliament event, following presentations on both biotechnology and nanotechnology, ARC Chair Peter Wills impressed upon attending researchers their responsibility to demonstrate commercial relevance. Wills stressed that greater ARC funding "is conditional upon Australian science and scientists demonstrating that this increased investment in research has the capacity to deliver demonstrable outcomes – 'returns on investment' – in terms of the social and economic well-being of Australians" (Hazell and Coloe 2002, 40), a point emphasised at the same meeting by the Chief Scientist (Hazell and Coloe 2002) and elsewhere at this time by Sara (2001, 14). Indeed, an article about Science Meets Parliament for *Microbiology Australia* provides a list of "ten rules for dialogue between scientists and politicians" gleaned from the event. Number one is: "Research is about wealth generation, not just 'science'" (Hazell and Coloe 2002, 40). Such exhortations provided the context for developing the ARC Research Priorities as the ARC Expert Advisory Committees and its Board met in Canberra in the days following the Science Meets Parliament event.

The apparently pragmatic and willing attitude with which senior research sector representatives approached priority setting, and the demonstration via it of Australian research's commercial relevance and political responsiveness, was not ubiquitous. Concerns had been building amongst academics prior to the BAA announcement, as rumours circulated of both a potential increase to ARC funding and the concomitant development of research priorities. Unease was magnified by uncertainty regarding the future operations and political autonomy of the ARC. At a Senate committee hearing in November 2000 into new legislative arrangements for the ARC, the President of the Federation of Australian Scientific and Technological Societies (FASTS) and incoming President of the Royal Australian Chemical Institute, warned against research priority setting via the political process (Senate Employment 2000). She rejected a suggestion that in fast-moving research areas such as nanotechnologies or information technologies there was a role for government to set research priorities and to re-order funding, warning that this was an activity government was ill-equipped to perform well (Senate Employment 2000, EWRSBE16). At the same hearing, the President of the National Tertiary Education Union warned that transferring greater powers to the Minister over ARC spending could mean that the "broader, long-term national interest for basic research across disciplines will be sacrificed to the more immediate short-term, fashionable of the day industry research topic, whether it is biomedical research, nanotechnology, or whatever is the latest thing that is in the newspapers" (Senate Employment 2000, EWRSBE27). That nanotechnology was identified in these hearings as a "fashionable" new area of science and an "industry research topic" is striking, particularly in light of the recognition by nanotechnology proponents at the CSIRO-DISR workshop five months later of industry's lack of engagement in the field (DISR 2001). It reflects the success of NNI proponents' enactment (cf. Law 2004; Mol 2002) of a highly heterogeneous field of largely non-commercial science as a powerful new engine of economic growth, and the validation the NNI's launch afforded this enactment (Chapters 2, 4). More pertinently to the analytic interests of this chapter, it is notable that two months prior to the BAA announcement, and fourteen months before the announcement of the ARC Research Priorities, concerns were already being expressed regarding appropriate roles for the state versus science in priority setting, and the political seductiveness of emerging technologies research.

3.3 "Picking winners" and "fashion science"

On 25 January 2002 the new Minister for Education, Science and Training Brendan Nelson issued a directive to the ARC to ensure that at least 33% of its 2003 uncommitted funding was allocated to: nanomaterials[19] and biomaterials; genome-phenome links; complex systems; and photonics (ARC 2003a).[20] It was the first time in the ARC's history that it had been directed by government to prioritise its grants. In a scathing written statement and in public comments, the AAS expressed "dismay" at the narrow focus of the priorities, and scepticism regarding the quality of research applications that such a large budget allocation would precipitate (AAS 2002b; Salleh 2002). The AAS "urged the Minister to... review his directive to the ARC to ensure that deleterious effects are minimised" (AAS 2002b, unpaged). Other researchers publicly accused the government of: "picking winners[21] within ... the high profile, very groovy, fashion sciences" (Ketchell 2002, 3) and "jump[ing] at trendy areas" (Illing 2002, 31). The

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[19] The identification of "nanomaterials" rather than 'nanotechnology' as a priority may have reflected the view that Australia's research strength lay largely in "materials nano-technology" (Ernst & Young 2002, 31). On issues raised by the common conflation in public policy of 'nanomaterials' with 'nanotechnology' see Georgia Miller and Fern Wickson (2015); see also Matthew Eisler (2013a). These themes are explored further in Chapters 5-6.

[20] $161.8 million (34%) of ARC competitive grants funded in the 2003 round (for the five years to 2007) was allocated to these four areas (ARC 2003b).

[21] On the origins of the term "picking winners" for activities of technology foresighting, and the negative response this attracted from 'free market' proponents see Ben Martin (2010).

Australian Vice Chancellors' Committee expressed concern about the budget implications for the humanities and social sciences, and for research that did not have near-term commercial applications (Jackson 2002a). Criticism came not only from the 'losers' of the exercise in "picking winners" but from the Academies at large. A central concern was of political interference in a process properly controlled by scientists.

The research sector was reported to be in "shock" and concerned that the "ARC's autonomy had been compromised" (Jackson 2002b, 1). FASTS criticised a lack of consultation in the process (Ketchell 2002), which the AAS (2002b) asserted had been inadequate and rushed. Labor Senator Kim Carr accused the government of an ambush, suggesting that the process had been "a series of secret deals behind closed doors" (Illing 2002, 31). *The Canberra Times* saw it as a "reflection of the Howard government's unrelenting political aggression" and an attempt to wrong-foot Labor (Anonymous 2002, 11). Conversely, a spokesman for the new Minister was reported to have "defended the move, saying there had been grants for questionable research projects in the past. The Government made no apologies for directing funding to subjects that analysts said were the real areas of growth. He denied there was a danger in picking winners and said the Government was merely seeking the best financial returns for taxpayers' money" (Jackson 2002a, 3).[22] Yet, rather than reflecting overt political interference as was widely assumed, the research priorities were largely what the ARC and CSIRO senior management had argued for. The CEOs of both institutions, along with the Chief Scientist, had been closely involved in the process prior to Cabinet making its final decision. Moreover, although defending them publicly, Nelson swiftly set about overseeing a quite differently structured process to develop the 'National Research Priorities' (see ARC 2003b), which would later that year deliver a divergent outcome (see below).

3.3.1 The central role of the PMSEIC working group

The development of ARC Research Priorities took place over the second half of 2001, and the process was initiated and overseen by PMSEIC (Sara 2001; Senate Employment 2002). PMSEIC was then jointly chaired by the Chief Scientist Robin Batterham and the ARC Chairman of the Board, Peter Wills, AM, and ARC CEO Vicki Sara and CSIRO CEO Geoff Garrett held seats on it.

[22] It is notable that both critics and proponents accepted the premise that the four ARC priorities were areas of commercial relevance. This again reflects the success of proponents' enactment of nanotechnology as economically compelling, and its receipt of R&D funding as conforming to 'market logics'.

Significantly, the response to questions taken on notice during Senate Estimates hearings show that Batterham, Sara and Garrett were also members of the ARC Research Priorities PMSEIC working group which received and deliberated on the final proposal before sending it to Cabinet (Senate Legislation Committee 2002b). Two meetings were held to solicit input from invited members of the wider academic community, discussed below. Yet the structure and secretive nature of the priority setting process privileged the role of the PMSEIC working group, and therefore the views of Batterham, Sara and Garrett.

The potential for this trio's problematisation of research priority development to shape priority setting was amplified by the extent to which a sense of common purpose had already been established between them.[23] Batterham, Sara and Garrett all worked at the high-level nexus between science, politics and industry, frequently in situations that required their collaboration. For example, the effectiveness of Batterham and Sara's teamwork was credited by observers for generating the political will to support BAA (AAS 2001; Brook 2001). In addition to their work together on PMSEIC: Sara and Batterham were *ex-officio* members of the ARC Board (ARC 2002); Garrett and Sara were members of the CSIRO Board (AAS 2001; Office of the Queensland Chief Scientist Undated); and Sara and Garrett were on the boards of the ICT and biotechnology Centres of Excellence established through BAA (Colbeck and Kemp 2001; Minchin and Kemp 2001). In their public communications, the trio had increasingly touted the inseparability of science, market and political imperatives: a focus on emerging technologies became their prescribed 'solution' to the 'problem' of political perceptions that Australian research had failed to deliver adequate returns on investment in it.

3.3.2 The process of priority setting

As is the case in much priority setting, as observed above, the process of developing ARC Research Priorities was opaque. Wider research sector input was solicited at two invitation-only forums for which no minutes were published. An initial roundtable attended by 42 people was held on 16 July 2001 at the CSIRO offices in Canberra, chaired by the Chief Scientist and the ARC Chair, and attended by the CEOs of both CSIRO and the ARC (Senate Employment 2002). Representatives of the research funding agencies, the research providing agencies, related Commonwealth departments, and the Academies were present. Yet the subsequent involvement in the process of the Academies and other agencies appears minimal. The AAS

[23] For a similar observation regarding the actors who drove US post-war research policy negotiations see Daniel Kleinman (1994, 1995).

Secretary (Science Policy) Michael Barber was later critical: "We only knew that the [PMSEIC] working committee existed, and had rumours there may be an impact on 10 per cent of ARC funding" (Salleh 2002, unpaged). After this July meeting, another was held by the ARC to solicit input from its Expert Advisory Committees. Approximately 60 individuals across these committees, who Sara later described as “leading research and industry representatives”, met on 22 or 23 August 2001 (Senate Employment 2002, EWRE177). This group developed a list of 12 proposed priorities – 6 “first order” priorities and 6 “second order” – for which it was proposed that 10% of the ARC competitive grants budget be allocated (Senate Employment 2002, EWRE261).[24] The 12 priorities and the 10% proposal were then provided to the ARC Board. Sara confirmed to Senate Estimates that the Board accepted these twelve priorities, although she would not confirm whether or not it accepted the 10% quantum proposed (Senate Employment 2002). In an “intervening process” (Senate Employment 2002, EWRE178) between the ARC-led deliberations and the government’s final decision making, the PMSEIC working group reviewed the ARC Board’s recommendation before submitting it to Cabinet. Batterham, Sara and Garrett were not only members of this group, but constituted 3 of only 4 people who attended its sole face-to-face meeting on 4 September 2001 before the group made the final recommendation to Cabinet (Senate Legislation Committee 2002b). The ARC Research Priorities were discussed by Cabinet on 24 September 2001, and a Cabinet decision was made on 6 October (Senate Employment 2002), before a direction was issued to the ARC on 25 January 2002. Cabinet-in-confidence protocols make it difficult to verify whether the decision to identify only four priority areas and to allocate 33% of the uncommitted funding originated in the PMSEIC working group or in Cabinet, although I draw on a range of sources to offer an analysis below.

3.3.3 Influences on the process

The ARC Expert Advisory Committees, and subsequently the ARC Board, supported a list in which four of six “first order” priorities were emerging technologies. This emphasis was consonant with the previously expressed diagnosis of ‘problems’ and ‘solutions’ offered by Batterham, Wills, Sara and Garrett, and with the outcomes of CSIRO’s internal strategic planning process. In an earlier conference presentation Sara (2001) had nominated a strikingly

[24] The priorities were: “genome-phenome link, nanomaterials and biomaterials, cultural transformation, production in these societies, complex systems, photon science and technology, human development and wellbeing in Australia, neuroengineering, long and thin infrastructure, biotechnologies in society, environmental informatics, OZDEEP, a priority for the earth sciences, and Australian solutions to the challenge of globalisation” (Senate Employment 2002, EWRE203).

similar set of candidate research priorities. Sara may have accurately anticipated the views of the ARC committees. Alternatively, Sara's views or their logic may have proved influential in the committees' deliberations. The latter is plausible given the very high regard in which she was held by her peers. Sara was credited by the AAS as "the driving force" behind BAA's doubling of ARC funding and had recently been elected to the highly prestigious role of "Fellow of the Academy" (AAS 2001). Any views expressed by Sara, including regarding research priorities likely to be viewed favourably by the Howard government, would carry considerable weight. The final four ARC Research Priorities were also closely in alignment with the recently developed research priorities and strategic goals of the CSIRO (see DEST 2003), as Garrett conceded during Senate Estimates hearings (Senate Employment 2002). Indeed prior to the ARC priority setting process, CSIRO had already determined that a focus on emerging technologies would suit its own institutional aims.

The influence of CSIRO on the priority setting process attracted critical questioning at Senate Estimates hearings, where the agency was described as a "400 pound gorilla" in the Australian research landscape (Senate Employment 2002, EWRE262). Senator Carr put to Garrett criticism he had received that: "the priorities established by government, which were notified to the ARC on 25 January, are effectively CSIRO priorities" (Senate Employment 2002, EWRE261). Indeed CSIRO's participation in ARC priority setting may have had an element of direct self-interest. Documents provided in response to questions on notice acknowledged that discussions had taken place between CSIRO and the Minister regarding the potential for the former's future access to ARC competitive grants (Senate Legislation Committee 2002a). Further, perhaps cognisant of the link between CSIRO's funding being frozen and a view that it was failing to collaborate effectively, Garrett had recently called for a new era of research cooperation across "Team Australia" (Garrett 2001). On both counts CSIRO would be best placed if research priorities were in areas of its own competitive strength. Beyond CSIRO's institutional influence, CSIRO researcher Braach-Maksvytis observed that the ARC Research Priorities were also a testament to the effectiveness of "behind the scenes" lobbying and outreach by Australian nanotechnology proponents including her own, within and external to CSIRO and of the ARC (Vijoleta Braach-Maksvytis, Interview June 2015).

There was an element of contingency in nanotechnology's inclusion among the four emerging technologies that were identified as "first order" priorities. After all, just some months previously, the field had been unmentioned in any of the BAA announcements. When asked in an interview for this research how it was that nanotechnology was sufficiently compelling as to be identified as an ARC Research Priority, the former Chief Scientist pointed to the need to pick something, the fact that CSIRO had already focused on nanotechnology as part of its own strategic planning, the visibility of nanotechnology proponents and the then promises being made for the field's commercial promise:

> "*if you're going to try and concentrate effort, you do have to pick a few winners and there's essentially two ways of – and people don't like to call it 'picking winners'. It's sort of opportunistic focusing which is the same thing. There's a couple of ways of doing that. One is ... Have a look at what people are doing, as to what we're good at, and then secondly, look at it opportunistically as to what it might produce. Now, CSIRO had done quite a bit of work and had gone through essentially its whole research portfolio and looked at it through a prism of opportunity, how big it is and degree of difficulty achieving it and that's not a bad way of going... So you pick the stuff that's quite large opportunities and isn't off the planet in terms of degree and difficulty. So given that you had a load of people saying, 'look we're doing interesting things in nanotechnology' and a whole load of people including the PMSEIC putting promissory notes [for economic outcomes] on the table which we've just rehearsed and said they haven't come through quite the way expected, it was a relatively easy one to home in on*" (Robin Batterham, Interview April 2015).

That is, as they attempted to demonstrate their willingness to "focus" and to propose priorities they saw as "politically doable", science-policy intermediaries "ha[d] to pick a few winners". Nanotechnology was the subject of international attention, promissory claims in PMSEIC, and had already been identified as a strategic priority by the CSIRO. Moreover, its listing as a research priority was neither unique nor unusual in the early 2000s.

The ARC Research Priorities were consonant with international trends. As one interviewee observed: "it didn't surprise me about the domains because when we were doing the international stuff and we looked at other countries' research priorities, they're all the same. They all have nanotechnology, they all have photonics and whatever, you know, they all had genomics or something. So there was nothing different about it" (Public servant, Interview 68, June 2015). Indeed, in contrast to Batterham's description of the CSIRO's strategic planning process as based on an analysis of institutional strength and opportunity, a Departmental report depicts it as: "based on an assessment of where future global trends are heading, where other nations and industries are investing their longer term research dollars, trends identified by future scenario reports such as those developed by the RAND Corporation, and the areas that will have the broadest impact across sectors and markets in the future" (DEST 2003, 288). Underscoring the opacity of the terms on which prioritisation often occurs, CSIRO's planning process was shaped not (only) by an assessment of local conditions and strengths, but by international trends, reflecting the success of nanotechnology proponents in securing state-backed research programs elsewhere and of 'promissory organisations' (cf. Pollock and Williams 2010) such as the RAND Corporation.

A crude explanation for nanotechnology's prioritisation was its growing status as a "fashion science". An alternative understanding of its success is that expectations for the field's future impact had been rendered more 'real' by the NNI and the nano 'race' it had sparked. During the 2002 consultations for the National Research Priorities, the head of the Department's priorities' taskforce Joanne Daly observed that: "The United States believes that nanotechnology will drive its industry in the year 2020, and that is why we also need as a country to get into nano, because it will be a fundamental technology of industry within the next two decades" (AAS 2002c). Daly's unequivocal statement that the "United States believes" that nanotechnology would "drive its industry" by 2020 is noteworthy, as is her characterisation of the nascent field as a near-term "fundamental technology of industry". Among influential Australian science-policy actors, nanotechnology's status as a commercially powerful technology-in-the-making had been naturalised by the success of the NNI. As one of a number of emerging technologies that were identified by science-policy intermediaries as consonant with their quest to show commercial relevance and political responsiveness, nanotechnology was made salient in part by the international success of its proponents in enacting the field as the driver of wealth creation. In turn, the ARC Research Priorities were a site at which proponents' imaginary of nanotechnology-based prosperity was embedded in Australian policy making, further consolidating the 'reality' of nanotechnology's promise.

3.3.4 Who made the final call?

It appears that the PMSEIC working group recommended the identification of only four ARC Research Priorities, although the genesis of the directive to allocate 33% of the ARC's uncommitted budget to these areas remains uncertain. Nonetheless, a Ministerial advisor cautioned against attributing too much agency to the working group, emphasising both the 'closing down' (cf. Stirling 2008a) that had already taken place before any formal recommendation was made, and the final decision making prerogatives of Cabinet: "...the decision wasn't actually made then, right. So those are the people who were in the room when the decision was *formally* made by the [PMSEIC] working group… [but] politicians get the results they want. So they can blame some working group, but *they* choose the working group, and... ultimately, it's their responsibility, they make the decision" (Ministerial advisor, Interview 46, December 2015, emphases in original). Underscoring the wisdom of these observations, and at the same time highlighting the influence that *apprehended* rather than directly communicated political priorities played in priority setting (see above), I have found no evidence to suggest direct political involvement in selecting the four priority areas. The preference of the Howard government for emerging technologies' research had been indicated through BAA; the decision to abandon the "first order" priorities in the humanities and social sciences[25] also appears responsive to its known scepticism regarding the value of research in these fields. Yet to the extent that political preferences were incorporated in identifying the four ARC Research Priorities themselves, they were *assumed*. The decision to allocate a full 33% of the ARC grants budget to these areas may reflect more direct political involvement, although this is not clear, as we will see.

Contemporary statements of Ministers, their spokespeople and senior bureaucrats attribute the directive to prioritise only four areas to the PMSEIC working group's recommendation. Nelson told Parliament that: "The priority research areas have been adopted by the government after an exhaustive process [of ARC-led consultation]... Finally, the expert committee recommended to the government that four research priorities be funded" (House of Representatives 2002, 111). Similarly Evan Arthur, a senior public servant within the Department of Education, Science and Training (DEST) advised a February 2002 Senate Estimates hearing that subsequent to the ARC-led consultation: "That [PMSEIC] working group considered the ARC priorities and identified what it regarded as the foremost prospective priorities. It was on the basis of that advice that the government took its decision" (Senate Employment 2002, EWRE178). Media stories also reported the relevant Ministers and their spokespeople as attributing the focus on only four priority areas to the recommendation of the PMSEIC working group (eg Anonymous 2002; Dunn 2002; Salleh 2002). Further, in an article received and accepted in December 2001, Braach-Maksvytis (2002, 1) appeared to foresee the outcomes of the ARC priority setting process: "Australia is undergoing a rapid process of

[25] These were cultural transformations, productions in society and human development and wellbeing (see Senate Employment 2002, EWRE 177, EWRE203).

strategic planning in nanotechnology, with outcomes planned in early 2002”. In an interview for this research, Braach-Maksvytis confirmed that she was aware before the ARC Research Priorities were announced that there would be a focus on nanomaterials: “Oh yes, absolutely. No, I was driving the ARC to get their priorities – so this is all in the background to sort of keep driving in all the different areas... that was very much the culmination of what I was doing behind the scenes” (Vijoleta Braach-Maksvytis, Interview June 2015). Braach-Maksvytis' planning for a strong ARC focus on nanotechnology supports the view that the narrow focus of the priority areas Nelson's was in line with recommendations from the PMSEIC working group, shaped in turn by the lobbying of CSIRO nanotechnology advocates.

The source of the decision to dedicate a full third of the ARC competitive grants to the four priority areas is less clear. Sara's comments at an academic consultation after the decision appear to suggest that it had surprised her (eg AAS 2002a). Similarly, one interviewee for this research “remember[ed] her being annoyed about that” (Ministerial advisor, Interview 46, December 2015). When asked whether they thought it possible that the PMSEIC working group could have recommended that the four areas be allocated a 10% quantum, and that Cabinet could subsequently have made a decision to increase the 10% to 33%, this interviewee agreed. Nonetheless, this is something I have not been able to confirm empirically.

None of the four members of the PMSEIC working group interviewed for this research could remember whether the group had recommended a focus on just four ARC Research Priorities, and/ or a quantum of 33%. Batterham stated that:

> “*Evan Arthur, whose competence I have always respected, is probably accurate but my recollection of the oversight group was more that we concentrated on the process of selection, rather than setting hard boundaries... overall, I really can't recall that the oversight committee got to the position of recommending 33% to be allocated to 4 areas. Remember though that the whole point of the priorities was to ensure a more focussed application of the R&D spend*” (Robin Batterham, Written comments September 2015).

Similarly, Sara stated that: “I *honestly* can't remember, going back that far. As I said, and this is just being perfectly honest, I treated priorities as packaging, and as long as I could get the money, to support the best research, I could package. That sounds terrible but it's not, it's what it's all about" (Vicki Sara, Interview September 2015, emphasis in original).[26] The former members of the PMSEIC working group are senior researchers who have participated in a great number of science policy activities. Their inability to precisely remember those of a working group thirteen years previously is perhaps unsurprising. Nevertheless, especially in light of the degree of controversy the process attracted, their failure to recollect this key decision – although in the case of both Batterham and Sara nonetheless remembering the rationale they employed in their negotiations – is interesting. It suggests these intermediaries' lack of personal investment in the specific outcomes of the prioritisation process, and even the contingency of their support for the priority areas themselves, including nanotechnology. It stands in contrast to the many nanotechnology researchers who told me of the formative impact its prioritisation had on their field. It also highlights the lesser commitment to nanotechnology of the elite intermediaries who drove Australian priority setting, compared to the more direct investment in the field of the "working level" US intermediaries who championed the NNI bid (see also Part A Conclusion).

3.3.5 Reservations regarding 'nanotechnology'

The nomination of nanomaterials as an ARC priority research area was a gesture towards promoting 'breakthrough science' (ARC 2003a) that had near-term commercial impact. Yet, in the same month as the ARC Research Priorities' announcement, a government-commissioned report gave a bleak assessment of the commercial prospects for Australian nanotechnology (Ernst & Young 2002). Echoing observations made at the CSIRO-DISR workshop a year earlier (DISR 2001) the report noted that: "nanotechnology remains largely unrecognised by most of modern (Australian) industry" (Ernst & Young 2002, 14). Further, it cautioned that Australia's limited micro-electronics, semiconductor and chemical industries would "impede uptake of nanotechnology" (Ernst & Young 2002, 18). The authors found that: "expertise surveyed has differing views on whether or not Australia has a distinct opportunity or competitive advantage in the field. A widely held view is that the field is still too new for a specific national niche to be discernable or (some argue) even desirable" (Ernst & Young 2002, 18). This suggests that beyond a network of vocal nanotechnology proponents, identifying nanotechnology as an ARC Research Priority may not have been widely supported even by those identified by the report's authors as "key national operatives" in the field. Moreover, just as in the US, it was not responsiveness to industry overtures or the expansion of "lively

[26] See above for Sara's views regarding the vital nature of priority setting in securing funding for basic research.

capital" that gave impetus to nanotechnology's rise as an object of research policy (cf. Sunder Rajan 2006, 2012; see also Chapter 2), but rather the advocacy of well-connected science-policy intermediaries who had themselves internalised the need to show 'market logics' in publicly funded research.

Beyond concerns that expectations of nanotechnology's near-term commercial potential were ill-founded, several Australian scientists expressed scepticism to me regarding the nanotechnology category *per se*. One senior scientist declared surprise at its success:

> "*it was almost an embarrassment, the term nanotechnology... certainly the scientific disciplines of physics and chemistry, they'd realised there was a reasonably self-serving speciousness about the fact that people were now rebadging themselves as nanotechnologists, and there was lots of sniggering behind the hands. And to an extent although I've been guilty of supporting various nanotechnology activities around Australia and the world it still does carry with it an air of cynicism that, you know, how can one manage to keep your lab open? Well, badge yourself as 'nanotechnology'... I think it is amazing that really in my mind the marketing of the name 'nanotechnology' has indeed overwhelmed so effectively the cynicism of most of the actual main players from science who saw it as just a sort of specious market push*" (Industry member, Interview 63, April 2015).

This interviewee suggested that as a mooted new object of technoscience 'nanotechnology' attracted derision before it was cynically, if with some "embarrassment", adopted by the established disciplines in an effort to "keep... lab[s] open". Another interviewee recalled saying to his colleagues:

> "*'I don't understand what all the fuss is about. CSIRO's molecular science has been doing what you folks are calling nanotechnology for the last 25 years'... and of course it was falling on deaf ears and this was my first real exposure to how aggressively competitive the whole ARC and research funding environment is in Australia*" (CEO R&D body, Interview 13, November 2013).

The reality enacted for nanotechnology in the ARC Research Priorities, just as it had been in the NNI, remained underdetermined and sometimes contradicted by its material 'truth' (cf. Law 2004; see also Part A Introduction). In Australia, as in the US, nanotechnology's meaning as a research policy object was shaped *in situ* (cf. Balmer, et al. 2016), reflecting the active work of science-policy intermediaries in response to the imperatives of their respective policy environments.

3.4 A delicate retreat

The development of National Research Priorities, which were announced in December 2002, contrasted with the ARC Research Priorities in both process and outcome. The opaque nature of the ARC Research Priorities' development largely shielded the ARC and CSIRO senior management from criticism by its own constituencies, whose accusations focused instead on suspicions of political interference.[27] Nonetheless, in the aftermath of the criticism surrounding the ARC Research Priorities and the process to develop them, the government promised a "full process of consultation" before developing National Research Priorities, which would apply not only to the ARC but also to the other research providing and funding bodies (Jackson 2002b, 1; see also Illing 2002). Rather than the process being driven by PMSEIC and accountable only to Cabinet, it had a publicly identified panel and support from a Taskforce within the public service (Daly 2002). Public forums with published notes and participant lists included some hosted by the Academies (eg AAS 2002a; Daly 2002). In contrast to its criticism of the secretive process surrounding the ARC Research Priorities, the AAS praised these extensive consultations (Barber 2002).

Instead of the narrow disciplinary focus of the ARC Research Priorities, the four National Research Priorities were thematic and broad: an environmentally sustainable Australia; promoting and maintaining good health; frontier technologies for building and transforming Australian industries; and safeguarding Australia (ARC 2003a). Emerging technologies remained a focus, but as one of the four final areas. Illustrating the diversity of views that existed within government regarding the merits of research priority setting, an interviewee suggested that this was not *only* a politically pragmatic retreat from an unpleasant controversy between the Minister and the research sector, but also reflective of the new Minister's own preferences (Ministerial advisor, Interview 46, December 2015). The disengagement of his Cabinet colleagues with innovation issues had previously led to Richard Alston exerting an "outsized impact" on policy. Now, Brendan Nelson's appointment as Minister for Education,

[27] Although Labor Senator Kim Carr later argued that the ARC Research Priorities "fiasco" could be attributed to the unrepresentative nature of PMSEIC: "It may well do a good job of championing the sector, but running an idea past the council is no substitute for real consultation. The PMSEIC is too small to be representative and too exclusive to enable diverse views on research to be heard" (Carr 2002, 18).

Science and Training, and the stridency of researchers' criticism of the ARC Research Priorities, enabled a new process to take a more expansive approach to priority setting.

Intriguingly, the ARC's commitment to prioritising emerging technologies research appeared undimmed in the wake of the controversy. The ARC's *Implementation Plan for the National Research Priorities* stated that the:

> "*four ARC priorities are in turn included in the national research priority of Frontier Technologies. It is in this national research priority area, and the related goal of breakthrough science, that the ARC believes it can make the greatest contribution to the implementation of national research priorities. Focusing its effort in this priority area will build on the strength, momentum, scale and focus which the ARC has built in these areas to date*" (ARC 2003b, 4).

The ARC's obvious preference to retain the earlier priority areas identified for (by) is noteworthy. It underscores the coincidence of the ARC Research Priorities with the preferences of the ARC senior management, and suggests that the ARC's commitment to an imaginary in which emerging technologies drove Australia's future competitiveness was more enduring than that of the federal government's.

3.5 Conclusion

Nanotechnology's nomination as an Australian research priority reflected not the strength of state support for the field, but rather the actions of science-policy intermediaries who played a largely obscure but unexpectedly influential role in processes of priority setting. The development of ARC Research Priorities took place amidst funding uncertainty, institutional change and political criticism regarding the insufficient return on investment of publicly funded research. Given political cues, policy precedent and the international currency of emerging technologies, a small number of individuals in senior management roles in the ARC, the CSIRO and the Office of the Chief Scientist were persuaded that a focus on "frontier technologies" and "breakthrough science" offered the 'solution' to the 'problem' of demonstrating the commercial relevance of Australian research. Their view that nanotechnology met these criteria was boosted by the success of the NNI, the growing number of other state-sponsored programs, and the lobbying of influential CSIRO researchers. Science-policy intermediaries assumed the interest in and (sometime) surveillance by the state of their work; they understood as "deadly serious" the need to show responsiveness to political preferences that were not always explicitly communicated. This chapter nonetheless demonstrates their largely unfelt agency to (re)shape research policy agendas, including through constitutive and promissory work, and to (re)frame judgments of public value in research.

The use by Australian science-policy intermediaries of "breakthrough science" as the principal route for "packaging" research funding requests was a practice that had both material and performative effects. Its use as part of a successful lobbying effort resulted in BAA's doubling of the ARC budget and, with the flexible interpretation of priorities, enabled much basic science to be funded. Further, the ARC Research Priorities provided tens of millions of dollars in research funding that helped to create a new 'nanotechnology' constituency which went on to lobby for dedicated national policy and political support, as explored in subsequent chapters. Yet the valorisation of the imaginaries of technoscience proponents and their instantiation in Australian research policy also performed other political work. This practice helped to affirm the value of particular kinds of knowledge and to marginalise that of others, and to consolidate the waxing view that the merits of research are significantly determined by commercial relevance. As in the US, it was not the advocacy of industry or the expansion of "lively capital" that underpinned nanotechnology's rise as a priority field, but rather the work of science-policy intermediaries who had themselves internalised the need to show 'market logics' in their management of publicly funded research. Ironically then, nanotechnology's prioritisation took place amidst warnings regarding the disengagement and perhaps disinterest in it of Australian business, and the barrier that Australia's industrial base presented to its commercial development. Despite the retreat from the emphasis on emerging technologies of the more broadly focused National Research Priorities, this period was one in which a new social contract between science and the state was posited – and contested – of which nanotechnology's prioritisation was emblematic.

This chapter has illustrated some parallels but also some differences in the appeals for priority public funding of nanotechnology researchers in the US and in Australia. The intermediaries engaged in developing the ARC Research Priorities had weaker levels of personal commitment to nanotechnology than that of NNI proponents. Additionally, the connection of Australian priority setting with high-level politics was more tenuous. The ostensible rationale for nanotechnology's receipt of priority public funding in each country also differed. US proponents enacted the field as one of high strategic value, but also high risk given the 10-20 year time horizons anticipated to turn research into nano-products (eg Committee on Science

1999; PCAST 1999). Indeed, the inadequacy of private sector investment in 'fundamental' nanoscience given its (proper) aversion to assuming such risks was a core argument for the NNI. Conversely, in Australia nanotechnology attracted support amidst government efforts to promote science whose commercial relevance would underpin its more rapid 'translation' to industry. That is, although research priorities were used by Australian intermediaries as "packaging" to obtain support for basic or fundamental science, there was a government expectation that prioritisation would itself result in a more rapid delivery of commercial outcomes. The next chapter compares the efforts of proponents in the US and in Australia to make claims regarding the future prosperity that could be achieved by nanotechnology sufficiently persuasive to political audiences to secure ongoing public funding and state resources to nurture the field into being.

Chapter 4: Consolidating national nanotechnology policy

In the years subsequent to the creation of the National Nanotechnology Initiative (NNI, Chapter 2), and the decision to make nanotechnology an Australian research priority (Chapter 3), proponents in each country sought to expand and to consolidate their respective governments' commitments to the field. Nanotechnology had gained attention as a new object of research and innovation policy; its champions now attempted to strengthen provisions for its prioritised funding and political patronage. In so doing they made a series of promissory claims, particularly regarding nanotechnology's future economic impact and geopolitical significance. Yet given its "very embryonic and infant stage" (Committee on Commerce 2003, 13), predictions for what nanotechnology would in the future be and do were necessarily speculative. In this chapter I investigate proponents' efforts to make promissory claims for future nanotechnology-based prosperity, predicated on the present day sponsorship of the state, "sound credible" (cf. Sunder Rajan 2006, 114) to political audiences. While recognising that making claims "sound credible" was not itself sufficient to obtain a new national nanotechnology strategy in Australia, or security for the NNI through a change in government in the US, I emphasise its importance nonetheless. I show that US proponents benefited by invoking an already familiar 'sociotechnical imaginary' (Jasanoff and Kim 2009, 2013; 2015; see also Part A Introduction) in which government-backed technology development is central to the (imperilled) nation's strength. Conversely, I find that their Australian counterparts encountered an 'absent imaginary' regarding technology's importance to the nation and to government's role in its development. Largely lacking discursive resources with which to articulate their claims, Australian proponents struggled to make their predictions of nanotechnology's future economic importance "sound credible".[1]

This chapter draws on and contributes to work in the 'sociology of expectations', which explores how expectations of technology-enabled futures are mobilised to secure present-day research resources and favourable policy settings (eg Balmer, et al. 2016; Borup, et al. 2006; N. Brown and Michael 2003; Petersen and Krisjansen 2015; Pollock and Williams 2010; van Lente and Rip 1998). Adding to this literature, I investigate proponents' efforts to make both their promissory claims for 'prospective techno-futures' (cf. N. Brown, et al. 2000), and also the sociopolitical work posited as necessary to these futures' realisation, "sound credible" to political audiences. In particular, I probe the discursive and ideational resources employed by

[1] On the generative role of discourse in nanotechnology policy making see Matthew Eisler (2013a, 2013b) and Jason Gallo (2009); on its influence in other science and technology policy see Herbert Gottweis (1998), Anne Hecht (1998), and Sheila Jasanoff (2005a).

proponents to render persuasive the envisaged role for the state as chief nanotechnology sponsor. That is, I investigate the challenge proponents faced in making salient to political audiences their imaginaries not only of future nanotechnology-enabled prosperity, but also the state's role in bringing that future into being.

I am particularly interested in the relationship between promissory claims being judged to "sound credible" and their performative power in nanotechnology policy. My analysis is informed by earlier work in science and technology studies (STS) on the achievement of credibility for scientific claims (eg Barnes and Bloor 1982; Bijker, et al. 2009; Collins 1981; Gieryn 1999; Shapin 1995; Shapin and Schaffer 2011 [1985]) and for the projects of technoscience (eg Ezrahi 1990; Gottweis 1998; Jasanoff 2005a). Much of this literature has investigated either the credibility of knowledge claims made by scientists among other scientists, or that of claims advanced by the state or technology proponents among wider publics. Indeed, Helga Nowotny makes the observation that whereas STS has extensively investigated relations between science and its publics, this work has typically overlooked 'publics' within government: the understanding of and engagement with science of policy makers and politicians has been a "blind spot" for the field (Nowotny 2014, 16). Addressing this lacuna, this chapter explores the dynamics of credibility among nanotechnology proponents and political actors. In so doing I address the first and second research questions of the thesis, investigating both how the governments of late-modern, capitalist states understand, justify and prosecute their role in creating, fostering and overseeing new fields of technoscience, and also how nanotechnology proponents sought to embed within the architectures of the state their imaginary of future wealth, health and international competitiveness enabled by nanotechnology, contingent only on the sufficiency of present-day government support.

The investigation of this chapter spans two key sites. Both sites were strategically important in proponents' efforts to consolidate nanotechnology policy in their respective country, and both provide a valuable window on to the articulation and reception of promissory claims. The first site is the series of US Senate (Committee on Commerce 2002, 2003) and House of Representatives (Committee on Science 2003a, b) hearings that preceded Congressional support for the *21st Century Nanotechnology Research and Development Act* (Public Law 108-153). This Act transformed the NNI from a discretionary Presidential initiative to one encoded in public law, with an authorised, albeit non-binding, budget allocation of US$3.6777 billion for five of the participating agencies over a period of four years; it was signed by President George W. Bush on 3 December 2003 (R.M. Jones 2003). The second site is the proposal for an Australian national nanotechnology strategy made at the 11 March 2005 meeting of the Prime Minister's Science, Engineering and Innovation Council (PMSEIC), "the Australian Government's principal source of independent advice on issues in science, engineering and innovation and relevant aspects of education and training" (DIS Undated-a). The PMSEIC meeting led to Australia's first dedicated policy for nanotechnology, the National Nanotechnology Strategy (NNS). The US hearings were open to the public, and transcripts were published. No transcript of the invitation-only PMSEIC meeting was published, although the working group's report and related PowerPoint presentation were (PMSEIC 2005a, b). In addition to examining the report and presentation, to investigate their reception I have interviewed four members of the PMSEIC working group, and the former Chief Scientist, then a member of PMSEIC. These interviews and my analysis of the records of these hearings are supplemented with wider archival work and interviews with key stakeholders as described in Chapter 1. The chapter is structured in three parts. I begin by providing a brief overview of the international circulation of nanotechnology promissory claims and the theoretical resources that I employ to investigate proponents' efforts to make them "sound credible" to particular political audiences. I then explore each site in turn.

4.1 The situated meaning of internationally circulating claims

In the recollection of Mihail (Mike) Roco, Chair of the US National Science and Technology Council (NSTC) Subcommittee on Nanoscale Science, Engineering and Technology (NSET) and Senior Advisor within the National Science Foundation (NSF), the NNI's creation had a powerful legitimating effect. In Roco's view, "it was as if nanotechnology had gone through a phase transition: what had once been perceived as blue sky research of limited interest (or in the view of several groups, science fiction, or even pseudoscience), was now being seen as a key technology of the 21st century" (Roco 2004, 3).[2] Yet, suggesting proponents' awareness of the fragility of the 'reality' they had forged for the field, in the years following the NNI's establishment they worked hard to consolidate their enactment of it (cf. Law 2004; Mol 2002) as "a key technology of the 21st century". This work took various forms, including the production of figures, diagrams and predictions for the course of nanotechnology's

[2] Such a statement can itself be seen as performative, seeking to bring about the conditions it claims to describe (cf. Pollock and Williams 2010).

development, which became "circulating references" (cf. Latour 1999) that travelled internationally.[3] Although they sought to distinguish their own promissory claims from those associated with K. Eric Drexler, which they dismissed as fantastic (McCray 2005; Selin 2007), US agency officials were the source of many spectacular predictions. Roco claimed that nanotechnology would employ 2 million workers and contribute to US$1 trillion of products in 10-15 years' time (Roco 2001; Roco and Bainbridge 2001). Even more ambitiously, 'promissory organisations' (cf. Pollock and Williams 2010) including US venture capital firm Lux Capital and its research division Lux Research predicted that the market for 'nanotechnology-enabled' products would be worth US$2.6 trillion by 2014, making up 15% of "global manufacturing output", with comparable value to that of information technology and communications (ITC) industries and ten times that of biotechnology (Lux Research 2004, unpaged). These figures rapidly became near-'obligatory passage points' (cf. Callon 1986) in the narration of the field, and featured prominently in the US hearings and the PMSEIC meeting investigated in this chapter.

Claims regarding nanotechnology's future market value were performative without either audiences or claims makers taking them literally. Indeed, many interviewees for this research described these predictions as 'hype'. Yet as Kaushik Sunder Rajan (2006, 116) observes, promissory claims, including those articulated in the "grammar" of hype, may be "successful" as "a discursive mode of calling on the future to account for the present" even where such claims are not understood to be literally 'true', as long as they are judged to "sound credible" (on the generative power of hype see also N. Brown 2003; N. Brown and Michael 2003; Hedgecoe and Martin 2003). Sunder Rajan suggests that: "A successful investor relations pitch for a company is one that *sounds credible*, even if no one who is being pitched to quite believes what is said" (2006, 114, emphasis added). This is a key observation to which I return throughout the chapter. Yet whereas Sunder Rajan identifies hype in the biotechnology sector as in part a product of the US venture capital environment, with its emphasis on speculative capitalism, I highlight similar sociological dynamics in science policy and the use of hype by government actors and science advisors. For example, Philip J. Bond, Bush's Under Secretary of Commerce for Technology, suggested that hype was key to the political support

[3] From the early 2000s there was also a concerted effort to render nanotechnology meaningful through illustrative work, including that which drew on iconic images such as those associated with space exploration, molecular machines and geodesic spheres. The sites and texts I investigate in this chapter do not make use of such imagery, so I do not evaluate their influence in corroborating promissory claims, but on their broader significance see, for example, work by Robert Frodeman (2006), Alfred Nordmann (2004), and the special section of *Leonardo* edited by Tami Spector and Tom Rockwell (2008).

nanotechnology received: "Politically, hype is necessary... Melding hype and hope creates social passion that forms our policies. It gets budgets passed so that the NNI can be funded" (as quoted in Thayer 2002, 18). This statement illustrates how hype is also a feature of public institutions, as seemingly unrealisable promissory claims are deployed to build the "social passion" that underpins political support for new technoscience initiatives. Yet this is not to say that promissory claims have a universal ability to "get budgets passed". The task of this chapter is to explore how similar claims for nanotechnology were made to "sound credible" – or not – to political audiences in the US and in Australia.

Earlier work has described how scientific knowledge and the inscriptions in which it is embedded become stabilised in "immutable mobiles" and available for wide distribution (Latour 1987). By contrast, I show how the meaning of internationally circulating promissory claims and the identity of the ostensibly universal objects of technoscience with which they were intertwined was locally (re)constituted (cf. Balmer, et al. 2016). Previous chapters have elucidated the political, economic and science policy environments of each country at this time, showing differences as well as similarities. In this chapter I investigate the discursive repertoires in which US and Australian proponents articulated promissory claims, and the divergent 'realities' for nanotechnology and its 'prospective techno-futures' these enacted. Despite widespread perceptions of the field as an exemplar of global technoscience, applications for public funding and political support necessarily responded to the imperatives of their particular policy environments. Indeed, proponents appealed to 'techno-nationalism' (cf. Edgerton 2007) in more or less explicit ways. Roco and some of the other NNI champions engaged in extensive international outreach to forge shared visions and definitions for nanotechnology that they hoped would create a 'technological zone' (Barry 2001) in which a 'universal' (and universalising) nanotechnology could circulate (eg Roco 2001; Roco and Bainbridge 2001; see also Chapter 2). Yet other US proponents worked to build an 'American' nanotechnology and rationale for its support by the state (cf. Hecht 1998). That is, their constitutive and promissory work to forge a politically salient identity and meaning for nanotechnology was deliberately and overtly undertaken *in situ* (cf. Balmer, et al. 2016). By comparison, Australian proponents struggled to articulate a compelling 'Australian' nanotechnology, a result in part of the 'absent imaginary' that they encountered regarding technology's importance to the nation-state and the state's role as technology sponsor.

4.2 The US effort

The US hearings investigated here were dedicated exclusively to nanotechnology, although their ostensible purpose varied. The September 2002 Senate hearing was held by the Committee on Commerce, Science and Transportation's Subcommittee on Science, Technology and Space to examine nanotechnology's potential. It was presided over by Senators George Allen (Republican, Virginia) and Ron Wyden (Democrat, Oregon), the same Senators who had that day, along with several colleagues, first introduced the *21st Century Nanotechnology Research and Development Act*. The March 2003 House Committee on Science hearing was held to consider the House companion bill, and featured Allen and Wyden as the first witnesses. The April 2003 House Committee on Science meeting was held to consider "the societal implications of nanotechnology". It took place in the wake of Bill Joy's 2000 intervention regarding the dangers of convergent technologies and the more recent success of Michael Crichton's science fiction bestseller *Prey*.[4] Finally, the May 2003 hearing was held by the full Senate Committee on Commerce, Science and Transportation to consider the *21st Century Nanotechnology Research and Development Act*, and presiding Senators again included Allen and Wyden. At these hearings Allen, Wyden and the other participating politicians played a hybrid and intermediating role. They acted as: nanotechnology champions and witnesses to its promise (cf. Shapin and Schaffer 2011 [1985]); sponsors of the Act that two of the hearings were called to scrutinise; assessors of evidence presented to them; knowledge brokers (cf. Meyer 2010) between the proponents in research, government and industry who appeared at these hearings as 'witnesses' and the members of Congress who served as their ultimate 'audience'; and elected representatives in search of advantage for their constituents.[5] I therefore treat both the hearings' 'witnesses' and the participating politicians as intermediaries acting between the spheres of science, policy and politics (cf. Meyer and Kearnes 2013).

[4] This hearing has been the subject of previous scholarly attention (eg Bennett and Sarewitz 2006; E. McCarthy and Kelty 2010; Rip 2006) and is examined here only to the extent that it bears on the chapter's central questions.

[5] Most of the hearings' Congressional participants represented states or districts that anticipated, or that had already received, funding associated with the NNI – a fact which these representatives readily recognised (eg Committee on Science 2003a, 16). For example, Senator Allen's state of Virginia became host to one of the first nanomaterials manufacturing plants, a collaboration between the Department of Defense and the private sector, which converted an old tobacco warehouse (Allen 2005). My aim in this chapter is not to explore the motivations of individual Congresspeople for supporting the NNI. Rather, I investigate the discursive and ideational resources mobilised by hearing participants to advocate, rationalise and justify state support for nanotechnology.

4.2.1 "Sweating bullets" on Bush's election

In the early months of the Bush administration, NNI proponents were wracked with anxiety regarding the fate of the program. Nanotechnology was not mentioned by Bush during the presidential campaign or in his administration's early budget blueprints (From the Hill 2001). As later recalled by the Department of Defense (DOD)'s James Murday in an oral history recorded by Cyrus Mody:

> "*Mike [Roco] and I, as well as others, but Mike and I in particular, sweat bullets. We've put a lot of time and energy into getting this initiative established on the last day of the Clinton Administration,*[6] *and it's not unheard of for a new administration to come in and say, 'Oh, that was the creation of the 'other' guys. It's gone. I want my own thing'*" (Murday 2007, 56; see also Murday's similar comments to Committee on Commerce 2003, 7).

To proponents' great relief, in Financial Year 2002 despite spending restraint in 'basic' science,[7] the NNI's funding was ultimately increased (NRC 2002).

The apparent sources of the Bush administration's early support for the NNI were multi-faceted. The strong argumentative resources possessed by NNI proponents are investigated in greater detail below, in particular, the widely declared support for the state's role in sponsoring technological innovation (albeit not technology commercialisation), and the largely unchallenged depiction of nanotechnology as vital to future US wealth, health and security. The NNI also had the benefit of incumbency, and the momentum built for it in 1999 and 2000 (Chapter 2). Yet, given the traditional absence of coordination within US research policy (Kleinman 1995), the individuals in a position to influence early policy making were also important. President George H. W. Bush's Science Advisor D. Allan Bromley, who is credited by some as initiating the progenitor to the NNI (Murday 2007, 51; Rudd 2009, 106-7), and who had provided President Bill Clinton with a glowing endorsement of the NNI (NSF Undated), had at Bush Snr's request also acted as an advisor to his son during the latter's campaign (Greiner and Lane 2009). There was continuity within non-politically appointed staff in the White House Office of Science and Technology Policy (OSTP), to which OSTP Director and Bush Jnr Presidential Science Advisor John Marburger III later attributed the NNI's maintenance (Caprio 2010). Additionally, Richard Russell, who had been the Deputy Chief of Staff for the House

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[6] See Chapter 2.

[7] On the flexible and strategic use of this term see Jane Calvert (2006); for my qualified use of it and the political dimensions in the US context of the basic/ applied distinction, see Part A Introduction.

Committee on Science that had responded so favourably to nanotechnology (Committee on Science 1999, see also Chapter 2), became the OSTP Associate Director for Technology and Marburger's deputy for technology (Committee on Science 2003a). Finally, two of nanotechnology's strong supporters on Clinton's President's Council of Advisors on Science and Technology (PCAST), continued on Bush Jnr's council (PCAST 2008, Undated). Given such continuity, and the bipartisan support that had been shown for nanotechnology by Congress, it seems unlikely that Bush received advice critical of the initiative.

Bush's own personal interest in technology, and conviction in its centrality to US interests, may be a further and under-recognised source of his administration's support for the NNI. Indeed, perhaps surprisingly, and distinct from the value their administrations accorded 'science' more broadly, there was a continuity in 'technologically progressivist' commitments (cf. Kleinman 2005) between Clinton and Bush Jnr. Put differently, although Bush Jnr was widely regarded as hostile to some fields of research (eg climate science and stem-cells research) and as marginalising, suppressing or distorting scientific advice within his administration (Baum 2003; Brumfiel 2004), he was convinced of technology's importance to US economic and military strength. Bush's enthusiasm for technology was emphasised by E. Floyd Kvamme, a former computer industry executive and venture capitalist who became Bush's PCAST co-chair, in an oral history recorded by John Hollar (Kvamme 2012).[8] During his campaign, Bush had asked Kvamme to set up a technology advisory board, his only issue-specific advisory board. Even as the dot-com bubble burst, Bush was convinced that the technology sector offered the means to restore economic growth (Kvamme 2012). In forming his new administration Bush first sought technology rather than science advisors: Kvamme was appointed as PCAST co-chair in March 2001 (Goodwin 2001), whereas Marburger was not confirmed as Science Advisor until October (Davis 2001). In this context, NNI proponents' enactment of nanotechnology – a nascent field from which few applications had then been commercialised – as an economically important and powerful new technology (Chapter 2) stood the initiative in good stead.

Nevertheless, the absence of the NNI from Bush's early budget blueprints, and Murday's recollection of his own anxieties regarding its future, seemingly challenge any assumed inevitability for the initiative's retention. Bush refined his Presidential priorities in the wake of

[8] E. Floyd Kvamme recalled that: "Michael [Dell, founder and CEO of Dell computers] had done a wonderful thing before [Bush's election]. He had spent hours with Bush telling him that this tech thing is real and it's going to change the world. Because he was right there in Austin, and they'd become friends. And so Bush was really into it" (Kvamme 2012, 40).

the September 11 2001 terrorist attacks and the dot-com demise. In early 2002 he affirmed a focus on the "war against terrorism, homeland security, and economic revival" (R.M. Jones 2002b, unpaged). Nanotechnology's 'interpretative flexibility' (Pinch and Bijker 1984) was sufficient to encompass all these priorities, and proponents were quick to align their own work with them, for example by adding a 'grand challenge' to the NNI that responded to homeland security (NRC 2002).[9] Yet the NNI's key backers still felt vulnerable to "presidential whim" (Murday 2007, 56). As Wyden told the March 2003 House Science Committee hearing: "[the NNI] exists at the whim of this and future Administrations" (Committee on Science 2003a, 19). Murday (2007, 56) emphasised that: "It was very important to get the legislation in place, because it took [the NNI] out of the political process". The following sections explore hearings at which nanotechnology proponents worked to build Congressional support for an ongoing, legislated state commitment to the field, and the discursive and ideational resources they mobilised in this task.

4.2.2 Technology and (imperilled) national strength

In his influential work on the nation as "imagined community", Benedict Anderson (2006 [1983]) observes that nationalism may exert significant political power despite its philosophical poverty, or even incoherence. US nanotechnology proponents readily understood the power of stories that located technology as central to the standing, strength and identity of this imagined community, and articulated their own claims using these "historically resonant discourses" (cf. Kinchy and Kleinman 2003, 872; see also Kleinman 2005; Sarewitz 1996). Imaginaries in which a once all-powerful US faced an uncertain future were invoked repeatedly by hearing participants. Threats associated with a loss of US economic standing to competitor nations, or the prospect of future terrorist attacks, were mobilised to create an urgent 'need' to which nanotechnology could uniquely respond (cf. Downey 1992). In this imaginary, as has been remarked of others by Nik Brown (2003, 4), "risk and opportunity [we]re the flip sides of hyperbolic expectations, inflating one another in equal measure". Hearing participants cast the 21st century standing of the (otherwise imperilled) nation as reliant on success in nanotechnology, which would be assured only through the sufficiency of state support.

[9] On the strategic use of 'grand challenges' to foster new areas of technoscience see Andrew Balmer and colleagues (2016); Jane Calvert (2013); and Matthias Wienroth and Matthew Kearnes (2011). On the parallels of the National Science Foundation's (NSF) use of security threats associated with the Cold War to boost its funding appeals see Daniel Kleinman and Mark Solovey (1995).

Allen's introductory remarks to the 2002 Senate hearing (Committee on Commerce 2002) illustrate the explicit mobilisation of nationalist imaginaries in appeals for state sponsorship:

> "*Nanotechnology is quickly transforming every corner of our modern world…* it *is certainly going to occupy a major portion of our technology economy. It is that promise, it is that potential that should impel us as Americans, in a land that has always historically valued and encouraged innovation and entrepreneurship, that we embrace and support this research and this work. Our Nation has been at the forefront of virtually every important and transformative technology since the Industrial Revolution, and we must continue to lead the world in the new frontier of nanoscience, and that is why, Mr. Chairman, I am so proud and enthusiastically joining with you in supporting and introducing the 21st Century Nanotechnology Research and Development Act. I think it is vitally important for the future of our country, for our competitive edge*" (Committee on Commerce 2002, 5-6; Allen made equivalent remarks at subsequent hearings, see Committee on Commerce 2003; Committee on Science 2003a).

Allen's comments depicted economic competiveness, the pursuit of discovery, and the ability to "lead the world" as distinctly "American" traits. Similarly, other witnesses described a "uniquely American" aptitude for technological discovery and innovation, while extolling technology's foundational role in US "global leadership" (Committee on Commerce 2002, 57), and the "secret weapon" the US enjoyed in its "venture capital community and our entrepreneurial spirit" (Committee on Science 2003a, 65).[10]

Participants repeatedly appealed to the collective 'memory' (cf. Hurlbut 2015) of US technological achievements in space exploration, agriculture, nuclear power, information technology and biotechnology as not only underpinning the much-touted US "global leadership", but also as emblematic of its "unique" pioneering and innovative spirit. Tensions between collective memories and historical events are well recognised in the literature (Attwood 2005, 2011; Chakrabarty 2007 [2000]; Hurlbut 2015). Yet rather than affirming or contesting the material basis of storylines of technology's centrality to American exceptionalism, I emphasise their value as a discursive resource. US audiences readily identified with representations of their country as a nation of innovative pioneers, and this was useful to nanotechnology advocates. As Sheila Jasanoff remarks of imaginaries' power in

[10] The irony of such characterisations being made in attempts to secure ongoing public funding to underwrite the future entrepreneurial exploits of US industry is explored later in the chapter.

national science and technology policy: “Projects of world making succeed best when they are well synchronized with ongoing projects of nation building and the reaffirmation, or reperformance, of dominant national identities” (2015b, 335). By reaffirming technological “leadership” as central to US national identity, a threat to such “leadership” could be cast as a threat to the nation itself, which could then be used to justify – even demand – an active role for the state as nanotechnology sponsor.

A potent strategy for nanotechnology proponents was emphasising its significance for national security. Even before the September 11 attacks on the World Trade Center and the Pentagon, advocates such as Newt Gingrich (2001, 33) had characterised nanotechnology as “an extraordinary national security issue”. In the attacks’ aftermath, Bush emphasised that high-tech transformation of US military capability was the nation’s “first priority” in its response to terrorism (Bush 2001, 95). And indeed, the NSF and other agencies rapidly framed their calls for funding increases, including for nanotechnology, through the prism of national security (cf. Kleinman and Solovey 1995). The NSF Director argued that subsequent to the terrorist attacks, maintaining US standing on the “leading edge of discovery and innovation” was vital to both US security and that of the world at large (as quoted in Hanson, et al. 2002, 34). In a similar vein, at the 2002 Senate hearing, Hewlett Packard’s Stanley Williams argued for greater funding for nanotechnology and an expanded government role in coordinating R&D. He issued a dramatic warning: “Make no mistake about it: we are in a global struggle to dominate the technological high ground, and thus a large portion of the economy, of the 21st Century... To fail places the wealth and security of this nation at serious risk” (Committee on Commerce 2002, 73). Also making the argument for the defence implications of economic competitiveness, another business representative claimed that nano-manufacturing “could be disastrous from the standpoint of national defense and economic competitiveness if it was in the hands of another nation. I used to oppose any government funding for any industry; however... It’s reasonable for the government to encourage economic competitiveness for national security reasons” (Committee on Commerce 2003, 58). In this way, some proponents buttressed arguments for government’s role as industrial sponsor by invoking a threat to the nation’s security for which strength in nanotechnology was required. Others warned of more direct implications for the military and for “homeland security”. For example, at the May 2003 Senate hearing, Murday advised that nanotechnology would have a “huge potential impact on national security and, by inference from that, homeland security, homeland defense”

(Committee on Commerce 2003, 5). In these representations maintaining strength in nanotechnology was cast as critical to defence of the "homeland".

4.2.3 Quantifying nano's value chain

Hearing participants used various strategies in their efforts to make promissory claims for nanotechnology's economic impact "sound credible", including by making apparently calculative predictions for its future market value and workforce, and estimating existing venture capital investments in the field. The first hearing took place amidst what the NanoBusiness Alliance's Mark Modzelewski described as the "dot-com disaster" (Committee on Commerce 2002, 20). Imaginaries of a 'new economy' (Romer 1990, 1994) or 'knowledge economy' (W. Powell and Snellman 2004; K. Smith 2004),[11] in which a nascent high-tech sector offered the foundation for future wealth creation and therefore justified generous and preferential state support, had been prominent in lobbying for the NNI (see Chapter 2). In the hearings examined here, while promissory claims were articulated using knowledge economy discourse, proponents appeared conscious of its now qualified influence, and used diverse means to bolster the credibility of their claims.

Hearing participants sought to distinguish nanotechnology's promise from that of the disappointments of the dot-com era. They emphasised nanotechnology companies' "real technology and real assets" (Committee on Commerce 2002, 11; see similar comments Committee on Science 2003a, 59), the money that was already being invested in the field, and government predictions for nanotechnology's future market value. The NSF prediction of a US$1 trillion dollar market for products using nanotechnology by 2015 was cited repeatedly (Committee on Commerce 2002, 3, 11, 61, 79; Committee on Science 2003a, 17, 43, 57, 69; 2003b, 51). Some industry witnesses described the NSF figure as a "conservative" assessment (Committee on Commerce 2002, 11; Committee on Science 2003a, 57). Yet the trillion dollar prediction was not based on any economic methodology but relied substantially on personal estimates of Roco's colleagues (see Roco and Bainbridge 2001, 3-4; Siegel, et al. 1999, 135).[12]

[11] As noted in Chapter 3, many actors used these terms interchangeably.

[12] Indeed, in answers to follow up questions from the House Committee on Science, a representative of JP Morgan Partners acknowledged that despite his description at the hearing of the NSF predictions as "conservative": "Long-term estimates of industry size as developed by NSF ($1 trillion market in 13 years) are not based on accepted economic methodology. Industry leaders—mostly the R&D professionals of companies—were polled and the numbers were simply added up at the end. It could be correct, but it would have more to do with luck than science" (Committee on Science 2003a, 88).

Similarly, the NSF prediction of a nanotechnology workforce of 2 million by 2015 was conditional on this market estimate and used very basic assumptions (Roco 2001, 354).[13] Wyden also offered generous estimates of venture capital investment in nanotechnology to support his claim that nanotechnology presented "an extraordinary opportunity to promote more jobs and an economic revolution", asserting that "venture capitalists are already investing $1 billion in American nanotech interests this year alone" (Committee on Commerce 2002, 3). However, demonstrating again that government actors were themselves a key source of inflated claims for nanotechnology, this figure is two to more than three times greater than that of other estimates including those of promissory organisation Lux Capital (see Lok 2010; Paull, et al. 2003). What is most interesting for this chapter is the work that such contingent figures, repeatedly cited with and without qualification, were able to perform among US audiences – even when no-one believed the figures themselves.

The contingency in these predictions of the field's future value was recognised by most interviewees for this research. Yet although these predictions were commonly considered to be inaccurate and inflated, many US interviewees did not see this as problematic. As one interviewee observed:

> "*Well the number was changed from one trillion to 2.5 trillion and all those numbers keep going up. Everything depends on how you define the trillions... There is no easy way to do an accurate number. As it is it was always a crazy pie in the sky estimate... this is just another number to allow you to comprehend, 'Whoa, there is so much at stake there'. I think that's what it is*" (Director R&D consortium, Interview 43, March 2014).

Rather than treating the figures as a literal claim, or product of precise calculation, this interviewee understood them as signalling the field's great potential. A technology analyst was even more circumspect regarding the NSF prediction of a US$1 trillion market by 2015:

> "*It was just like an afternoon's worth of back of the envelope [calculations] that became this figure that every single person put on slides at the beginning of conferences... I think there was an open secret that that number was complete and total bullshit, but it also sort of didn't matter. If you were a researcher you just wanted to get your research grant, and you were probably young and brilliant and deserving. If*

[13] Mark Modzelewski made an even more ambitious workforce prediction, telling the Senate hearing that: "it is safe to say that 10 percent-25 percent of all U.S. jobs in a decade will be directly related to nanotechnology" (Committee on Commerce 2002, 61).

you were an entrepreneur you needed external validation... and here's the US government validating things with a trillion dollar market figure, that's great, this is like slide one" (Technology analyst, Interview 29, May 2014).

These statements emphasise the work that promissory claims may perform – and be seen by stakeholders to perform – even when the figures underpinning such claims are not understood to be literally 'true'. In the context of an imaginary in which technology was a potent source of US wealth, claims of a trillion-dollar nanotechnology market "sounded credible" as an indicator of nanotechnology's economic prospects, even when the figure itself was regarded as "complete and total bullshit".

4.2.4 The nano 'race'

The money invested by countries other than the US in nanotechnology R&D was also referenced as evidence of nanotechnology's compelling potential. The emergence of a nano 'race', with parallels to the space race of the 1960s, was invoked frequently (eg Committee on Commerce 2002, 39; 2003, 1, 28-29, 58; Committee on Science 2003a, 17, 57, 65; 2003b, 66, 76). Hearing participants warned that not only was the US "being outpaced by foreign competition" but the NNI had "set off a global competition not seen since the space race of the 1960's" (Committee on Commerce 2002, 67).[14] It is striking that this storyline of a nanotechnology 'race' centred on an international competition in research *funding*. Like previous efforts to compare governments' support for technological innovation via estimates of research expenditure, the figures cited were certainly, if incalculably, affected by double counting, ambiguities in research taxonomies, and other contingencies (see Godin 2006, 2009; see also Kearnes and Wienroth 2011b). Nonetheless, the money invested by 'competitor' nations in nanotechnology research was cited repeatedly at the US hearings as testament to the field's geopolitical significance and as justification for more generous state support.

Hearing participants stressed the geopolitical stakes of the nanotechnology race. Williams observed that: "the creation of the United States NNI has seeded tremendous competition

[14] This notion of a competition in new technology development has both a Cold War variant (in the US-USSR space race, see Kleinman and Solovey 1995; Weiss 2014) and a more contemporary form that foregrounds global economic competition (see Boesman 1997), and comparison of national 'systems of innovation' (see Godin 2009).

worldwide. As soon as we had an NNI, the world had an NNI" (Committee on Commerce 2002, 43). Moreover, he emphasised that the US was struggling to maintain a "lead" in the 'race':

> "*Other countries are determined to keep pace and even surpass our efforts. Even though Japan has experienced significant economic problems, they make certain that their NNI meets or exceeds the funding levels approved in the U.S. The European community is doing the same. Korea, Singapore, Taiwan and China are pouring a much higher percentage of their economy into research in this area, and when considering the local purchasing power of currencies, the PRC has the largest NNI in the world in terms of the number of researchers they intend to support*" (Committee on Commerce 2002, 35).[15]

Senator Joseph Lieberman (Democrat, Connecticut) made the threat this posed explicit in suggesting that: "Other nations have grasped the fact that the first players to fully capitalize on the promise of nanotechnology have the potential to leapfrog in productivity and precipitate a reshuffling in the economic, and perhaps aspects of the military, pecking order" (Committee on Commerce 2002, 57). In this way, competition in nanotechnology was cast as the site at which the uncertain 21st century global "pecking order" would be resolved.

The story of an international race in which US economic wealth, military dominance and prestige was at stake explicitly leveraged the familiar discourse and historical experience of the space race. Drawing on these rich discursive resources and the collective 'memory' of the Cold War race (cf. Kleinman and Solovey 1995; Weiss 2014), the nanotechnology race – or rather, the estimated spending of other countries on nanotechnology R&D – was used to make the field "sound credible" as the new site of economic and military competition. Notably in these accounts, the race appears as an unintended 'downside' of the NNI, rather than as the product of careful nurturing by the NNI's proponents, as described in Chapter 2. The race discourse was deployed not to show the legitimating power of the NNI program (although this was also recognised by hearing witnesses, see especially Committee on Commerce 2002), nor the persuasive outreach by NNI officials, but the value that competitor nations' governments placed on nanotechnology, and the stakes of maintaining a US "lead". This enabled proponents

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[15] In the great number of competitor nations cited by hearing participants it is notable that there is no single 'great enemy'. Paradoxically, the post-Cold War world, in which international competition was understood to take place largely in economic rather than military arenas, was seen to introduce a greater level of uncertainty and geopolitical instability.

to mobilise the imaginary of (state-supported) technology's centrality to (imperilled) national strength, and served as rationale and justification for expanded state support for the field.

4.2.5 The centrality of the state

The vital nature of government support to past, present and future US technological success was emphasised by politicians, scientists and industry spokespeople at the hearings, and used to bolster appeals for a proactive state role in nanotechnology development. For example, academic Nathan Swami argued that:

> "*We owe our world leadership in high technology to the government's timely investments at critical early stages... From the dawn of modern agriculture to aerospace to the launching of the Information Age, government support has been a powerful catalyst to drive basic research and accelerate technology transfer from the laboratory to the marketplace... The Internet itself is an outgrowth of federally supported research. We are now at another critical juncture in our technological evolution, and timely passage of this bill will go far to assure continuing American leadership in the global economy*" (Committee on Commerce 2002, 38-39).

The recurring use of this storyline performed important work. Lauding historical examples of the US government's role in underwriting technological successes – or at least repeating widely shared 'folk theories' (cf. Eisler 2013b; Rip 2006) about the role of federally-sponsored research in such successes – helped to make claims that present-day state support for nanotechnology could drive future wealth creation "sound credible". Emphasising past success stories also helped to gloss over the recent disappointments of the dot-com bust.

Invoking a long-standing political consensus for the state funding basic science – sometimes even explicitly referencing Vannevar Bush's envisaged 'social contract' for science (eg Committee on Commerce 2002, 5; see Part A Introduction) – performed valuable work. It obscured contemporary budget complaints from the science lobby and partisan disputes regarding government's role in technology development. Perhaps most importantly, it helped to justify NNI funding in terms that would satisfy fiscal conservatives, despite both the initiative's ostensibly commercial rationale and difficulties distinguishing between the basic and applied research it supported (cf. Calvert 2006; Godin 2006; Kleinman and Solovey 1995).[16] The responsibility of the federal government to assume the burden of 'high-risk' research was emphasised by many hearing participants. For example, the OSTP's Richard Russell argued that:

> "*The role of federal R&D funding in this area is to provide the fundamental research underpinnings upon which future commercial nanoscale technologies will be based... Because of the complexity, cost, and high risk associated with these issues, the private sector is often unable to assure itself of short-to-medium term returns on R&D investments. Consequently, industry is not likely to undertake the basic research investments necessary to overcome the technical barriers that currently face the nanotechnology field. The NNI program is structured to overcome these barriers so that America's industries will prosper from our investment in nanotechnology*" (Committee on Commerce 2002, 9; see also Committee on Science 2003a, 26).

Russell's statement at once naturalised the risk aversion of the private sector and its unwillingness to fund 'basic' research (cf. Kleinman 1994, 1995), the economic importance of "future commercial nanoscale technologies" to "America's industries", and therefore the responsibility of the state to fund and 'de-risk' nanotechnology's development.[17] Such arguments mirrored those advanced previously by the National Economic Council's Thomas Kalil, by Nobel laureate Richard Smalley, and by Clinton himself in support of the NNI (Chapter 2). They can be summed up in the argument of IBM's Thomas Theis to the House Committee on Science that: "The breakthroughs funded by the Federal Government are the foundation that enables subsequent efforts by the business sector to translate that research into products on the marketplace" (Committee on Science 2003a, 33). This argument provided a core rationale and justification for public funding for nanotechnology R&D and was used by Republican and Democrat politicians, academics and business representatives at the hearings. Republican House Committee on Science Chairman Sherwood Boehlert put it succinctly: "We have got to be the investors" (Committee on Science 2003a, 66).

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[16] As the interagency working group observed: "It is difficult at this moment to make sharp distinctions between fundamental and applied science in nanotechnology. This is not a new phenomenon: recall that the discovery of the laser revolutionized several fields, including both communications and surgery, while the basic scientific principles were still being investigated" (Roco, et al. 1999, ix).

[17] This statement casts "risk" as commercial. Earlier STS work has emphasised also the "recurrent pattern" of the state "letting private developers reap technology's benefits while [safety and regulatory] risks and costs are absorbed, without explicit accounting, by the public purse" (Jasanoff and Kim 2013, 191).

Yet beyond the state's role in funding high-risk basic science, much of the hearings' discussions centred on the more politically sensitive question of how to foster nanotechnology commercialisation. Several hearing participants argued for an expansive government role in nurturing nanotechnology commercialisation through incentives and technology transfer programs, private sector loans, the fostering of regional development hubs, government procurement policies or greater use of the Advanced Technology Program (ATP).[18] Indeed, even as repeated assertions were made regarding the "uniquely American" "entrepreneurial spirit" and capabilities of US 'innovators', the NanoBusiness Alliance's Modzelewski urged the necessity of government support for industry development (for earlier parallels in biotechnology see Vallas, et al. 2011; see also Block 2008; Block and Keller 2011). Modzelewski cautioned that "Wall Street" had shown marked ambivalence towards nanotechnology and implied that "new incentives and, grant and loan programs" [sic] were needed to overcome its risk aversion (Committee on Commerce 2002, 64). He warned that given the "severe downturn" on Wall Street and the "stagnant" state of venture capital, "the U.S. nanotechnology market is in need of serious attention and assistance from the Federal Government" (Committee on Commerce 2002, 67). Such testimony complicates Sunder Rajan's (2006; 2012a) characterisation of emerging technologies as a fertile new ground identified by a "lively capital" for its expansion. Indeed, venture capital is here depicted as in need of remedial attention from the state, and its interest in nanotechnology actively coaxed. Support for an active government role in "engender[ing] the rapid development of nanotechnology" was affirmed by the National Nanotechnology Coordination Office's Director Clayton Teague, who averred that "technology transfer and commercialization have been the key elements of the NNI plan from its inception" (Committee on Commerce 2003, 13, 14). Similarly, Murday spoke of working with Small Business Innovation Research programs and the "venture capital community" with such a goal (Committee on Commerce 2003, 23).[19]

While much of the discussion centred on the role of the NNI in fostering the commercialisation of nanotechnology, hearing participants were careful to situate their interventions in nominally 'free market' logics. Their sensitivity to arguments surrounding the proper limits to government backing for technology commercialisation was explicit in discussion of the politically "controversial" ATP (eg Committee on Science 2003a, 66-67). Nonetheless, a

[18] These included representatives from the NanoBusiness Alliance, Zyvex Corporation, Luna Innovations and JP Morgan Partners, but also the Office of Science and Technology Policy's Richard Russell.
[19] Although for the limits of government-backed commercialisation efforts see Yasuyuki Motoyama and colleagues (2011).

surprising degree of unanimity was apparent in the view that the government's role should be to 'back the nation's innovators'. As Republican Senator Allen, chairman of the Subcommittee on Science, Technology and Space argued:

> "... *our role, as elected leaders, should be to create or to foster the conditions precedent for our researchers and innovators to compete and contribute and succeed, both domestically and internationally. I am not here to say that we ought to guarantee anyone's success, but the Government's role is to make sure the field is fertile, our tax policies, our research policies, our regulatory policies, allow the creative minds in the private sector, in our colleges and universities, as well as in some of our Federal Government Agencies, to reach their full potential*" (Committee on Commerce 2003, 2).

The hearing participants expressed a collective expectation that the US government would actively support the competitive prospects of US firms within this new field of technoscience, including by creating or fostering favourable market conditions for nanotechnology's development (cf. Callon 2007; Garcia-Parpet 2007 [1986]; see also Mirowski and Nik-Khah 2007). That is, illustrating the interpretative flexibility of 'free market' commitments (Part A Introduction), US actors assumed that government would absorb the costs of conducting high-risk basic research, and subsidise its translation, while enabling the private accumulation of subsequent benefits (on the historical correlates of such assumptions see Block and Keller 2011). An expectation of government support for the sector's development was expressed even by actors who appeared otherwise sceptical of appeals for direct sponsorship of commercialisation programs. These expectations for science-state-market relations were particularly valuable for US proponents in their efforts to make the sociopolitical dimensions of nanotechnology promissory claims "sound credible", and a resource which their Australian counterparts lacked.

4.3 The Australian effort

Following the announcements of other national nanotechnology programs after that of the NNI, and subsequent to nanotechnology's nomination as an Australian research priority (Chapter 3), the growing numbers of Australian proponents became more committed to securing their own national initiative. As they sought a dedicated policy apparatus to guide the research investment and to foster nanotechnology's development, the PMSEIC meeting offered proponents a key opportunity to gain the support of high-level politicians. The *ad hoc* PMSEIC nanotechnology working group included some of the country's most highly recognised nanotechnology researchers, and the representatives of some nanotechnology businesses (PMSEIC 2005a, i). Yet in pitching their proposal for a new national nanotechnology strategy, this group lacked political champions. Rather than the Prime Minister and Cabinet members present at the PMSEIC meeting (DIS Undated-b) being already enthusiastic nanotechnology supporters, these politicians figure in interviewees' recollections as a somewhat disengaged audience. Further, nanotechnology was not the focus of the meeting, but the fourth agenda item (DIS Undated-b). And whereas US proponents could articulate their promissory claims using storylines that claimed innovation and entrepreneurial capabilities as core to the national character, and technology as central to economic and geopolitical strength, such discursive resources were not available to their Australian counterparts. In key respects, the challenges faced by Australian science-policy intermediaries in making their promissory claims "sound credible" to the PMSEIC audience were greater than those of participants in the US hearings examined above.

4.3.1 "We don't get too over-hyped"

Promissory claims for nanotechnology made in the PMSEIC report mirrored those made in the US hearings and associated with the NNI bid before them. Illustrating the ways in which some promissory claims circulated internationally (cf. Latour 1987), the report directly cited Lux Research forecasts of nanotechnology's future value chain, observing that:

> "*The disruptive innovations that should arise from nanotechnology over the next decade could be as significant as electricity or the microchip. They could give rise to a whole new set of industries as well as transform current technologies in manufacturing, healthcare, electronics and communications. It has been estimated that the sales of products incorporating emerging nanotechnologies will rise from 0.1% of global manufacturing output in 2004 to 15% in 2014, totalling US$2.6 trillion. This would be as large as information and communication technologies combined and more than ten times larger than biotechnology revenues*" (PMSEIC 2005a, 3).

However, claims that originated in the US concerning the size of the future market for nanotechnology products acquired an alternative meaning and significance in the Australian political and policy environment, as I outline below. In the context of the PMSEIC meeting, these claims' reception was shaped also by the differing practices employed by the working group in its promissory work compared to those of their US counterparts (cf. Balmer, et al. 2016). The claims contained in the excerpt above are quite remarkable – not least the prediction that nanotechnology "should" drive "disruptive innovation" "as significant as electricity" within the space of ten years. However, the otherwise cautious, descriptive and prosaic manner in which the PMSEIC presentation couched these claims contrasted greatly with the bold and dramatic style of US science-policy intermediaries, and their use of nationalist storylines that foregrounded technology's centrality to national identity and strength.

In the absence of a meeting transcript, the PowerPoint presentation used to make the PMSEIC presentation (PMSEIC 2005b) provides an insight into the narrative strategy employed by Australian proponents. In appraising this digital document, I recognise that it cannot fully capture the delivery or the reception of the live presentation (Stark and Paravel 2008).[20] Nonetheless I view it as an informative supplement to my analysis of the written report to PMSEIC, and to my interviewees' recollections of the meeting. US hearing participants began their addresses by appealing to collective 'memories' of the nation's past technological triumphs, and the threats it faced to which technological strength could respond. They posited "leadership" in nanotechnology as the site at which the 21st century fate of the US depended. Conversely, the first slide of the PMSEIC PowerPoint presentation focused on a detailed explanation of nanoscale metrics, comparing the relative sizes of the earth, a coin, a human hair and a blood cell. The second slide explained the use of nano-composites in long-life tennis balls, and the third slide showcased water and stain-repellent surfaces (PMSEIC 2005b). That is, the introduction of nanotechnology to this high-level (and eminently distractible) political audience focused on quotidian applications of nanomaterials, with no link to an ambitious vision for future nanotechnology, or what the field meant for Australia. The executive summary of the written report took a similarly descriptive approach that explained the role of scale in novel physicochemical properties, and gave examples of extant applications of nanomaterials (PMSEIC 2005a).

The PMSEIC report adopted a considered tone. Focused on the detail of nanotechnology definitions, nanoscale metrics, and examples of nanomaterials' application, it eschewed

[20] On the analysis of PowerPoint documents separate from the contexts in which they were presented, and PowerPoint's affordances for "the work of persuasion, representation, and misrepresentation", including beyond initial audiences for any presentation, see David Stark and Verena Paravel (2008, 36).

flamboyance, or the overt exercise of imagination. As well as touting nanotechnology's anticipated economic benefits (discussed further below), it paid particular attention to concerns regarding health and safety risks posed by manufactured nanoparticles, and to the threat of a public backlash to the field. The working group identified ten "needs" for Australia to "capitalise on the opportunities presented by nanotechnology". Strikingly, first among them was "a national nanotechnology strategy coordinated across all levels of government, to inform the public debate on social, health and environmental issues, and to provide an appropriate regulatory framework" (PMSEIC 2005a, 4). Although the NNI had highlighted the need for safety and social issues work, regulatory aspects were never accorded such prominence as this in general reports, and were deliberately removed in initial NNI pitches to Congress (Karn and Schottel 2016). Whereas the US hearing participants sought to make their promissory claims "sound credible" by appeals to the 'memory' of the moon landing and the contribution of technological success to the pride of the nation-state, Australian nanotechnology proponents articulated similar promissory claims in a sober if curiously placeless discussion of the "potential positives and negatives" of the new field (PMSEIC 2005a, 21).

The stylistic differences between the two groups may reflect 'civic epistemology'-based judgments (cf. Jasanoff 2005a) regarding the form in which knowledge claims should be expressed. Like King Lear's daughter Cordelia (Shapin 1995), several Australian interviewees expressed distrust of truth claims made in the form of 'hype'. One scientist suggested that Australians are: "sort of moderate in the way they look at things. We don't get too over-hyped and it's because of our laid back nature whereas people in some of the other countries, they get really over-hyped on things" (CEO R&D body, Interview 13, November 2013). I do not attempt to discern the contribution of culture-based aesthetics to the presentation styles of Australian as compared to US science-policy intermediaries. However I do make two observations. Firstly, to the extent that common storylines about Australians' aversion to hype influenced Australian nanotechnology proponents' articulation of promissory claims, these storylines may themselves have been performative, for example by channelling promissory claims into supposedly 'realistic' forms. Secondly, and relatedly, in a context in which all expectations for a field's future impact are necessarily speculative but also generative (Borup, et al. 2006), an avowed aversion to "over-hype" is also performative by licensing particular kinds of expectations and their expression and delegitimising others.

4.3.2 Illustrating the absence of an 'Australian' nanotechnology

The notion of a distinctly 'Australian' nanotechnology was only faintly discernible in the PMSEIC report. The report made the early claim that "global developments in nanotechnology will certainly impact on many of Australia's most important traditional industry sectors" (PMSEIC 2005a, 3). However it was not until page 23 of the 39 page report that Australia's nanotechnology efforts received focal attention, and it was on page 28 that a table summarised "nanotechnology applications and opportunities in Australian industry". The report made no detailed arguments for why nanotechnology could or should be seen as central to the country's existing industries and interests.[21] Perhaps reflecting a judgment that references to a nanotechnology 'race' would not inspire confidence in Australia's ability to compete in it, there is no use in the PMSEIC report of this storyline that featured so prominently in the US hearings. Instead, the report modestly suggested that as a "smaller player" the country's best hope was for "collaboration" with larger "players":

> "*Even the largest countries and multinational companies will be faced with the prospect that research efforts in nanotechnology will become more expensive, complex, multidisciplinary and dispersed globally. While these developments pose major problems for smaller players, all players will be seeking strategic alliances, and good research performers, such as Australia, should find plenty of opportunities by pursuing international collaboration*" (PMSEIC 2005a, 18, see also 4).

Despite this analysis, the report's authors apparently failed to realise that in the estimations of their political audience (nano)technology was itself a "smaller player" whose prospects for patronage would be improved by demonstrating "collaboration" and "strategic alliances" with Australian industries of greater standing.

In an interview for this research the former Chief Scientist Robin Batterham, then a member of PMSEIC, criticised the working group's report and presentation as failing to demonstrate nanotechnology's domestic relevance. Batterham recalled that the report:

> "*...didn't get much traction. I look back on that and say that was partly because the line that was adopted by the working party that worked on it tended to be, 'Well the US is doing it and it looks terrific, you know, classic new ground, absolutely laden with*

[21] A "senior public sector interviewee" cited in Stephen McGrail's (2011) study made a similar observation regarding this deficiency in Australian advocacy for nanotechnology more broadly.

possibilities, etcetera, therefore Australia must do it' rather than 'Who in Australia might be interested? How would you get it organised? What might it lead to?' So it was a 'me, too' type request which doesn't really work or it doesn't go down too well" (Robin Batterham, Interview April 2015).

The impression that nanotechnology was a "me too" request, or worse – something 'foreign', was underscored by the use of the illustration "Nanotechnology in future everyday life" on the second page of the report, as part of the Executive Summary (Figure 1 below; PMSEIC 2005a, 2), an illustration originally found in a European Commission (2004, 28-29) report.

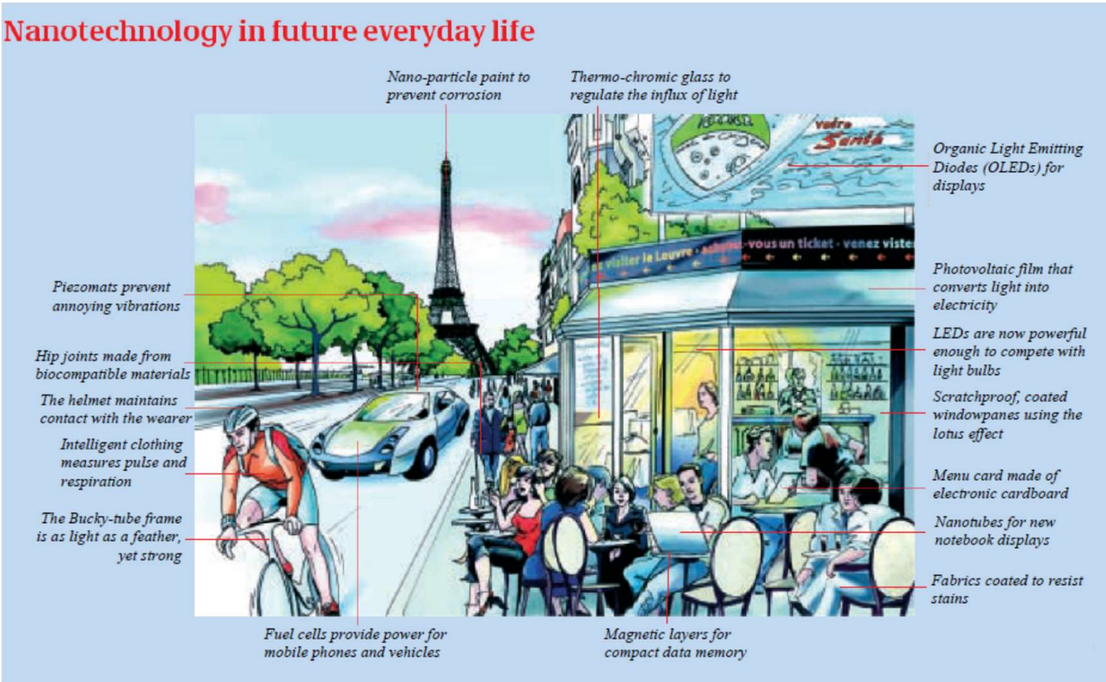

Figure 1: "Nanotechnology in future everyday life" (from PMSEIC 2005b, 2, reprinted from European Commission 2004, 28-29).

As Batterham looked again at the illustration during our interview, he exclaimed at the lack of relevance it held for Australian political audiences: "'Nanotechnology in future everyday life' and it's got a picture of the Eiffel Tower... and it's very much a Paris street scene. 'Bucky tube framed [bicycle]' – who around the Cabinet table was travelling with bicycles? When I look at it now – it's from the European Commission Report..." (Robin Batterham, Interview April 2015).

Batterham’s indignant response to the illustration underscores the insight that sense-making tools developed for one context (European publics) don’t circulate without friction to another (Australian politicians): meaning is always (re)constituted *in situ* (Balmer, et al. 2016). Rather than helping proponents to make their promissory claims for Australian nanotechnology “sound credible”, for Batterham the Parisian illustration situated nanotechnology *elsewhere*.[22] It is possible that some members of the PMSEIC working group, or the Department’s staff who assisted them, realised the ‘audiencing’ problems (cf. Mahony 2015, 157)[23] associated with this illustration at a late stage. In its use as the final slide in the PMSEIC PowerPoint presentation (Figure 2, from PMSEIC 2005b, slide 24), Australia’s Parliament House has been substituted for the Eiffel Tower – although the French language signs and billboards remain. The awkward imposition of an Australian element to a vision developed elsewhere is a striking illustration of intermediaries’ failure to enact an emplaced ‘Australian’ nanotechnology (cf. Hecht 1998).

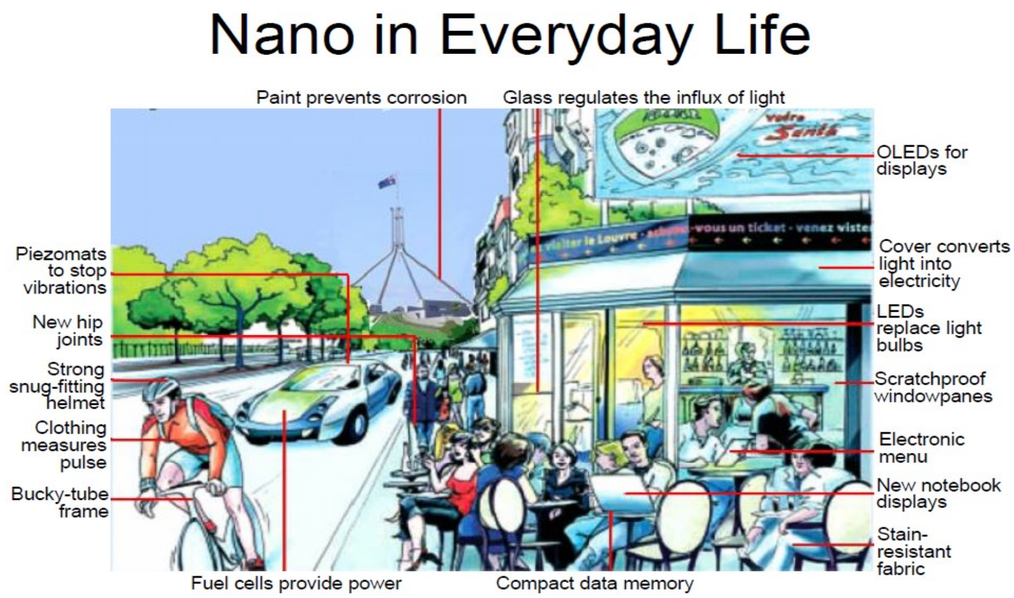

Figure 2: “Nano in Everyday Life” (PMSEIC 2005b, PowerPoint slide 24).

[22] The choice of a French-themed illustration may have been particularly politically tone deaf given then President Chirac’s high-profile criticism of President Bush’s war in Iraq, in which Australia participated, and his lobbying for international action to curb climate change, which Prime Minister Howard opposed.
[23] On subject-object co-construction and the imagined publics of science see Brian Wynne (2002, 2005). On relationality in promissory work see John Gardner and colleagues (2017).

4.3.3 *“2.6 trillion... blah, blah, blah”*

Internationally circulating promissory claims for nanotechnology’s economic impact, cited by the PMSEIC working group, were not axiomatically salient to Australian political audiences. In the US, whereas trillion dollar nanotechnology market estimates were not understood to be literally ‘true’, in the context of a shared imaginary of technology’s centrality to US economic strength they functioned effectively to signal high expectations for the field. Conversely, amidst scepticism from Howard’s government regarding the ‘return on investment’ of Australian R&D (Chapter 3), ambitious predictions for nanotechnology’s value chain did not “sound credible”. The former Chief Scientist recalled being nonplussed by the report’s citations of predicted economic impact: “’Disruptive technologies, 2.6 trillion...’, blah, blah, blah. It didn’t catch on” (Robin Batterham, Interview April 2015).

Indeed rather than predictions of US$2.6 trillion in market value and favourable comparisons with the size of the ITC and biotechnology industries leveraging collective ‘memories’ of technological achievement as they did in the US, such storylines raised uncomfortable associations. In the eyes of many in the research sector and in government, Australia had missed its chance to develop a local ITC sector (Chapter 3) – although responsibility for the “failure” to successfully commercialise Australian ITC research (PMSEIC 2005a, 5) was largely attributed by each sector to the other (on this broader pattern see Chapter 5). Rather than recognition of past “failure[s]” in technology commercialisation inspiring a more vigorous government commitment to nanotechnology, it is possible that it had a dampening effect.[24] The reference to nanotechnology’s “commonality with biotechnology in terms of community concerns with public safety” (PMSEIC 2005a, 5) also recalled the protracted political struggles that had led to several Australian states declaring moratoriums on the commercial production of genetically engineered (GE) crops, and the ongoing debates about food labelling for GE ingredients. In this way, associating nanotechnology with ITC and biotechnology indirectly reminded of Australia’s past policy “failure[s]”, which themselves played into storylines of national deficiency (see below).

Members of the PMSEIC nanotechnology working group were aware that they had not wholly succeeded in making their promissory claims “sound credible” to the Prime Minister and Cabinet members. Their evaluations of the meeting and its outcomes varied. One interviewee recalled a sense of disengagement within the room:

[24] The commonly expressed view that Australians are averse to risk and to failure is discussed below.

> "*the will from the federal government just simply wasn't there... the next time the federal government says 'oh gee, we'd like another report for PMSEIC'... you tend to say 'well I worked really hard on the 2005 report and it went nowhere, is there any reason we should think this should go further, or should we just photocopy the 2005 one and put that back in there*?'" (Industry member, Interview 60, December 2013).

Another member of the working group felt that Howard was "very serious in his wish to have a longer-term view" of science and technology, but that since the late 1990s government's willingness to support strategic innovation policy had been dissipated by the mining boom: "all heads turned and foolishly they dashed after the extractive industries because it was easy and cheap" (Industry member, Interview 63, April 2015). A further working group member was more positive, observing both Howard's personal enthusiasm for the field and that the creation of the NNS resulted directly from the working group's PMSEIC presentation. Nonetheless, they expressed disappointment with the limits of that policy and with the lack of subsequent government leadership for nanotechnology development compared to that of other countries (Technical scientist, Interview 31, November 2013). Despite the personal interest that some PMSEIC working group members identified from the Prime Minister, they recognised that they had not made predictions of state-supported, nanotechnology-enabled prosperity sufficiently persuasive to secure the kinds of proactive political support they sought for the field.

4.3.4 An absent imaginary

A key difficulty for the PMSEIC nanotechnology working group was the lack of supportive discursive and ideational resources available to them. Their US counterparts could leverage storylines that posited technological 'leadership', underwritten by the timely investment of the state, as central to the nation's strength and standing. The meaning of these "historically resonant discourses" among political audiences was largely accepted (cf. Kinchy and Kleinman 2003, 872). Conversely, Australian nanotechnology proponents encountered an 'absent imaginary' regarding technology's relevance to Australia's economy and identity, and government's role in its development. They needed to formulate new arguments for why the state should sponsor technological innovation in general, and their own field in particular. Australia lacks storylines that celebrate collective memories of technological pride. Indeed, some of the most widely known technological and engineering achievements, such as the establishment of weirs, dams and irrigation systems throughout the Murray-Darling Basin, and the Snowy Mountains Hydro-Electric Scheme,[25] have been plagued by controversy (Australian Government 2015; Muir 2014).[26] Technological achievements made possible by the contributions of Australian researchers such as the cochlear implant (bionic ear), the technology that supports wifi, polymer bank notes and black box flight recorders are mostly uncontroversial. Yet attempts to claims these as 'Australia's own' have met with mixed success. Although cited in documents produced by government and the CSIRO (eg CSIRO Undated), as public spectacle (cf. Ezrahi 1990) such innovations are incommensurate with a moon landing, and are not celebrated in popular storylines. Finally, Australia's reliance on imported technology is often held to damn its innovative prospects, despite some analysts suggesting that the local adaptation and transformation of scientific knowledge and technology developed elsewhere has been central to past economic achievements (Barlow 2006; Todd 1995).

As proponents sought to enrol Howard and his ministers in their imaginary of state-supported, nanotechnology-enabled prosperity, they encountered a two-fold friction. The Howard government's 'free market' commitments limited its in-principle preparedness to support the commercial development of any sector.[27] Also, more pragmatically, it was unconvinced that Australian scientists had the aptitude or willingness to generate commercial returns on any investment made in them (Chapter 3). The influence on nanotechnology policy of debates regarding government's role in sponsoring innovation is explored in detail in Chapter 5. Here, I contrast technology's 'absent imaginary' with competing and comparatively robust imaginaries associated with the minerals sector.

Mining has been long been an important component of the Australian economy. In June 2001 a separate PMSEIC report had observed that: "The Australian minerals industry is Australia's largest export earner, contributing $43.8 billion to Australia's economy in the year 1999-2000 … help[ing] Australia achieve its position as the sixth wealthiest nation, per capita" (PMSEIC

[25] The Snowy Mountains Scheme is described by government as: "by far the largest engineering project ever undertaken in Australia... [and] one of the largest and most complex hydro-electric schemes in the world" (Australian Government 2015, undated).
[26] Both were the subject of high-profile disputes during the Howard years for their adverse ecological impacts on associated river systems.
[27] Notwithstanding this, the government's 'free market' commitments possessed sufficient flexibility to enable selective state investment in some industries (eg rail and port infrastructure for mining) and its withholding from others (eg nanotechnology). On the Howard government's concessions to political pragmatism in industry and innovation policy more broadly see Elizabeth Thurbon (2012), on the incoherence of Australian industry policy and its public justifications, see Richard Denniss (2016).

2001, 3). Further, the report claimed for mining a foundational role in the national psyche: "The value of the minerals industry is etched in Australian history and identity" (PMSEIC 2001, 3). Australia was infamously depicted by author Donald Horne (1964) as "the lucky country", having achieved wealth through the ready exploitation of natural resources rather than any application of its own knowledge or enterprise. Several interviewees suggested that such criticism remains apt in the present time. They lamented Australia's status as the world's largest coal exporter while, in their view, the government was disinterested in proactively fostering a more diversified 'knowledge economy'. That is, nanotechnology proponents identified a competing imaginary to that which they offered, in which Australia would rely economically on "fossil fuels forever" (cf. Levy and Spicer 2013).[28]

Emphasising that imaginaries are underdetermined by their material referents, any dichotomous distinction between Australia's commodity-based mining and agricultural sectors and research-based, high-tech capability is undermined by these industries' historic reliance on science and technology-based innovations (Batterham 2000) and the automated, data-intensive nature of their extant operations. Government-commissioned reviews of the innovation system have recognised technological innovation as key to the success of Australia's resources sector (Cutler 2008; Office of the Chief Economist 2015). Nonetheless, many interviewees for this research did make such a distinction. Several interviewees, including some who participated in the PMSEIC nanotechnology working group, counter posed what they saw as the federal government's focus on the mining industry with its apparent disinterest in nurturing technological innovation.

However, in contrast to the representations of many nanotechnology proponents, Batterham stressed that technological innovation *was* sometimes seen as compelling by senior government figures – but that its relevance to existing industries needed to be demonstrated. Batterham compared the pitch of the PMSEIC nanotechnology working group unfavourably with a contemporary presentation on research into using insect vision and object recognition to build autonomous robotic devices, including for the mining sector:

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[28] For example, one interviewee stated: "It disturbs me a bit looking at the Australian situation where, you know, we have, as you know, very rich mining reserves and yet... I don't see the government sort of directing this towards some of the things of the future; some of the technologies of the future. I'd put nano in that category..." They compared Australia unfavourably with the Netherlands where they described the government taking revenues from natural gas extraction and "putting it aside for research in emerging technologies such as bio and nano. They realise that one day the natural resources are going to be depleted and they're going to need something to replace that revenue stream" (Regulator, Interview 53, January 2014).

> "*When Hugh Darrant-Whyte came along and showed how he was using [new technology] to help a 400-tonne [bauxite] truck pick up that there was an obstacle and it was getting nearer to it and it had better slam on the brakes – again, edge of the seat stuff. Compare that with talking on nanotechnology that the US is going to spend x hundred million and they're expecting x billion and so forth* – with a bunch of words – *... different game... [when] you're talking about haul trucks in mining – Australia's largest exports and companies actually getting into autonomous vehicles, etcetera, you could see the credibility of it being much higher*" (Robin Batterham, Interview April 2015, emphasis added).

Batterham's recollections show that researchers could achieve "much higher" "credibility" for their own work by aligning it with Australia's major industries, whose centrality to wealth creation was already firmly established in imaginaries (and royalty payments) of their own. Conversely, predictions of billions of dollars in nanotechnology-driven wealth did not "sound credible" without this. Whereas in the US predictions of trillion dollar profits from nanotechnology "sounded credible" even if not understood to be literally true, in the Australian context such claims were simply "a bunch of words".

The former Chief Scientist's recollection points to an important point: the identity of those making promissory claims may influence the extent to which such claims are judged by political audiences to "sound credible". In the US hearings, politicians, senior government advisors, and representatives from major US firms such as IBM and Hewlett Packard joined scientists in predicting nanotechnology's future centrality to the nation's economic interests. In lacking such influential connections, the message offered by Australian proponents – academics and the representatives of start-up firms – was more vulnerable to perceptions of 'special pleading'. That is, illustrating co-production at work, the credibility of their message was in part shaped by the identity of its deliverers. This is not a new observation. Indeed, it is twenty five years since Brian Wynne (1992, 281) stressed that "the credibility of scientific communication" rests in large part on "the trust and credibility public groups are prepared to invest in scientific institutions and representatives". And yet, underscoring Nowotny's (2014) observation regarding the lack of STS attention to science's publics within government, the applicability of Wynne's insight to *policy makers'* appraisal of the credibility of technoscience claims making has been insufficiently recognised.

Ulrike Felt (2015) describes an "imaginary of absence" in Austria's technopolitical identity, associated with its actively "keeping out" technologies such as GE crops and nuclear power. Somewhat differently, Australia evinces a largely 'absent imaginary'. Australian political audiences showed no inclination to actively "keep out" nanotechnology, but nor were they convinced of its relevance to Australia's political economy, or of the value for the state in supporting its development. As an imagined source of national wealth and pride technology *per se* did not feature. Technology became legible and "sounded credible" only in association with industries whose economic and political importance was already recognised. This observation underscores one of this thesis' central arguments. State support for nanotechnology development was neither 'natural' nor inevitable, but the situated product of intermediaries' active work. Significantly, this work was not always successful.

4.3.5 Nanotechnology as response to Australia's postcolonial condition

As we have seen, science and technology policy is a site at which competing imaginaries of the nation and its sociotechnical future "struggle to establish themselves on the same social terrain" (cf. Jasanoff and Kim 2015, 323). The PMSEIC report and its presentation lacked an explicit appeal to nationalist imaginaries. Yet storylines problematising Australia's identity, industrial structure, and place in the world, and foregrounding (nano)technology's capacity to offer 'solutions' to these, were pronounced in proponents' interview statements, including those of members of the PMSEIC nanotechnology working group. Such storylines may be understood as both reflecting interviewees' perceptions of Australia's "(dubiously) postcolonial status" (Ang and Stratton 1996, 21), and attempting to resolve it. Old national insecurities and tropes of deficiency recurred in interviewee comments, including in relation to Australian science and science policy. This illustrates the 'cultural cringe' described by Libby Robin (2007, 8) as the "persistent colonial deference" Australians show to the symbols, traditions, cultural achievements and knowledge of others, particularly Britain and the US.[29] Yet at the same time, interviewees touted achievements in science and technology and the prospect of strengthening participation in a 'knowledge economy' as the means for Australia's modernisation and transcendence of its colonial roots. As Warwick Anderson and Vincanne Adams (2007, 186) observe more generally, "technoscience provides yet another stage for the colonial drama".

[29] The corollary to this insecurity in national identity is a sometimes blatant parochialism, for example through undue emphasis on the originality of Australian achievements (cf. Barlow 2006).

Among interviewees for this research, nanotechnology proponents repeatedly cast nanotechnology and advanced manufacturing as the 'solution' to 'problems' surrounding Australia's 21st century identity and political economy.[30] They emphasised the need to transform Australia's heavy reliance on commodities' trade and its struggling manufacturing sector to ensure the ongoing viability of "first world" living standards. The sub-text of such comments was Singaporean Prime Minister Lee Kuan Yew's famous warning that Australia was at risk of becoming "the white trash of Asia" (as quoted in Ang and Stratton 1996, 29). As one interviewee argued:

> "*... our geographical isolation is an impediment... we're hampered by our distance from other markets. But we're also hampered by what I call dumb politicians... what we need is quality. [But] what seems to be the push right now is to push the minimum wage down... I don't want a third world wage. I want a first world wage... The way to do that is to get smarter about our manufacturing sector... [but] we just think we're competing with China*" (Industry association representative, Interview 42, November 2013).

This interviewee, like others, argued that nanotechnology was the 'smart' route to create high-value goods that could enable 'island-nation' Australia (cf. Perera 2009) to be competitive on quality, not cost. Similarly, other interviewees spoke of "our geographical distance from the rest of the world" (CEO R&D body, Interview 67, May 2015), Australia as "a small economy in the South Pacific" (Ministerial advisor, Interview 57, November 2013), and the difficulties for exports given "Australia is 20 million people sitting here hanging off the tip of Asia" (Public servant, Interview 68, June 2015). Such statements more or less explicitly located Australia as an Antipodean outpost of the imagined poles of commerce and culture in North America and Western Europe ("the rest of the world"). Although some interviewees spoke warmly of collaborations with Asian partners, or the superior examples of Asian countries' science and technology policies, in many characterisations Asia figured predominantly as the source of cheaper and increasingly highly educated competition. For many interviewees, representations of Australia as a commodity-dependent, "isolate[ed]" island-nation were central to understanding the challenges to which nanotechnology could respond – if only the "dumb politicians" would offer sufficient support.

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[30] As we have seen above, the view held by nanotechnology proponents that Australia's reliance on mining and commodities trade was a 'problem' was not universally shared, especially by political audiences.

Many interviewees made reference to the ongoing influence of Australia's 'cultural cringe' in shaping science-state relations. For example the co-director of CSIRO's Centre for Nanotechnology Vijoleta Braach-Maksvytis described the importance of bringing prestigious international nanotechnology advocates to Australia, such as Roco, to boost Australian researchers' status among both scientists and politicians (see Chapter 3): "I mean the classic Australian, you know 'it can't be really important' or 'we can't be any good' unless you get the outside view" (Vijoleta Braach-Maksvytis, Interview June 2015). Braach-Maksvytis described Australian nano-science as "very much up there with the world players", but as under-recognised because of a "classic Australian" tendency to devalue our own achievements. Yet interviewees themselves employed storylines that foregrounded Australian deficiency. In addition to bemoaning Australian scientists' failure to innovate or to commercialise their research, a common criticism was of risk aversion in the funding, conduct and oversight of Australian science. In this way, many researchers themselves located innovation and innovative behaviour *elsewhere*, particularly in the US.[31] Similarly, interviewees extolled state support for science and technology development as taking place *elsewhere*, but not in Australia. A recurring complaint among academic and industry interviewees was that the Australian government did not value the economic contribution of science and technology. One interviewee compared the view within the Australian government unfavourably with Asian and European countries: "who actually I think properly and genuinely believe that science is important, but in Australia there's this geek sort of view of science that it's not really going to do much for us... it's all anti-learning, anti-academic, not good" (Technical scientist, Interview 44, December 2013). Another suggested bluntly that science was seen as the "pursuit of losers" (Industry member, Interview 63, April 205). In this way, interviewees argued that a corrosive anti-intellectualism and lack of state support for science and technology was itself a product of Australia's postcolonial condition.

Storylines depicting the unique lack of interest in science and technology of Australia's "dumb politicians" were challenged by one interviewee. They observed that: "I think if you ask most scientists, they will claim that there's very little political interest here compared with other countries. I'd be very nervous about making that claim. I suspect in most countries, science and research is… a somewhat peripheral topic politically" (Ministerial advisor, Interview 46,

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[31] One senior scientist argued: "we're afraid of failure. You know, in America, you start a company, you fail, you failed in one company, the investors are willing to really put money into you. Because you know what not to do... But whereas in Australia, you know if somebody starts a company and then fails, you know, nobody wants to touch them with a barge pole" (Technical scientist, Interview 31, November 2013).

December 2015). Rather than interrogate the material referents of the storyline of Australian politicians' disinterest in science, I observe that it is widespread and influential within the Australian research sector. Even as nanotechnology proponents posited nanotechnology as the 'solution' to the 'problems' of Australia's postcolonial condition, their own storylines reinforced tropes of Australian deficiency.

4.3.6 A limited role for government

Despite caveats on the extent to which the PMSEIC working group made their promissory claims "sound credible", their presentation led directly to Australia's first dedicated policy office for nanotechnology and a national strategy to oversee the field (DITR 2006). Ironically, the federal budget surplus associated with the mining boom appears likely to have favourably influenced the decision to develop the NNS, given its lack of a "popular, political imperative" (Ministerial advisor, Interview 46, Written comments, July 2016). The government took two years to announce the NNS, its AUD$21.5 million funding over four years was modest,[32] and its remit was constrained by 'market failure' justifications, focusing on metrology, risk regulation, and providing "balanced advice to the community" (Macfarlane 2007, unpaged). The design and implementation of national nanotechnology policy is investigated in detail in Chapter 5. The salient point here is that nanotechnology proponents on the PMSEIC working group and beyond were disappointed in this outcome, which they compared unfavourably with the more prominent role assumed by the state in nanotechnology development in the US. Interviewees attributed the Australian government's unwillingness to play an active role as nanotechnology sponsor not to the field's uncertain commercial prospects,[33] or to the limits of their own communication capabilities, but to the disinterest of political actors in fostering the emergence of new, 'knowledge-based' industries. In other words, Australian proponents felt that their promissory claims for future nanotechnology-based prosperity were not taken seriously by political audiences, in part large because of the implied – and rejected – role for the state in conjuring this future into being.

[32] This was for policy activities additional to the ongoing provision of research funding through competitive grants and institutional budget allocations (cf. Senate Standing Committee on Economics 2008, E94).

[33] For example one government-commissioned report suggested that nanotechnology was a solution in search of a problem which Australian business may not be interested in (Ernst & Young 2002). The same characterisation was made by two Australian stakeholders in McGrail's (2011) study.

4.4 Conclusion

This chapter has compared the use of discursive and ideational resources by nanotechnology proponents in the US and in Australia as they sought to make internationally circulating promissory claims “sound credible” to their respective political audiences. Adding to previous work in the sociology of expectations, I have explored efforts to achieve credibility for the *sociopolitical* underpinnings of promissory claims, in particular the mooted role for the state as chief nanotechnology sponsor. US proponents benefited by appealing to an already widely shared imaginary in which government-backed technology development is central to the (imperilled) nation’s strength. Conversely, Australian proponents encountered an ‘absent imaginary’ regarding technology’s importance to the nation and government’s role in its development, and struggled to make their own claims “sound credible”.

In the series of hearings that preceded the codification of US support for the NNI in law, proponents leveraged storylines in which US wealth, health and security was underpinned by its technological “leadership”. By mobilising a sociotechnical imaginary in which (state-supported) technology is central to the (imperilled) nation’s strength, nanotechnology proponents made their promissory claims “sound credible”, even as these claims were not understood to be literally true. Long-standing storylines regarding the state’s obligation to fund high-risk, long-term research, and collective ‘memories’ of the technological triumphs this had supported, were important resources for nanotechnology proponents. Their use obscured recent partisan conflicts regarding the adequacy of support for basic science and the proper limits to government involvement in technology development, while glossing over the disappointments of the dot-com bust. At the same time, nanotechnology’s interpretative flexibility remained an asset, enabling various witnesses to emphasise the field’s importance for industrial competitiveness, homeland security or scientific discovery, and to build political consensus for, and to forestall political objections to, the state’s role in its sponsorship.

At the PMSEIC meeting of 11 March 2005, collectively shared storylines were not available to recall ‘memories’ of technological achievement supported by the state, and without them, imaginaries of nanotechnology-driven prosperity underwritten by government investment were less convincing. Faced with an ‘absent imaginary’ regarding technology’s contribution to the nation’s strength and standing, proponents struggled to achieve emplaced meaning for internationally circulating predictions of nanotechnology’s projected economic value. Without demonstration of nanotechnology’s relevance to established Australian industries, economic promissory claims for nanotechnology were dismissed as "a bunch of words". Storylines in wide circulation among both politicians and the research sector which emphasised Australian deficiency did not aid proponents' efforts.

The findings of this chapter differ from those of earlier work in the US regulatory sphere that emphasise a constitutional commitment to the separation of science and the state. Jasanoff has observed that in order to perform legitimating functions for politics and to "close, or foreclose, political debates" on science and technology policy, "science itself has to stand apart from the contaminating touch of politics, and there is no dearth of actors prepared to do the boundary work that makes this separation seem real" (2005a, 288). That is, despite the implicit assumption (common to other STS scholars) that states will adopt pro-technology policies on instrumental grounds, in the context of *regulatory* policy, Jasanoff identifies a "peculiarly American" "enveloping myth" that science is, or should be, neutral, objective and socially disengaged, "which persists in spite of scepticism toward most individuals' contributions to it" (1996, 400; see also Jasanoff 2005a, 2011c). In the context of *innovation* policy I find a different set of assumed social relations. Researchers, government officials and industry spokespeople in the hearings investigated here all assumed the interlocking and mutually dependent relationship between publicly funded science, US firms' competitive prospects, and the national interest. Moreover, rather than an unequivocal embrace of "a high-risk, free-market frontier ideology" (Sunder Rajan 2006, 113), these actors expressed their expectations that the state would provide the budgetary, legal and policy environment within which 'high risk' would be reduced to 'acceptable' and 'attractive' risk, and the 'free market' structured on terms favourable to US firms. These expressed expectations regarding the interdependent nature of commerce and science and the responsibility of the state to support the nation's 'innovators' were highly valuable to US proponents in making their promissory claims "sound credible", and a resource unavailable to their Australian counterparts.

Following a brief conclusion of the findings of Part A of this thesis, I turn next to Part B, where I offer a more detailed investigation of how the structural features and phenomena identified in previous chapters were articulated in the implementation of Australian nanotechnology policy.

Part A Conclusion

The first three chapters of this thesis have clarified the circumstances in which nanotechnology became the object for a major new innovation policy in the United States (US), and a research priority and object for a somewhat more modest policy in Australia. The creation of these policies was not the consequence of the field's 'inevitable' momentum, high-level political direction, or the demands of capital. Far from being pre-determined either by nanotechnology's material claims, or by sociopolitical dynamics (or, crudely put, by 'internalist' or 'externalist' dynamics, see Shapin 1992), policy designed to foster nanotechnology development was itself situated and conditional. While conditioned by wider political and economic circumstances and given impetus by the growing 'buzz' surrounding nanoscience, state support for nanotechnology was in each country a context-specific achievement in which intermediaries acting between the spheres of science, policy and politics (cf. Meyer and Kearnes 2013) played an important role. Intermediaries were influential in shaping research agendas and rationales for research funding, and – at least to some extent – in bringing into being the conditions that would favour nanotechnology's prioritisation. A key focus of their efforts was promissory work that enacted (cf. Law 2004; Mol 2002) nanotechnology as central to future economic and geopolitical interests. There was little industry advocacy for nanotechnology policy in either country. Yet, revealing their internalisation of the need to demonstrate 'market logics' in science policy and the 'interpretative flexibility' (Pinch and Bijker 1984) of such logics, intermediaries based their appeals for new research funding on claims for the field's future economic impact. The ambivalence with which Australian political actors responded to these promissory claims highlights the importance of credibility dynamics within policy makers' and politicians' own engagement with science (cf. Wynne 1992; see also Nowotny 2014). Relatedly, the divergent responses of political audiences in Australia and the US to imaginaries of nanotechnology-enabled prosperity made possible through state support underscores the advantage that world-making enjoys when it affirms already existing sociotechnical imaginaries (Jasanoff 2015b). These chapters challenge the assumed interest of the state in fostering new technology development, and illustrate the messiness and unevenness of the state's technopositivity in practice.

Proponents worked hard to constitute the policy object 'nanotechnology', enacting a highly heterogeneous field of largely non-commercial research as a powerful and economically compelling new technology. Proponents' constitutive work responded to the interactional imperatives of the policy environment in which it was located. For example, in the US such work was shaped by proponents' wish to simultaneously appeal to enthusiasm for technological innovation, while navigating epistemic and normative arguments regarding the proper autonomy of both science and markets from government. 'Nanotechnology' was therefore carefully constituted to permit both the assertion, and denial, of its industrial relevance. This leads me to a somewhat surprising conclusion, as I observe that 'interactional co-production' was present at the heart of 'constitutive co-production' (on the two strands see Jasanoff 2004; for an elaboration of this argument see Part A Introduction). That is, efforts to resolve controversies associated with "competing natural and social orders" were themselves present in "the creation of fundamental ordering devices and categories" (cf. Jasanoff 2004, 274). The consequences of this are significant: to understand the form in which scientific knowledge and objects are produced, and with them metaphysical claims regarding boundaries between 'science' or 'nature' and 'society' (cf. Calvert 2010), we must look to their location in and responsiveness to broader political, economic and epistemic struggles.

The diverse social and material practices through which policymaking was accomplished, and in which nanotechnology's identity and meaning were enacted, were performative. The 'realities' enacted by these practices shaped innovation agendas, influenced processes of research prioritisation, underpinned the creation of new policy apparatuses, and contributed to reshaping the terms on which the value of publicly funded research was judged. Such outcomes also rendered the enactments themselves somewhat obdurate, as did the international proliferation of nanotechnology discourse, research and policy making they prompted, which in turn renewed and boosted the 'reality' of nanotechnology's promise. That is, the effects these enactments produced were not simply ephemeral and "essentially coextensive with the practices that create[d] them" (cf. Woolgar and Lezaun 2015, 463), but also produced more far-reaching effects, illustrating how ontological politics (Mol 1999, 2002) may be both a site and a mechanism of co-production.

Key differences are apparent between the US and Australia in the identities and levels of commitment to nanotechnology of the intermediaries who contributed to its elevation as a policy object, with implications for the stability of the policy settlements that emerged. The US effort was led by "working level" program managers of the National Science Foundation and Department of Defense who were personally and passionately dedicated to advancing nanotechnology, and who obtained the backing of influential White House staff. The NNI was the product not only of fortuitous circumstances and chance, but also years of their preparation (Chapter 2). Once established as a Presidential initiative by Bill Clinton, the NNI enjoyed high-level political support from the White House, the bipartisan enthusiasm of key Congresspeople, and endorsement from major US firms, although it still required dedicated work to nurture it through the early years of a new administration (Chapter 4). Conversely, the decision to include 'nanomaterials' among the 2002 Australian Research Council Priorities was strongly shaped by elite science-policy intermediaries, whose primary objective was not to promote nanotechnology, but rather to establish research priorities that would be seen by government to be commercially relevant, and so to safeguard their institutions' autonomy and future budgets (Chapter 3). In supporting nanotechnology, these intermediaries mobilised *apprehended* rather than *expressed* political preferences. Similarly, their judgments of the field's commercial relevance reflected its successful enactment in these terms by nanotechnology proponents, rather than any meaningful engagement by Australian industry. These dynamics help explain how, despite being nominated one of Australia's top four research priorities in 2002, nanotechnology subsequently struggled to gain high-level political attention and provision for dedicated policy (Chapter 4, see also Part B).

Debates surrounding the purpose, value and terms of state support for nanotechnology were a site at which imaginaries of the nation-state (cf. B. Anderson 2006 [1983]), technology's relevance to its future, and relations between science, the state, markets, and to a lesser extent wider publics, were contested and renegotiated. The divergence of interpretations in the US and in Australia of 'free market' commitments and their implications for the state's role in sponsoring technological innovation was particularly apparent. In the US, 'free market' objections to state support for applied science were historically associated with a belief that the private sector is best equipped to drive commercialisation, and with arguments that such funding would inappropriately compete with industry, distorting the market (on the self-interest of science-based industry in arguing for this post-war settlement, see Kleinman 1994, 1995). However, despite the sometimes dramatic partisan battles between 'developmentalists' and 'fiscal conservatives' (Weiss 2012; Chapter 2), and the "taboo" nature of industry policy (Keller and Block 2015, see also Part A Introduction), there was broadly expressed agreement that government should 'back the nation's innovators', including by funding 'high-risk' science, and by creating a policy environment designed to stimulate research commercialisation (Chapter 4). Despite discursive deference to 'free market' principles, I identify state support as a key component of the US imaginary of technology's centrality to (imperilled) national strength. By contrast, Australian nanotechnology proponents encountered an 'absent imaginary’ regarding technology’s importance to the nation-state and government’s role in its development (Chapter 4). Indeed, Australian politicians and policy makers took a comparatively sceptical view of science and technology’s economic relevance. In a competing interpretation of what ‘free market’ logics mean for science policy, political actors insisted that publicly funded researchers should themselves pursue commercially relevant science, to deliver a greater return on the research investment. This proved opportune for nanotechnology proponents when the field was made a research priority in 2002, despite mixed views regarding its commercial prospects (Chapter 3). However, subsequent appeals for government to play an active role in sponsoring its commercial development received a more ambivalent response (Chapter 4). The influence of the Australian government’s equivocal commitment to sponsoring new technology development, and the constraints associated with ‘market failure’ rationales on the design and implementation of Australian national nanotechnology policy, is explored in greater detail in Part B.

Part B: Implementing Australian nanotechnology policy

Part B Introduction

The first part of this thesis explored how particular fields of technoscience, and the 'prospective techno-futures' (N. Brown, et al. 2000) with which they are intertwined, capture the attention of policy makers. The second examines the specificity of the forms in which state support for such fields is subsequently expressed. Influential work in science and technology studies (STS) has conceptualised the reception of new technologies into states' "political and policy systems" as a window through which "the perplexities of governance in twenty-first century knowledge societies" may be illuminated (Jasanoff 2005a, 272). The framing of regulatory settings, the assessment of risk, and public debates regarding the meaning of new forms of innovation have been examined as key sites at which science and social order is co-produced (Jasanoff 2004), and political culture is itself reconstituted (Frickel and Moore 2006; Gottweis 1998; Jasanoff 2005a; Levidow and Carr 2010). This literature shows how governmental reasoning may be contested or affirmed by publics' responses to the products of technoscience and their regulation. It highlights also how arguments regarding the social value of new technologies may challenge the power relations they reflect and reproduce, conceptions of political accountability, and even aspects of national identity. And yet, despite the compelling insights of such work, it often posits the state's commitment to fostering certain forms of technological innovation as outside the "perplexities of governance". Policy makers' and politicians' sometimes qualified view of technoscience's relevance to projects of nation-building remains relatively under-studied by STS, as do the resistances and accommodations that occur as policy designed to promote new technology development encounters competing political imperatives and policy rationales, such as those associated with neo-liberalism (but on the latter see, for example, Block 2008; Block and Keller 2011; Levidow, et al. 2012).[1] In illuminating such tensions in Australian nanotechnology policy making, Part B probes what they mean for our analysis of co-production in science policy itself, and for the frequently assumed relationship between regulatory policy and the pursuit of innovation objectives.

Given that the Australian government was ambivalent towards sponsoring technological innovation, as we saw in Part A, Part B asks how such ambivalence was articulated in the design and implementation of national nanotechnology policy and in policy responses to nano-product regulatory debates, which I investigate using the example of nano-sunscreens. Just as Part A showed how nanotechnology research benefited from the application of (variably

[1] For my treatment of neo-liberalism see Chapter 1.

interpreted) ‘market logics’ to research policy, Part B probes how the extension of ‘free market’ thinking to the operations of the state constrained subsequent support for the nascent sector’s commercialisation. In so doing, Part B addresses all the research questions asked by this thesis but focuses on the third, asking how ‘market failure’ policy rationales (Dodgson, et al. 2011; Marsh and Edwards 2008) and ‘scientistic’ commitments (Doubleday and Wynne 2011; Kleinman 2005; Wynne 2006; see discussion below) shaped the architecture of national nanotechnology policy. Consonant with the central thesis argument, Part B shows that the form taken by Australian national nanotechnology policy, and the policy object ‘nanotechnology’ within, were situated achievements (cf. Balmer, et al. 2016), in whose production science-policy intermediaries (cf. Meyer and Kearnes 2013) played an influential role.

In Part B I draw on the conceptual tools and theorisations I elaborated in Part A, including the co-production of science-state relations and the historically and politically situated character of Australian science policy settlements and the rationalities and practices that underpin them (cf. Haraway 1988, 1991). I continue also my analysis of ‘ontological politics’ (Mol 1999, 2002) as a site and a mechanism of co-production. I show how proponents enacted versions of nanotechnology that were shaped by their institutional contexts, but also responsive to epistemic and political conflicts in the wider policy environment. In this brief introduction to Part B I begin by outlining the limited attention the relationship between innovation and regulatory policy has received from STS, before introducing some additional concepts I employ in Chapters 5 and 6: that of scientism and its relationship to public and political meanings of science and technology policy.

The neglected corner

Science and technology governance has been approached by STS as a site at which the “three-cornered” relationship between science, society and the state is reconfigured (Jasanoff 2005a). Previous studies have investigated the diverse ways in which science attempts to secure social and political licence in the context of its shifting ‘social contract’ (Balmer, et al. 2016; Benjamin 2013; Calvert 2013; Kearnes and Wienroth 2011a; Thompson 2013), taking varied stances on the application of concepts such as ‘responsibility’ within innovation policy (Guston 2015; Stirling 2016). Policy responses to environment, health and safety (EHS) risks, and public debates surrounding them, have also been a particular focus of STS enquiry (Callon, et al.

2009; Irwin and Wynne 1996; Jasanoff 1990; Stirling 2008a, b; Suryanarayanan and Kleinman 2013; Szerszynski, et al. 1996; Whatmore 2009; Wynne 1982). Such studies probe responses to uncertainty and relations between democracy and expertise, providing rich insights into the 'politics of public knowledge'. They show how framing certain questions as 'scientific' or 'technical' rather than 'political' can perform epistemic and political ordering, 'closing down' (Stirling 2008a) the terms of public policy debates, privileging the role within them for scientific experts over wider publics (Callon, et al. 2009; Doubleday and Wynne 2011; Gottweis 1998; Wynne 2002), and ultimately reducing the space for sociopolitical dissensus and critique (Barry 2001; Kleinman 2005; Moore, et al. 2011), although always incompletely (Kinchy, et al. 2008; J. McCarthy 2013). However, whereas the political mobilisation of science for all manner of ends has been well documented, what has been less considered are the complex ways in which the politics of knowledge plays out *within* the architectures of research support and in science and technology policy. I suggest that this is a 'neglected corner' within STS inquiry.

The focus of much STS work on public knowledge controversies[2] may implicitly frame epistemic and political conflicts as external to the state's own development of technology policy. And yet the epistemic authority of science is rarely uncontested within policy making, and scientific findings do not necessarily serve political imperatives. Similarly, while indisputably influential, the key tenets of 'technological progressivism' (Kleinman 2005; see discussion below) are not uniformly accepted. As Part B's investigation makes clear, support for technoscience routinely encounters competing political exigencies, alternate forms of moral and political authority (cf. Callon, et al. 2009; Chilvers and Kearnes 2016), and the dictums of 'free market' commitments.[3] In the context of policy designed to promote new technology development, frictions recur between 'developmentalist' aspirations for the state to play an active role in techno-industrial transformation (Thurbon 2012; Weiss 2012), and arguments against interventions that could distort 'the market' or act as a form of unaccountable corporate welfare. Questions over which science holds assumed 'sovereignty' (cf. Wynne 2014) in such debates are marginalised: they sit in uneasy relation to arguments

[2] Of course, as discussed in Chapter 1, science and technology studies (STS) has also paid significant attention to knowledge controversies within scientific communities.

[3] The heterogeneity of policy making logics and science's subordinate status within them is observed by one interviewee: "a politician and her or his staff would, you know, they'd want the economic viewpoint, and then they'd want the political viewpoint, and then they'd want the scientific viewpoint – and if they are going to go to the effort of finding a scientific viewpoint, in most cases it would often be an after-thought, like 'see what science says'... I just kind of raced around and found the best argument that I could [to support decisions that had already been taken], and generally it would be an economic argument that came to our attention first" (Ministerial advisor, Interview 51, February 2014).

regarding the prerogatives of the state compared to those of the market. The limited attention of STS to such frictions may be related to its foregrounding of *risk regulation* as the vehicle through which states pursue innovation objectives, largely eliding the heated debates that have surrounded *industry policy*[4] in all its varied forms (but for exceptions to this claim see, for example, Frickel and Moore, 2006; Vallas, et al. 2011).[5] In Part B I use the design and implementation of national nanotechnology policy and political and policy responses to nano-sunscreen regulatory debates to explore the politics of knowledge within government, the tensions between competing rationales for policy making, and relations between regulatory and innovation policy.

Scientism, public and political meanings

To help me explore the design and implementation of Australian national nanotechnology policy and its focus on regulatory measures, the approach to nanotechnology as a 'scientific' rather than a 'political' policy object, and the 'scientific' terms in which political and policy responses to nano-sunscreens regulatory debates were articulated, I employ the concept of 'scientism'. Scientism is a discourse that "has a long and varied history" (Kleinman 2005, 3), but in this thesis I draw particularly on its treatment by Daniel Kleinman and Brian Wynne. I highlight three key, inter-related and occasionally contradictory dimensions of scientism: its denial of normativity within technoscience and related policy; its denial of active social work associated with technology's expansion; and its presumption of science as the natural arbiter of policy meaning. I show that the influence of scientism affects not only the production of *public meanings* (cf. Doubleday and Wynne 2011; Wynne 2006, 2014) within science and technology policy, but also that of *political meanings* (see below).

Scientism denies the normative dimensions of science and the technological projects promoted in its name. It reflects the "culturally entrenched premise" (Wynne 2006, 214) of the separability of facts and values, the superiority of the former in "credibility and cognitive authority", and its natural possession by scientists (Kleinman 2005, 4). Scientism treats scientific knowledge as 'true' knowledge – neutral and objective. It denies subjectivity and the presence of political and value judgments not only within science itself, but also in the projects

[4] My treatment of industry policy is elaborated in Chapter 5.

[5] Other exceptions, not strictly in STS but at the intersection of sociology and innovation studies, include work by Fred Block and Matthew Keller (Block 2008; Block and Keller 2011; Keller and Block 2015) and Ben Martin and Paul Nightingale (2000).

justified in its name. As Wynne (2014, 61) observes: "technological innovation mega-programmes" in nuclear energy, the military, chemicals, artificial intelligence and biotechnology have been justified by trading on the authority of "modestly self-sceptical, utterly disinterested [scientific] research", despite their "normative social interventions, promises and ambition". Presenting government support for particular technological projects or programs as 'science-based' at once leverages the epistemic authority of science, denies the value-laden political judgments and the choices between alternatives that are taken at each juncture of policy making, and obscures the social relations, and political and economic interests that are embedded in them (Stirling 2009a, 2012, 2014; Winner 1986). This supports the claim that the "basic meaning" of debates surrounding technological projects justified in the name of science is indeed scientific, rather than also pertaining to contestable questions of purpose, values, alternatives and trust (Wynne 2006, 214; see also Doubleday and Wynne 2011), a point to which I return below.

Scientism denies social agency, effort or choice in the pursuit of particular projects of technoscience. It depicts scientists as trained experts "unearthing" (Kleinman 2005) or "dis-covering" (Bijker, et al. 2009) already existing facts through their empirical research, and the 'diffusion' of scientific knowledge into society as frictionless (Latour 1987). Extended to programs of technoscience, such representations have underpinned policymakers' attribution of "self-unfolding deterministic power to 'science'", imputing that state support for nuclear energy, biotechnology and other programs was a matter "of alleged necessity, not choice" (Wynne 2014, 61). Imbricated in such "invocations of an apparently unitary and objective 'way forward'" (Stirling 2009a, 4) are deeply normative assumptions regarding the inevitability and desirability of (particular kinds of) technological change. Kleinman (2005, 5) describes the conceptualisation of "technology as self-propelling, moving forward along a singular path without human intervention", and "always for the good" as 'technological progressivism'. That is, science and technology are assumed to both *progress* (develop) autonomously, and to be inherently *progressive* (socially beneficial). Whereas he distinguishes this from scientism, Kleinman identifies both discourses as influential features of the discursive landscape that limit critical reflection on and debate regarding science and technology.

The final dimension of scientism I wish to highlight for the purposes of Part B's investigation is the "presumption, projected onto society, that science has natural sovereignty over public meanings" (Wynne 2014, 61). In work with Robert Doubleday, Wynne elaborates this concept:

> "... *as scientific advice took on a greater role in post Second World War public policy, it became by default not only an* informant *of public policy (its classical role), but also a powerful* cultural *agent, as arbiter of* public meanings*. This extension of science into* scientism *was not a consequence of deliberate design but rather of mutual accommodation and mutual reinforcement between policy and science as institutionalized epistemic (and hermeneutic) authority. Thus science assumed the role of authoritatively providing the* meaning *of many public issues, which came to be defined as 'risk issues' or even 'scientific issues,' obscuring other key dimensions*" (Doubleday and Wynne 2011, 239-40, emphases in original).

I differ from Doubleday and Wynne in recognising that policy makers sometimes make deliberate efforts to reduce public policy debates to scientistic terms, for example as explored in Chapter 6. Nonetheless, their central observation is an important one: the expansion of science's role to that of the author and arbiter of public policy meanings has had far-reaching effects. Given scientistic assumptions of technoscience's objectivity, inevitability and social benefit, scientifically appraised EHS risks have commonly been framed as the only 'legitimate' site at which publics may challenge new technology development (Gottweis 1998; Jasanoff 2005a; Kleinman 2005; Wynne 2002).[6] Scientistic and 'free market' discourse has also been deployed by technoscience proponents to "remove" technoscientific programs and commercial applications "further from political debate and state intervention" (Kinchy, et al. 2008, 147; see also Kinchy and Kleinman 2003; Moore, et al. 2011). And, in a parallel move that I explore in Part B of this thesis, scientism has exerted a powerful reductive influence on processes of policy development and appraisal *internal to government*.

In Part B, rather than investigating how scientistic framing of technology policy reduces its *public meanings*, I investigate its effect on *political meanings* – that is, those held by political actors and policy makers. I explore the tensions between scientistic frames for nanotechnology policy and the ostensibly developmentalist objectives of government, the depoliticising effects of such framing in policy appraisal, and the recurrence of sociopolitical concerns internally to government, in its relations with nanotechnology proponents, and in proliferating risk debates, including those surrounding nano-sunscreens. I find that despite the "hermeneutic

[6] Nonetheless, efforts to restrict policy debates to questions of risk have often proved unsuccessful (eg see Callon, et al. 2009). Risk debates have not only proved a 'condensation point' (Kearnes, et al. 2006b) for broader sociopolitical concerns, but have in many cases propelled technoscience controversies and made them more intractable.

imperialism” of scientism (Wynne 2014, 62), its achievement was neither hegemonic, nor entirely compatible with either ‘free market’ commitments or the developmentalist appeals of nanotechnology proponents.

Chapter 5: Tensions in Australian nanotechnology policy

As I outlined in Chapter 4, the Prime Minister's Science, Engineering and Innovation Council's (PMSEIC) nanotechnology working group was successful in 2005 in obtaining a commitment from government to develop dedicated nanotechnology policy. However, it was 2007 before such policy was released. Even then, there was a striking disjuncture between the working group's appeals to government to harness the "global nanotechnology revolution" (PMSEIC 2005a, 4) and the form and focus of subsequent policy. The National Nanotechnology Strategy (NNS, 2007-09) launched by the conservative Coalition government, and the National Enabling Technologies Strategy (NETS, 2009-13) developed by its Labor successor, were narrow in scope and modestly funded: both focused on metrology, risk regulation and public awareness activities. In this chapter I investigate the design and implementation of Australian nanotechnology policy, and the influence on it of 'market failure' policy rationales (cf. Dodgson, et al. 2011; Marsh and Edwards 2008)[1] and scientistic commitments (cf. Doubleday and Wynne 2011; Kleinman 2005; Wynne 2006).[2] I explore the policy emphasis on regulatory measures as the means to pursue innovation objectives, the enactment (cf. Law 2004; Mol 2002) within such policy of nanotechnology as a 'scientific' rather than a 'political' policy object (cf. Jasanoff 1990), and the recurrence of 'political' questions associated with the state's sponsorship of the nascent field. Concordant with my central thesis argument, this chapter shows that the form in which state support for nanotechnology was articulated, and the policy object 'nanotechnology' itself, were situated achievements (cf. Balmer, et al. 2016), conditioned by structural and ideational features, but reflecting also the work of intermediaries acting between science, policy and politics (cf. Meyer and Kearnes 2013).

Policy makers' reduction of the sociotechnical relations and normative judgments associated with technoscientific projects to questions of science and science-based regulation has been a long-standing subject of science and technology studies (STS) inquiry (Part B Introduction). This rich body of STS work has shown that the enactment of public policy debates as 'scientific' or technical in character rather than sociopolitical may 'close down' (Stirling 2008a) the terms on which they are conducted, and privilege the role within them for technical experts (Barry 2001; Callon, et al. 2009; Gottweis 1998; Jasanoff 2005a; Kleinman 2005; Moore, et al. 2011). Yet the implications of scientistic framing for the relations of actors *within* government, and more broadly, for states' capacity to develop policy to foster the growth of favoured new

[1] For an explanation of 'market failure' policy rationales see Chapter 1.
[2] For my treatment of scientism see Part B Introduction.

technologies, have received considerably less attention. In this chapter, rather than investigating nanotechnology policy's *public meanings* (cf. Doubleday and Wynne 2011; Wynne 2006, 2014, 2016), I investigate the influence of scientism on its *political meanings* – that is, the meanings nanotechnology policy held for politicians, their advisors, and bureaucrats within government.

This chapter asks how, once nanotechnology proponents had successfully lobbied the Australian government for dedicated policy to support development of the nascent field, we can account for the design and implementation of the policy that eventuated. In particular, it explores the apparent disjuncture between proponents' appeals for government to play an active role in promoting the development of a 'revolutionary' new field, and successive governments' policy focus on metrology, environment, health and safety (EHS) risk regulation, and public awareness initiatives. This policy architecture is found to be a product of Australia's hesitant approach to innovation policy, and the scepticism of many political actors – in part based on 'free market' thinking – towards an active role for the state in sponsoring technological innovation. 'Market failure' policy rationales amplified the scientistic framing of nanotechnology policy, leading many government actors to assume that 'science' would assume "natural sovereignty" in policy appraisal (cf. Wynne 2014, 61). Nonetheless, tensions recurred between scientistic, 'free market' and 'developmentalist' (cf. Thurbon 2012; Weiss 2012) policy logics, and with them sociopolitical questions regarding the purpose, justification and value of nanotechnology governance. In illuminating and exploring these tensions, this chapter continues responding to the broader research question of how late-modern capitalist states understand, justify and prosecute their role in creating, fostering and overseeing new technoscientific fields and industries.

I begin the chapter by providing a brief introduction to the disputes that have shaped Australian industry and innovation policy in recent decades, tracing the ascendance of 'free market' thinking within public policy. I then offer an overview of political and policy responses to nanotechnology under the Coalition government led by John Howard, and its successor Labor government led by Kevin Rudd, Julia Gillard and again Kevin Rudd. In the final sections of the chapter I trace the depoliticising influence within government of nanotechnology's enactment as a 'scientific' rather than a 'political' policy object, before showing how sociopolitical questions recurred internally to government, and in its relations with nanotechnology proponents. My analysis is based on archival and observational work, and interviews as described in Chapter 1.

5.1 The contested role of the state

High-level political engagement in Australian national nanotechnology policy making was limited, reflecting both the ambivalent reception by political actors of promissory claims for the field (Chapter 4), and wider disagreement regarding the state's role in technological innovation. *Backing Australia's Ability* (BAA; Commonwealth of Australia 2001) and the subsequent BAA II had taken a 'science push' approach to innovation by funding research seen to be commercially relevant (Chapter 3; see also Marsh and Edwards 2008, 2009). Indeed, nanotechnology *research* was a beneficiary of what one critic described archly as "the 'tail' (publicly funded R&D)... being expected to wag the 'dog' (the innovation capabilities of Australia's business and industry)" (Craig 2004, unpaged). In 2008 alone AUD$170 million[3] was allocated to nanotechnology by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Research Council (ARC), and various government-backed science bodies (Senate Standing Committee on Economics 2008, E91). Yet as proponents lobbied for a coordinated national nanotechnology strategy that would go beyond providing research funding to also proactively "support and strengthen Australia's fledgling nanotechnology industry" (PMSEIC 2005a, 38), they met with less success. In this section I offer a brief summary of the tensions plaguing Australian industry and innovation policy, by which nanotechnology policy was shaped, and to which it in time succumbed (see also Part A Introduction).

5.1.1 The ascendance of 'free market' rationales for public policy

Following their introduction by Labor "in a soft form" in 1975, Michael Pusey (2003, 8) observes that "economic rationalist", "free market" or "neo-liberal" policy settings[4] have enjoyed broad support within both major Australian political parties.[5] Pusey (1991, 2003)

[3] Unless specified otherwise, all figures in this chapter are for Australian dollars. This funding was largely allocated in a devolved process over which the federal government did not exert direct control.
[4] Michael Pusey (2003, 8) suggests that "all the[se] terms mean the same"; for a more nuanced view see Kean Birch (2015). For my treatment of neo-liberalism see Chapter 1.
[5] As occurred internationally in this period, policy stances hostile to industry policy and supportive of limited government spending, privatisation and deregulation were given local impetus by thinks tanks whose origins can be traced to the Mont Pèlerin Society (Mendes 2003).

argues that the 1980s marked a sharp ideological shift in government as senior politicians and bureaucrats – especially in the central agencies of Treasury and Finance[6] – rejected long-standing support for "nation building" programs in which government played a key role in fostering development and economic activity,[7] and embraced "economic rationalist" commitments that were hostile to any such active role for the state. This hostility extended to efforts to promote techno-industrial transformation, exerting a constraining influence on subsequent decades' research and innovation policies.[8] Nevertheless, the hegemony of the 'neo-liberal turn' and its influence in Australian politics has been contested by Elizabeth Thurbon (2012). She emphasises the strong role that political pragmatism and opportunism has played in industry and innovation policy commitments and their jettison under both Coalition and Labor governments. Thurbon points also to the competing, if often subordinate, presence of developmental tendencies (see also Conley and van Acker 2011) and the re-emergence of developmental programs under Rudd particularly associated with the global financial crisis (GFC; see also Wanna 2011).

These ongoing disputes regarding the proper limits to the state's role in shaping or directing economic activity have plagued Australian industry and innovation policy. Governments led by both major parties have largely eschewed strategic interventionist measures to nurture new industries' development. Indeed, much of Australia's political elite regard industry and innovation policy as contravening market imperatives, and the industry department itself as vulnerable to capture by its "client" groups (Pusey 1991). This view is particularly pronounced in Treasury, an agency that has vetoed even initiatives that enjoyed high-level political support, such as the 'Innovate Australia' program championed by Labor Prime Minister Paul Keating (Watson 2002, 670). In this light, the removal of tariffs coupled with the *ad hoc* allocation of financial assistance to struggling sectors – or those that were not struggling but nonetheless exerted sufficient political power, for example in the minerals and resources

[6] On the influence of Treasury's 'free market' commitments on government decision making, and occasional struggles between Cabinet Ministers and Treasury officials, see John Wanna (2011).

[7] A more critical view of this earlier era of "statist developmentalism" is offered by Ken Walker (1999). Walker decries the violent treatment of Indigenous Australians and the ecological destruction of 'development' efforts that were driven by British imperial ambition.

[8] In contrast to any position of 'techno-nationalism' (cf. Edgerton 2007), the central agencies have privileged the role for the market in technological innovation and the quest for efficiency in government's science policy. This is illustrated in a Ministerial advisor's observation that: "there are plenty of people in the policy environment, and particularly in the central agencies from Finance to Treasury, who really think we should just be free-riding on large research centres like the US and Germany, and adopting and adapting technologies that are developed elsewhere. That is not an unusual view" (Ministerial advisor, Interview 45, November 2013).

sector – has driven industry policy from the late 1980s.[9,10] Coupled with ideological objections to industry policy, this approach has attracted additional criticism on more pragmatic grounds. Analysts have observed that: "The mishmash of initiatives masquerading as policy means that industry policy continues to be associated with quasi-protectionist political interventions designed to shore up electoral support rather than future prosperity" (Conley and van Acker 2011, 504; see also Hampson 2012). In summary, approaches to Australian industry policy are characterised by the political mobilisation of market liberalisation rhetoric, even as overlapping and inconsistent tendencies are evident in practice.[11]

The scepticism evinced by many Australian political actors towards interventionist industry and innovation policy, and the dominance of 'free market' commitments in public policy rationales, has led to the ascendance of 'science push/ market failure' framings for innovation policy. Mark Dodgson and colleagues observe that despite growing recognition of the merits of systems-based approaches to innovation policy: "the predominant logic behind policy choices still remains one of addressing market failure, and the primary focus of policy attention continues to be science and research rather than demand-led approaches" (Dodgson, et al. 2011, 1145; see also Marsh and Edwards 2008, 2009). That is, government's role in sponsoring technological innovation is understood narrowly: funding research ('science push') and responding to instances of 'market failure' in areas such as EHS regulation, metrological work and standards development, and awareness activities to overcome 'information asymmetries'.

5.1.2 Affinities between 'scientistic' and 'free market' policy rationales

Before tracing the influence of 'market failure' policy rationales on the design and implementation of Australian national nanotechnology policy, I make some brief comments on affinities, but also sites of friction, between scientism and 'free market' policy paradigms. Resonant of scientism's attribution of "self-unfolding deterministic power to 'science'" (Wynne

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[9] From Federation to the 1970s Australia's manufacturing industry was protected by high import tariffs. As tariffs have been reduced, a series of governments has provided financial assistance to adversely affected sectors, particularly the automotive, textiles, clothing and footwear industries. During the 2000s mining boom, some sectors exposed to the exceptionally high Australian dollar also received support (Bell 1992; Clibborn, et al. 2016; Conley and van Acker 2011).

[10] Additional to railway, road and port construction for use by the mining industry that is subsidised by state and federal governments, one estimate is that the industry receives from the federal government fuel subsidies and tax deductions for capital works, exploration and prospecting totalling $4.5 billion each year (Grudnoff 2013). The mining industry's political clout is widely credited for such generous treatment: its ability to influence federal governments' policy and electoral prospects is the subject of popular debate and scholarly work (Denniss 2016; G. Pearse 2009; R. Pearse 2015).

[11] An inconsistency that some argue is the hallmark of neoliberalism (eg see Ryan 2015).

2014, 61; see also Kleinman 2005), a ‘free market’ view of innovation accords market-driven technological change an inexorable power. Technological innovation is approached as a linear process (cf. Callon 2007; Godin 2006; Sarewitz 1996) in which, by funding research, “the state can influence the pace but not the direction of technological change” (Marsh and Edwards 2008, 10; see also Dodgson, et al. 2011; cf. Stirling 2009a, 2010a). Scientism assumes technoscience’s delivery of social and economic benefit without active work to shape its path. Similarly, a ‘free market’ view of innovation assumes outcomes achieved by the ‘free market’ to be axiomatically optimal: government measures that would favour the development of particular sectors over others are derided as doomed efforts to ‘pick winners’ (on the origins of this terminology see B. Martin 2010) that will produce only distortionary effects in the economy. Earlier STS work has observed the synergistic effects of scientistic and ‘free market’ policy discourses, and their strategic mobilisation in regulatory debates to limit the terms on which publics may critique, or governments regulate, the products of technoscience (Kinchy, et al. 2008; Moore, et al. 2011; Swyngedouw 2010). Yet sympathetic study has also highlighted sites of friction between the two paradigms, including “the increasing experience of science’s subordination to neoliberal political-economic” rationalities (Wynne 2016, 99). In this chapter I explore both synergies and frictions between the ‘free market’, ‘developmentalist’ and scientistic logics that shaped political and policy responses to nanotechnology.

In the context of Australian national nanotechnology policy, scientistic framing offered a means for policy makers to pursue innovation goals while ostensibly meeting ‘free market’ commitments. Rather than nanotechnology policy explicitly supporting activities to boost industrial development, the epistemic authority and disinterestedness of ‘science’ was leveraged to justify policy interventions that were concomitantly cast as responding to ‘market failure’. This was despite government sponsorship of metrological work, risk regulation and public awareness activities being ultimately intended to promote the nascent sector’s commercial expansion (DIISRTE 2012c; see also Chapter 6). Such a strategy is not new; the use of 'market failure' arguments to legitimate state interventions whose purpose is to support new markets' creation has been described in earlier STS work (Levidow, et al. 2012). Nonetheless, it illuminates the contortions in which policy making engaged as it attempted to rationalise state support for an area of technoscience singled out for strategic attention with dominant ‘free market’ commitments.

Yet even as scientistic policy framing supported the industry department's efforts to create an "optimal operating environment" to foster nanotechnology's expansion (DIISRTE 2012c, 238), it presented a barrier to developmentalist appeals for the state to play a more active role in the nascent sector's development. As discussed above, scientistic policy framing has often been seen as benefiting technoscience proponents by reducing the terms on which their projects may be constrained by government. However, I find that the narrow framing of Australian nanotechnology policy worked against proponents' appeals for more concrete forms of industry support, capability building and market development (eg as made by Future Materials and Australian Nanotechnology Alliance 2009; Rankovic 2008). At the same time, I find that although 'free market' rationales amplified scientistic approaches to nanotechnology policy, these two policy logics also ultimately proved incommensurable: nanotechnology policy's 'scientific' meaning was eventually subordinated to a meaning produced by 'market' thinking. As we will see, in the wake of the GFC, and following the displacement of nanotechnology's few key political champions, the view that government had no proper role in sponsoring technological innovation, even through policy whose meaning was framed as 'scientific', contributed to the 2013 disbanding of Australia's dedicated nanotechnology policy apparatus. The following section explores the influence of 'market failure' rationales in shaping the development of national nanotechnology policy under both Coalition and Labor governments.

5.2 Australian national nanotechnology policy[12]

5.2.1 The National Nanotechnology Strategy (2007-09)

As a consequence of the March 2005 presentation to PMSEIC investigated in Chapter 4, the Coalition government decided to create a national strategy for nanotechnology. The $21.5 million, four-year policy was announced on 1 May 2007 as part of the government's *Industry Statement*. In a media release, Ian Macfarlane, Minister for Industry, Tourism and Resources, announced that the NNS would: "Establish a nano-particle measuring capability at the National Measurement Institute; address regulations and standards; and provide balanced advice to the community on nanotechnology" (Macfarlane 2007, unpaged). The Minister had already predicted the strategy's great success: "A national strategy will give the fledgling industry a co-

[12] As elsewhere in this thesis, this chapter focuses on national nanotechnology policy, that is, policy developed by the federal government rather than the states.

ordinated direction and set out the rules under which Australia supports the growth of the nano sector, it means business certainty and public support" (Macfarlane 2006, unpaged).

Macfarlane's reference to nanotechnology as an extant if "fledgling" *industry* is striking,[13] as is his stated belief that government funding for metrology, EHS regulation and public awareness activities would deliver "business certainty" in a sector whose commercialisation prospects were elsewhere judged at best uncertain (see Ernst & Young 2002). Rather than enacting nanotechnology as a nascent, even nebulous field of technoscience whose own ontological status and promissory claims were in doubt, Macfarlane's statements implied that "growth of the nano sector" was inevitable, contingent only on establishing clear "rules" for the field – understood here in terms of EHS regulation. Yet despite the Minister's reference to giving the "fledgling industry a coordinated direction", there was no subsequent effort to manage the public research investment or to develop an industry strategy. The Australian NanoBusiness Forum later described the NNS as "significantly lack[ing] in provision of industry support" and "silent" on measures to assist small businesses in commercialising nanotechnology, to promote its uptake by larger companies, or to assist Australian firms' access to international markets (Rankovic 2008, 6).

In the absence of high-level political support for nanotechnology, a Ministerial advisor described the NNS as "a little bit of a holding pattern":

> "*[it was] kind of a waste of time. I think it became one of those things where there were enough people banging on about it the government felt it had to do something, but it was never too sure what it should do or how big it should go... That could have been an area where they say 'actually this is this emerging new technology – we've got to do something* big *in this area', but they could never bring themselves to do something big, and even if they had they wouldn't have been clear on what they* should *do… I think it was just one of those things where they didn't need to do anything, it became a minor political issue, a very minor political issue, and at some point someone thought 'oh well we should do something so that we can say we've done something'… if it suddenly becomes important, because it's really taking off globally and we don't*

[13] This appears to reflect the political exigencies, jurisdiction and habits of the industry portfolio, and the experience of a minister accustomed to managing the resources and manufacturing sectors, rather than any belief that Australian nanotechnology was unusually commercially advanced. It underscores analysts' observation of "a lack of clarity and tensions between education, science and industry policy" in Australian innovation oversight (Dodgson, et al. 2011, 1149).

want to be left behind, then you've got a platform to start with" (Ministerial advisor, Interview 46, December 2015, emphases in original).

In this advisor's recollection, political logic played an influential role in the creation of the NNS. Amidst uncertainty regarding both nanotechnology and the proper role in its sponsorship of the state, the NNS emerges here as a bet-hedging initiative – the investment of a minimal amount by the Coalition government so that it could, in response to proponents "banging on about it", "say we've done something" and establish a "platform" in case stronger political opportunity or threat emerged.

The Howard government's support for the NNS responded to the lobbying of Australian nanotechnology advocates and to the growing numbers of national nanotechnology programs internationally (Chapters 3-4). It was influenced also by the emerging recognition of novel toxicological risks associated with nanomaterials (eg PMSEIC 2005a; RS/RAE 2004). Australian political actors were sensitive to such risks and their (perceived) perception by publics, given prior controversies surrounding asbestos and genetically engineered (GE) crops (see McGrail 2011). Yet in the context of ambivalence towards innovation policy and Macfarlane's personal focus on the resources and manufacturing sectors, the NNS received limited political attention. It is perhaps not surprising that the NNS was not announced until two years after the PMSEIC meeting at which it was proposed, and that detailed policy for nanotechnology was never produced by the Howard government.

5.2.2 The National Nanotechnology Strategy under Labor

In the days prior to the November 2007 election, the Labor party led by Kevin Rudd released a media statement titled *Innovation Future for Australian Industry*. Demonstrating the periodic use by Australian politicians of innovation policy as a modernist signalling device, Senator Kim Carr declared that: "In the 21st century, innovation policy is industry policy", and that if elected "Federal Labor will restore the key place of science and innovation in our community" (Carr 2007, unpaged; on the use of innovation policy as a signalling device in US politics see Chapter 2). In this way Labor sought to use a focus on science and innovation to differentiate itself from what it cast as the regressive tendencies of the Howard government. Nonetheless, this did not imply any commitment to nanotechnology policy. Indeed, another pre-election statement advised that a Rudd Labor government would save $11.9 million by terminating the NNS in July 2009, two years early (see Senate Standing Committee on Economics 2008).

The newly elected Rudd government released a 4-page implementation plan for the NNS in January 2008 (DIISR 2008). Yet its interest in developing further nanotechnology policy, beyond the ongoing commitment to fund research, was uncertain. At a Budget Estimates hearing in June 2008, Australian Greens Senator Christine Milne criticised the decision to terminate the NNS, citing both nanotechnology's anticipated transformative potential and nanomaterials' novel EHS risks. As Minister for Innovation, Industry, Science and Research, Carr reassured Milne that the $170 million *research* commitment was not in doubt, although a decision regarding the future of nanotechnology *policy* within the federal government would be informed by a review of the national innovation system (Senate Standing Committee on Economics 2008, E94). Nonetheless, in the month following these Budget Estimates, along with an assessment of Australia's regulatory response to nanotechnology (Ludlow, et al. 2007), Carr released a 2-page statement that established three "high level objectives" for nanotechnology policy: "1. protect the health and safety of humans and the environment; 2. foster informed community debate; and 3. achieve economic and social benefits from the responsible adoption of nanotechnology" (Australian Government 2008, 1).

The innovation review *Venturous Australia: Building Strength in Innovation* (Cutler 2008) was released in September 2008. The 224-page report made only brief mention of nanotechnology in a few paragraphs that addressed government's role in relation to "enabling technologies". In order to "facilitate favourable conditions for the development and use of new and emerging technologies" it advised that: "there is a role for government in: providing support where there are information asymmetries and large spillovers; providing the community with balanced and factual information; supporting the science and metrology essential to underpin effective regulation; and ensuring regulation supports the adoption of innovative services and products" (Cutler 2008, 93, 92). That is, similar to the Coalition's earlier nanotechnology statements, the review adopted a strong 'market failure' rationale for technology policy. It implied that the commercial development of nanotechnology, and the maximisation of economic and social benefit, would necessarily follow the creation of "regulation based on sound scientific evidence" (Cutler 2008, 92).

5.2.3 The National Enabling Technologies Strategy (2009-2013)

The government's May 2009 response to the innovation review, *Powering ideas — An innovation agenda for the 21st century*, provided the first, brief introduction to the new NETS program. In a striking display of 'technological progressivism' (Kleinman 2005), *Powering Ideas* asserted that emerging technologies such as nanotechnology and biotechnology: "will help us conquer hunger and disease, carbon-dependence and climate change. They will spawn new products, new processes, new industries, and thousands upon thousands of jobs in the coming decades" (DIISR 2009c, 56).[14] Similar to earlier statements by the Coalition and by *Venturous Australia*, there was no envisaged role for government to manage either the public research investment or commercialisation processes in order to secure the touted social, economic and environmental benefits. Nor was there any engagement with the demand-side dimensions of nanotechnology development (cf. Dodgson, et al. 2011; Marsh and Edwards 2008). Again, the implicit assumption in both *Powering Ideas* and in the related NETS budget statement (DIISR 2009a) was that markets for nanotechnology were extant, ready and willing to incorporate the products of Australian research, and that commercialisation would self-evidently produce social benefit, so long as areas of 'market failure' were addressed. That is, government's role was cast as sponsoring metrological work, formulating "the best possible regulation", and building "community confidence" through the provision of "reliable information" (DIISR 2009c, 56). Even in a report that espoused developmentalist intent and which employed 'innovations systems' discourse, the policy challenges for both growing the nanotechnology industry and maximising its delivery of social value were largely reduced to addressing 'market failure'.

Details for the NETS program were released in February 2010 (DIISR 2010). It was announced that of $38.2 million allocated to NETS over four years, $18.2 million would be allocated to metrological work undertaken by the National Measurement Institute, $9.4 million to "public awareness and engagement" by the NETS office, and $10.6 million for "policy coordination, industry uptake, international engagement, and strategic research" initiatives (DIISR 2010, 4). Some non-government organisations (NGOs) and researchers (eg Lyons and Whelan 2010, 2013; Petersen and Bowman 2012) criticised the Department's use of both 'deficit model'[15] and scientistic policy framing, including in the NETS discussion paper (DIISR 2009b). Responding to such criticism, and perhaps also to international initiatives that sought to

[14] On the determinism which characterised many predictions for nanotechnology's future benefits see Cyrus Mody (2006).

[15] The deficit model attributes publics' ambivalence towards or rejection of the projects of technoscience solely to their ignorance or misunderstanding of scientific knowledge (Wynne 1991, 1993).

broaden the basis of nanotechnology policy deliberation (see Guston 2014; RS/RAE 2004), the Strategy contained several measures to expand processes of social appraisal and public participation. NETS explicitly supported "community engagement which feeds into policy development" (DIISR 2010, 4). It included an objective of "using technology for a better future" by "increas[ing] government, industry and the community's understanding of the ways in which applications of enabling technologies may help to address major global and national challenges and increase industry productivity". Another objective, "planning for the future", was announced to "prepare for the advent of new technologies by undertaking foresighting activities and supporting the development of policy and regulatory frameworks" (DIISR 2010, 4). NETS also established a "Stakeholder Advisory Council" (SAC)[16] to advise the Minister, and an "Expert Forum" (EF) to assist with foresighting activities.[17]

The NETS statement made a discursive shift from earlier nanotechnology policy. Moreover, as one interviewee emphasised, the breadth of stakeholder consultation initiatives was "quite unusual" for the industry department (Public servant, Interview 30, November 2013), which typically focused primarily on its industry clients (cf. Pusey 1991). Yet many 'public engagement' activities show continuities with earlier 'public education' initiatives, and often serve undeclared instrumental purposes (Davies 2013; Stirling 2008a; Wynne 2006, 2016). The public awareness and community engagement (PACE) program run by NETS attracted such criticism. Analysts warned that without reframing, NETS' "'engagement' strategies are destined to amount to little more than mechanisms to engineer consent" (Petersen and Bowman 2012, 78; see also Lyons and Whelan 2010). Materials produced by NETS-PACE were criticised for their promotional tone and perceived lack of "balance", including in focus group evaluation commissioned by the Department obtained via a *Freedom of Information Act 1982* (FoI) request (Ipsos 2012). Some NETS-PACE initiatives made an apparently sincere effort to foster deliberation, for example via the Science and Technology Pathways program (STEP; see Marks and Russell 2015; Russell 2013). However, a diagram produced by the Department and obtained under FoI makes clear the envisaged instrumental role of NETS-PACE in building "community confidence", which in conjunction with metrology and regulatory activities was intended to support "industry uptake" of nanotechnology (Figure 3 below, from Figure 3

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[16] Of which I was a member 2010-2012.

[17] On the origin of 'foresighting' activities in science policy see Ben Martin (2010), and on its prominence since the 1980s in states' attempts to shape fundamental research in areas deemed to be of strategic importance see Aant Elzinga (2012). For the Expert Forum's Chair's reflections on foresighting associated with NETS, and government officials' primary interest in the tool's ability to diminish policy uncertainty, see Ron Johnston (2011).

DIISRTE 2012c, 271). When NETS was reviewed by an evaluation wing of the industry department in 2012, the initiatives to support foresight, stakeholder consultation and better achievement of nanotechnology benefits were appraised by it as having limited value, and were recommended to be discontinued (DIISRTE 2012c).[18]

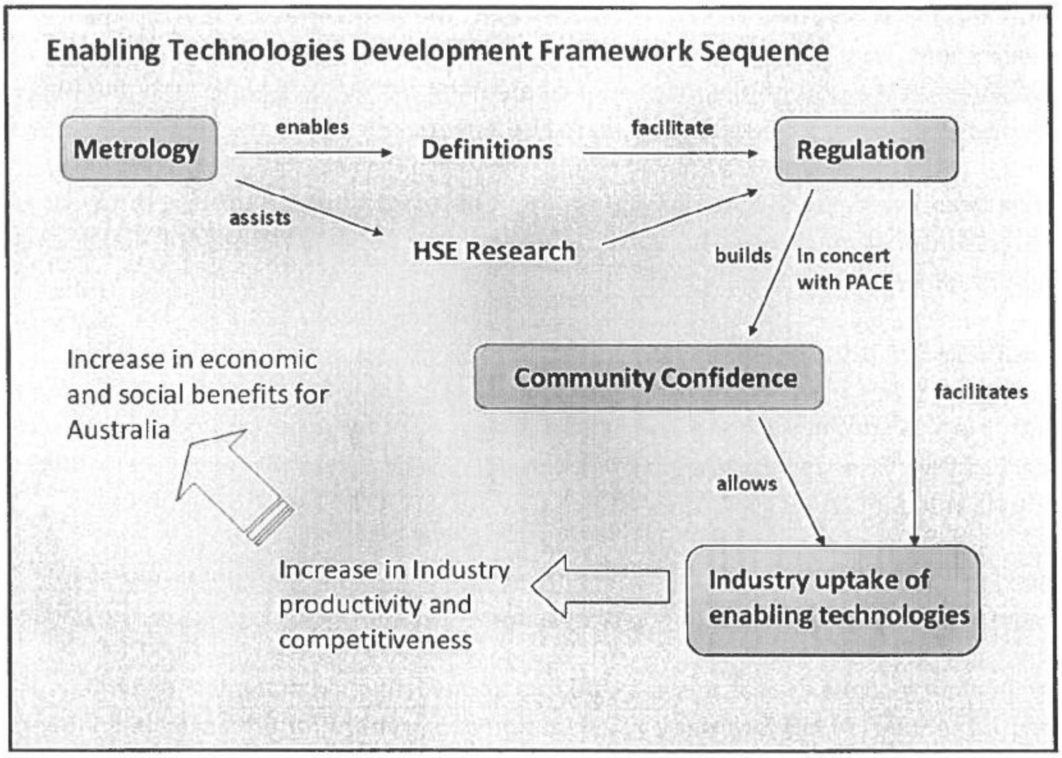

Figure 3: "Enabling technologies development framework sequence" (from Figure 3, DIISRTE 2012c, 271).

The 2012 NETS review offers a fascinating window on to both policy makers' own understanding of the nanotechnology policy architecture, and the central influence of 'market failure' logics within it. The review explicitly investigated NETS' conformance with 'market failure' justifications as the primary means to determine the "appropriateness" of its "policy rationale" (DIISRTE 2012c, 265). And, as Figure 3 makes clear, NETS' own activities were envisaged through a lens that focused solely on areas of assumed 'market failure': metrology, regulation, and "community confidence". Tellingly, Figure 3 does not engage with demand-side factors potentially affecting nanotechnology commercialisation, such as the country's industrial structure "imped[ing] uptake of nanotechnology", or the lack of awareness or

[18] The review was particularly critical of the SAC as overly focused on questions of "risk" rather than "reward", and for having failed to produce consensus outcomes in its advice to government.

interest in the field of Australian business (Ernst & Young 2002, 18). Nor does it acknowledge supply-side issues, such as the difficulties in developing commercial products from what remained a heterogeneous field of largely 'basic' science.[19] Perhaps surprisingly, Figure 3 shows no connection between NETS activities and the substantial public investment in nanotechnology research (beyond EHS research). Instead, the 'barriers to innovation' (cf. Balmer and Molyneux-Hodgson 2013; Molyneux-Hodgson and Balmer 2014; see also Kearnes and Wynne 2007) identified in Figure 3 and elsewhere in the NETS review relate solely to instances of 'market failure', namely the absence of clear EHS regulation and the need for "community confidence".[20]

The NETS review concluded that "the breadth of NETS activities" had "diluted the focus of the Strategy" (DIISRTE 2012c, 238). It recommended that:

> "*in order to meet its stated objectives, NETS should give priority to the 'foundation' activities of metrology, regulation and public awareness. These are the building blocks for creating an optimal operating environment for enabling technologies to develop and grow... This focus on these 'foundation' activities should be clearly placed in the strategic context of industry and innovation development*" (DIISRTE 2012c, 238).

That is, two years into its operation the industry department recommended that NETS abandon its more progressive initiatives and re-focus on its science-based, 'market failure'-justified "'foundation' activities" as the means to foster industry development.

5.3 Sources of policy continuity

The continuity in the scientistic framing of consecutive nanotechnology policies had multiple sources. Earlier in this chapter I observed that whereas 'free market' or 'neo-liberal' commitments have exerted a dominant influence on Australian innovation policy, they are not hegemonic. In this section I explore two further sources of continuity in the focus of Australian

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[19] On the flexible and strategic use of this term see Jane Calvert (2006); on my qualified use of it see Part A Introduction.

[20] Strikingly, the NETS review urged a continued focus on "public awareness" even as it recommended that the NETS office abandon its attempts to build "awareness amongst industry" of nanotechnology's "potential", judging the latter to be "premature" and observing that "many of these technologies are still in their infancy" (DIISRTE 2012c, 238). This emphasis on "community confidence" as the major potential impediment to future "industry uptake" (cf. Kearnes and Wynne 2007) both marginalises demand-side issues affecting nanotechnology's development, while positioning public opinion as a key if latent 'threat' (on publics as imagined 'threats' to innovation see Hess 2015; Welsh and Wynne 2013).

nanotechnology policy on science-based regulatory measures: the convergent policy prescriptions produced by the technological progressivism of some key actors in Labor; and the central role in policy making of public servants in the industry department.

5.3.1 "A social democratic view of innovation"

The approach to policy of Kim Carr, Minister for much of the NNS and during NETS' development and early implementation, was strongly shaped by his conviction that new technologies offer the means for jobs creation and progressive social change. As one Ministerial advisor observed:

> "*… it's a huge driver, a certain number of people in the progressive side of politics who tie technology to jobs, and that's very much where Kim [Carr] is coming from as well when it comes to new technologies. It's about innovation, creating new industries, new businesses, all that. So it is very strong, and what I mean by very strong is that it is an imperative that virtually nothing can or should slow down... there's questions about occ[upational] health and safety, there's questions about kind of ruining business through bad products and all that sort of stuff. But in a way, they're specific considerations to be given to certain problems, they're not up there with the jobs imperative. I mean it's – it's kind of right up there*" (Ministerial advisor, Interview 7, September 2013).

The approach to new technologies described in this statement counter poses wholesale support for emerging technologies development in anticipation of "new industries, new businesses" and "jobs" with "specific considerations to be given to certain [safety] problems". It exemplifies risk/ benefit framing, in which narrowly defined safety risks are juxtaposed with expectations of broad ranging social, economic and even environmental benefits of new technology development (see G. Miller and Wickson 2015). Yet most arresting is the interviewee's depiction of Carr's view of technology development as "an imperative that virtually nothing can or should slow down". This accords technology development a moral urgency and reinforces an imaginary of technoscientific progress as a 'one-track race' to an axiomatically 'better' future (cf. Stirling 2009a, 2010a; see also Kleinman 2005; Sarewitz 1996).

In public statements as Minister, Carr attributed his support for technological innovation to its capacity to progressively re-order social relations. For example in a speech on nanotechnology to the Australian Council of Trade Unions, Carr (2010, 1) argued that technology transforms society not only by making us "richer, safer and healthier" but also "by altering the relations between individuals and groups" (for a similar argument see Carr 2009). In an interview for this research, Carr described the quest for "social change" as motivating his support for NETS:

> "*I think this Enabling Technology Strategy was so important, you know the government was spending $170 million a year on research into nanotechnologies. It was not something we were just doing in a small way, but $38 million towards the Strategy I felt was a relatively small amount of money to actually try to promote these what I thought were powerful new technologies, and you know as well as I do what the economic forecasts and potential are here in terms of jobs and development of new materials. Now that's what innovation's about, it's about developing – what I call welding together white coat and blue collar… putting science at the cutting edge of social change because the best way I could see to secure the living standards of working people was to actually have secure high technology jobs... I consider myself to be a socialist so I say the role, the state's role in the development of these technologies is extremely important*" (Kim Carr, Interview December 2013).

Expressed here, Carr's vision enacts nanotechnology as a site where "science" could be applied "at the cutting edge of social change" to create "secure high technology jobs" that would "secure the living standards of working people". Carr emphasised that "I openly argue what I call a social democratic view of innovation... [and] I saw this as a broader philosophical question about 'what is the role of Labor in government?'" (Kim Carr, Interview December 2013). Carr advocated a proactive role for government to nurture new technologies, although, as discussed below, this was not a position fully shared by his Labor colleagues.

Yet, perhaps surprisingly, Carr's desire to use innovation policy to foster progressive societal transformation may not have significantly challenged the core framing of NETS. The NETS policy architecture likely reflected the influence of the Department in drafting nanotechnology policy (see next section) as well as the wider commitment of the Labor government to 'market failure' rationales for technology policy (see above and below). Nonetheless, Carr's aspirations for nanotechnology's development, when understood in light of his conviction in the axiomatically beneficent power of technology to make us "richer, safer and healthier", present no apparent challenge to the policy approach illustrated in the "Enabling technologies development framework sequence" above (Figure 3). Both 'free market' and "social democratic" views of innovation assume the "self-propelling" (cf. Kleinman 2005, 5), socially desirable outcomes of technological innovation (although the outcomes they envisage diverge). That is, assuming no need for government intervention to ensure social benefit, these different ideological commitments may produce policy framings that are to a substantial degree convergent.

Reinforcing scientistic rationales for public policy, Carr's interview comments also assume the "natural sovereignty" of science over policy meanings and the privileged role for scientific experts in policy appraisal. That is, his comments show the influence of liberal notions of science as a means to truth alongside a more Marxian analysis of technology's social relations. As noted above, the final NETS statement pledged to "increase understanding of public concerns and aspirations by technology developers and in policy formulation" (DIISR 2010, 8). In our interview Carr similarly acknowledged that technology policy is "always going to be a matter of public discussion" (Kim Carr, Interview December 2013). Nonetheless, as Minister, Carr's public interventions rejected criticism of the vision, purpose or value of the state's investment in nanotechnology.[21] Carr's interview statements also emphasised that policy must be made by governments "on the best advice" "on the basis of evidence" rather than by broader processes of public engagement, which his comments suggest would be vulnerable to public fears resulting from flawed understandings of risks to safety (Kim Carr, Interview December 2013).[22] Carr argued against measures such as "referendums" or "citizen-initiated stuff for legal rights", and instead supported expert-led assessment that would support politicians making decisions "on the basis of evidence" – whose nature we understand to be necessarily 'scientific'.[23] This position recalls the process of 'double delegation' described by

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[21] For example, in one newspaper opinion piece Carr argued that nanotechnology critics were emblematic of "a new reactionary romanticism [that] wants to turn back the Enlightenment". He urged "Australians [to] turn their backs on those who would encourage us to stay in the caves of mediocrity" (Carr 2011, 14).

[22] GM: "What do you see as the role for the public in decision making around new technologies?"
Kim Carr: "Oh I think it's always going to be a matter of public discussion. You can't put this stuff to a referendum... I don't go for that sort of citizen-initiated stuff for legal rights, no – governments have to make decisions based on the best advice they have available to them and that means that there may well be occasions where the public will have – you know there will be different points of views expressed publicly. All you can do is evaluate that on the basis of evidence that you have before you. I do take a very strong objection to people stopping kiddies from being inoculated, you know I think fluoridised water is actually something important, I mean public health issues are – you know if we rely on some of the attitudes today I suspect we would never have got the sewerage system cleaned up" (Kim Carr, Interview December 2013).

[23] On the epistemic and political ordering performed by arguments for evidence-based policy see Susan Hodgson and Zoë Irving (2007) and Helga Nowotny (2007); on the political work performed by privileging particular kinds of 'epistemic form' see Daniel Kleinman and Sainath Suryanarayanan (2012).

Michel Callon and colleagues (2009).[24] In making this argument, Carr simultaneously extended the authority of science to "democratically debatable questions" (including those raised by his own public statements), and "seamlessly defined public *understanding* of science with public *compliance* with those normative choices woven into 'science'" (cf. Wynne 2014, 64, emphases in original).

Carr's comments reveal an ever-present concern for public opinion, and for the potential sociopolitical rejection of the products of technoscience. Nonetheless, he supports the restriction of policy responses to 'science-based' regulatory measures – not to protect the 'free' operation of the market, but rather technology's assumed ability to effect progressive societal transformation.

5.3.2 "It is actually driven by the Department"

Beyond the convergent implications of politicians' "social democratic" and 'free market' commitments, an important source of continuity in nanotechnology policy was central role played in its development by public servants. The similarities in nanotechnology policy between the Howard and the Rudd-Gillard-Rudd governments were attributed by one interviewee to the key role played in each by public servants in the industry department: "it wouldn't have been particularly noticeably different I don't think. Because essentially it is actually driven by the Department" (Ministerial advisor, Interview 45, November 2013). Public servants used the biotechnology policy developed under the Howard government as a template for both the NNS and NETS. As one interviewee remarked:

> "*I think NETS as a whole probably didn't [represent a shift from the NNS] because it built – when we were developing it we built on the National Biotech Strategy and the National Nanotech Strategy in the sort of areas it covered and including the different strands of wanting to see it picked up [commercially] but that sort of overarching thing about encouraging the responsible development. So that brought in the different strands of seeing development but wanting to address HSE and other issues and also*

[24] Michel Callon and colleagues describe 'double delegation' as a process in which knowledge creation is delegated from laypeople to technical specialists ('secluded' scientists), while the articulation of sociopolitical preferences is delegated from voters to their elected representatives. The authors warn that in such a system, decision makers may come to believe "that democracy can function only if the people are kept at arm's length" (Callon, et al. 2009, 119-123) – a tendency apparent in Carr's argument that politicians must be left to make decisions for wider publics "on the basis of evidence".

the public awareness, community engagement strands. They were common to the three strategies in different ways" (Public servant, Interview 30, November 2013).

Similarly, another public servant emphasised that "NETS came as an evolution. NETS, as its first incarnation was in 1999 in Biotechnology Australia" (Public servant, Interview 28, March 2014). The influential role of the Department in developing nanotechnology policy points to the lack of high-level political engagement in the field, and also to political actors' deference to the expertise of public servants in developing 'scientific' policy (see below). It also underscores a central observation of the thesis: the form in which state support for nanotechnology was expressed was conditioned by structural, institutional and ideational features, but was also a product of particular individuals' work (cf. Kleinman 1995; Mackenzie and Spinardi 1988a, b; Wright 1994). In this instance, many of the same public servants who drafted or implemented biotechnology policy and the NNS under the Coalition government were also involved in developing NETS under Labor, and were guided by policy precedent.[25]

The focus of nanotechnology policy on sponsoring metrology, regulation and public awareness activities was not only a reflection of the Department's efforts to pursue innovation objectives while conforming to 'free market' principles, but arguably enabled it. Nonetheless, tensions between developmentalist, 'market failure' and scientistic logics and discourse recurred in the Department's activities, as apparent in one interviewee's statement. Responding to NGOs' criticism of the Department's role in industry promotion, the public servant emphasised that NETS was not part of "the really target industry development", which might "promote particular companies... the really dodgy end", but added:

> *"...then there is the general promoting innovation and commercialisation... that was such a central part of the Department's agenda, it wasn't just a case of 'well of course that's good to do'. It wasn't that so much as 'well of course we're going to be doing that'. And I have to say sometimes that criticism about that kind of pushing industry, I did find that a bit naive in that sense because it is the industry portfolio, it's going to push industry. Sometimes I was a bit surprised that the Department even would take so much trouble to defend itself against that*" (Public servant, Interview 50, October 2013).

[25] On the "carrying over of issues" from one emergent technology to another, and its potential to "imply a narrow and predetermined framing of what is important" in policy making, see Jane Calvert (2013, 470).

This interviewee distinguished the Department's work from "really target industry development" that might be "dodgy". On the other hand, they naturalised "promoting innovation and commercialisation" and "pushing industry" as "a central part of the Department's agenda", expressing surprise that "the Department even would take so much trouble to defend itself against that". Yet the Department's attempts to "defend itself" against charges of promoting industry and its insistence that nanotechnology policy and communication about it was 'balanced' and 'science-based' (see below and Chapter 6) is instructive. Efforts to promote nanotechnology development through a focus on metrology, EHS risk regulation and "balanced and factual" public communication (DIISR 2010, 3) produced normative and epistemic frictions with which the Department was at times uncomfortable. Documents obtained under FoI state clearly that in undertaking NETS activities "the end goal [is] public acceptance and industry uptake" (DIISRTE 2012c, 238). Yet seeking to defend itself against charges of compromising the integrity of either 'science' or the 'free market', the very industry department could not own its role as nanotechnology proponent.

Having traced the multiple sources of scientistic framing for nanotechnology policy, the final sections of this chapter illuminate its depoliticising influence on the day to day interactions and relations of Ministers, their advisors, Department staff, and regulators, before showing how sociopolitical questions recurred within government and in its relations with nanotechnology proponents.

5.4 Expertise, delegation and the recurrence of the political

5.4.1 The depoliticisation of policy making

Andrew Barry suggests that "we should not speak of the *inherent* political properties of scientific objects but the ways in which objects may become more or less political" (2001, 209, emphasis in original). That is, rather than seeing particular objects as more or less likely to become a site of contestation at which political questions may be 'opened up' (cf. Stirling 2008a), we should look to the spaces in which such objects circulate, the containment or amplification of sociopolitical dimensions in the social and material practices that (re)enact them, and the subject-object relations that emerge. Previous chapters have explored the 'ontological politics' (Mol 1999, 2002) that surrounded nanotechnology's enactment as an object of innovation policy, asking how, in what circumstances, and for whom nanotechnology acquired ontological significance, and what political work this performed (cf. Lynch 2013). My interest in this chapter is the influence of policy framings on nanotechnology's (re)enactment as a 'scientific' rather than a 'political' policy object, and the depoliticising effect this enactment had within government. I find that given widely shared assumptions that 'science' has, or should have, "natural sovereignty" over the *political meanings* of 'scientific' policy objects (cf. Wynne 2014, 61), this enactment amplified the tendency of traditionally technocratic Australian policy makers (Pusey 1991) to defer to the epistemic authority of scientific 'experts'. This led to the locus and epistemic basis of nanotechnology policy making being shifted away from the political sphere towards the technical, if always incompletely.

Nanotechnology's enactment as a 'scientific' policy object had the effect of reordering relations between Ministers and their advisors – the ostensibly 'political' wing of government – and the public servants they deemed to be 'experts'. One advisor stressed that the "specialised" nature of nanotechnology policy, and the absence of "real expertise" within Ministers' offices led to an acute reliance on and "trust" in "the experts":

> "*I think it's particularly relevant to this area because it is so specialised and almost no one in a Minister's office is going to have a – and no Minister is going to have real expertise in this area whereas in things like manufacturing and even in a whole range of social policy areas and science policy generally, higher education policy generally, staff and Ministers are going to have quite substantial expertise. In this particular policy area because it's so specialised it's very unlikely that your staff and Ministers are going to have expertise. Therefore because there is a view that 'well we need to trust the experts' there will actually be quite a high level of trust in the Department and the scientists*" (Ministerial advisor, Interview 45, November 2013).

This advisor draws a remarkable distinction between the knowledge required to engage with a diverse range of other policy areas and nanotechnology. In their view nanotechnology requires a unique level of "specialised" technical expertise, making the Minister's office reliant on "the experts" "in the Department" and "the scientists". These observations are echoed by another advisor:

> "*I think maybe in this question the flow of authority goes in the opposite direction to any other portfolio in government, where because it is seen as a scientific question, maybe there is more deferral to the scientific advice and a devaluing of the political perspective, which would be the inverse of any other portfolio in government*" (Ministerial advisor, Interview 51, February 2014).

This observation is striking: the assumption of 'scientific' meaning "devalu[ed] the political perspective" and reversed "the flow of authority" that would be found in "any other portfolio" where Ministers would naturally assume and exert the prerogative to make political judgments on questions of policy.

The perception of lacking the technical expertise to engage in nanotechnology policy appraisal was not unique to Ministerial offices that deferred to their advisors in the Department. In turn, public servants in the Department deferred to the epistemic authority of 'experts' in the regulators. In response to a question regarding whether the Therapeutic Goods Administration (TGA) should have done more to address concerns regarding the use of photocatalytic anatase titanium dioxide nanomaterials in sunscreens (investigated in Chapter 6), a public servant was emphatic: "That's something where it's in the hands of the TGA. They're the ones who are the experts. They have access to all the research and they make the decisions. So it's not really for me to judge that they should or shouldn't have done something because they're the ones whose purview it's in to make that decision" (Public servant, Interview 30, November 2013). The unqualified deferral to the TGA on questions of 'science' that is evident in this statement may be in part a learnt behaviour. A social scientist observed that the NETS office and the TGA:

> "*did work together and definitely on particular issues I think they worked together very well but when you had questioning of regulatory oversight or policy – well, regulatory policy development – that's when the concept of the TGA being the experts and 'this is our area' would come into play and that's when you would see the power dynamics in terms of who has the ability to influence and who does not coming to the fore as well*" (Social scientist, Interview 48, March 2014).

This interviewee identified the performance of expertise by the TGA as a successful tactic to assert autonomy and to reject the legitimacy of NETS policy oversight: "'this is our area'".[26] In so doing, the regulators asserted the asymmetric agency of "experts" to decide on questions of 'science' – as Ministers, their advisors, public servants and other interviewees largely framed issues of regulatory oversight and policy.

[26] A Ministerial advisor was more critical in their assessment of the role played by the TGA: "you know my view of the TGA is that they were a law unto themselves. So [a] very old, very established outfit, and they... sort of probably liked to float out from the government mainstream" (Ministerial advisor, Interview 7, September 2013). A community sector interviewee was even more blunt, and suggested that the TGA's fractious relations in government extended to those with other regulators: "I think TGA think they're God and they sometimes talk to NICNAS [the chemicals regulator] and NICNAS has to kiss their arse basically... they're just bizarre" (Community sector, Interview 39, October 2013).

Yet the delegation by public servants to regulators of policy appraisal went far beyond propositional questions regarding the safety of particular nano-ingredients (cf. Wynne 2002). When asked to clarify the relationship between federal policy makers and the regulators in considering issues such as nano-product labelling or whether a mandatory register of nanomaterials should be developed, a senior public servant stressed that considering such issues was not the role of the Department:

> Interviewee: "*So our role was never in that space, that was up to the experts in that space*".
>
> GM: "*The regulators*?"
>
> Interviewee: "*Yeah, the regulators that's right, and they did that and approached the task in an objective sort of way. Our role was really one of facilitation and coordination and information flow*" (Public servant, Interview 10, November 2013).

This interviewee's response re(enacts) nanotechnology's status as a 'scientific' policy object that possesses only 'scientific' meaning. Their view that decisions regarding the introduction of measures such as product labelling, and nanomaterial notification and disclosure provisions should be made by "the experts" on an "objective" basis is striking. By deferring to a technocratic "culture of no culture" (cf. Traweek 1988, 162) on these policy questions, this interviewee denied such questions' normative and political dimensions (cf. G. Miller and Wickson 2015) recognising only their 'scientific' meaning. The agency and political work of such judgments is unacknowledged in the interviewee's description of the Department's role as "one of facilitation and coordination".

Despite the NETS office being the primary site for nanotechnology policy making within the federal government, another public servant also emphasised its key role as one of facilitation:

> "*We really had our hands on very few of the levers, only sort of indirectly... Our role was really to bring people together to talk and to coordinate and in briefing to government and everything to sort of point out the issues and help them to come to decisions... all we could do was suggest, point things out, help them et cetera, [the regulators] were the ones with the actual responsibility*..." (Public servant, Interview 30, November 2013).

Given NETS' location in the industry department, outside that of the health department which had oversight for several of the key regulators, this interviewee emphasised that public servants in NETS had no "actual responsibility" for regulatory policy. Moreover, they stressed that no other body had the power to direct or to compel action from the various regulators either. In light of these structural constraints, the interviewee identified the most valuable role of the NETS office as one of "coordinat[ion]" and "in briefing to government to sort of point out the issues and help them to come to decisions". The framing, content and presentation of advice by policy makers to decision makers is inherently value-laden (Mackenzie and Spinardi 1988b, 609; Stirling 2008a). Yet this interviewee's statement again diminishes the agency and political dimensions of such work.

Public servants deferred and delegated policy appraisal to regulators on the basis of the latter's "objective" scientific expertise, despite regulatory work necessarily involving hybrid social and scientific judgments (Abraham 2008; Abraham and Reed 2002; N. Brown and Beynon-Jones 2012; Jasanoff 1990). Despite this, some public servants revealed an awareness of the responsiveness of regulatory work to sociopolitical context. For example, one interviewee described the value for regulators of the Department's public opinion surveys:

> Interviewee: "*Regulators tend to operate in a bit of a vacuum. They have no idea what the public think of them. They have no idea what people want from regulation... if you're talking public good, you have to find ways to engage with the broader public, know what the issues are, know what the concerns are, know where they are, know what they expect and want of regulation. That was only one input of many that a regulatory agency uses to form things. They also listen to the stakeholders, they listen to the politics, but it changed the nature of the debate a bit that way*".
>
> GM: "*My understanding was that regulators were supposed to basically just look at the science and at some point look at the costs of implementation. So I'm interested to hear that they're actually looking at a broader spectrum of issues*".
>
> Interviewee: "*They are. As I say, it might not be one of the big issues for them. It sets a lower level certainly, how it feeds into what it does, but I think regulators when they pay attention to the broader socio-economic climate within their country and overseas are making better regulatory decisions*" (Public servant, Interview 28, March 2014).

This statement underscores the political work performed by public servants who "suggest" and "point things out". It shows that NETS staff understood that in addition to making decisions in "an objective sort of way", regulators "listen to the stakeholders, they listen to the politics", and that public servants also encouraged the regulators to take account of the public opinion surveys they commissioned (on the Department's use of public polling see Chapter 6). Perhaps most significantly for the interests of this thesis, the statement suggests that public servants saw technical "experts" in the regulators as the ultimate and proper decision makers not only on questions of safety but also on broader issues of "public good" – even as regulators' authority to make policy decisions was predicated on their capacity for "objective" appraisal of a 'scientific' policy object whose sociopolitical dimensions were denied.

The enactment of nanotechnology as a 'scientific' rather than a 'political' object led to the delegation of policy appraisal from executive government (Ministers and their advisors), to the Department, to the regulators. This resulted in a double process of depoliticisation, as the site and epistemic basis of policy was shifted away from the political sphere towards the technical. The political appraisal of nanotechnology policy was ostensibly reduced to a consideration of EHS risks by actors and institutions shielded from public view – a move that, while incomplete, was nonetheless problematic on both substantive and normative grounds (cf. Stirling 2008). Ironically then, in other branches of government questions were asked regarding the purpose and value of the NETS program and the state's role as innovation sponsor which stubbornly 'overflowed' scientistic frames (cf. Callon 1998; Callon, et al. 2009; Wynne 2002).

5.4.2 Political questions recur within government

In the aftermath of high-level political instability in the Labor government that resulted in Gillard replacing Rudd as Prime Minister, the "philosophical question" regarding the state's role as industry and innovation sponsor recurred. Carr's "passion" for science and innovation had led to him having an "outsized" impact on Labor government policy (Ministerial advisor, Interview 46, December 2015), yet this did not mean that Carr's "social democratic view of innovation" was shared by influential colleagues. Asked whether he felt that he had been able to build broad support for his position, Carr replied: "Well I felt that I was up when I got [NETS] established but you know notice as soon as I was removed to Siberia[27] they dropped it. I mean you can't help but notice that" (Kim Carr, Interview December 2013). While Rudd was Prime

[27] Prime Minister Kevin Rudd was replaced by his Deputy Julia Gillard in a leadership spill in June 2010. In subsequent leadership unrest, Carr's support for Rudd is reported to have led to his demotion from the Cabinet in December 2011. When Rudd successfully challenged Gillard in a further leadership spill in June 2013, Carr was returned to his former Ministerial portfolio just as NETS was terminating.

Minister Carr observed that there was a "very strong level of support for what I was doing". Moreover, he emphasised that "you need an activist Minister but you need the support of the Prime Minister because there are always conflicting priorities and pressures on government budgets" (Kim Carr, Interview December 2013). Underscoring this point, following Carr and Rudd's loss of their respective positions, NETS proved vulnerable to critics of state-sponsored innovation programs and to those who sought budget savings in the wake of the GFC.

As 'free market' policy logics had shaped the architecture of Australian national nanotechnology policy, under Gillard arguments regarding the proper limits to government's role in facilitating techno-industrial transformation were extended to NETS itself. A Ministerial advisor recalled that the Treasurer Wayne Swan and the Finance Minister Craig Emerson "did not believe in intervention other than by adjusting economic settings—i.e. industries should work out technology issues for themselves"; by 2013, when NETS was terminating, these two were "dead against any funds for stimulating new technologies in industry" (Ministerial advisor, Interview 7, Written comments, August 2016). This marked a point at which NETS' 'scientific' meaning was subordinated to a meaning associated with 'market' thinking. As a sectoral program, despite its scientistic and 'market failure' framing, NETS was judged to transgress 'free market' principles. Yet it was not only ideological objections that sealed the program's fate, but also political opportunism. When Carr's replacement Greg Combet launched Labor's new *Industry and Innovation Statement* in February 2013 just months before NETS' expiration, there was "intense competition within the portfolio" for funding associated with the new statement (Ministerial advisor, Interview 7, Written comments, August 2016). Given Combet's wish to announce new initiatives "to give the impression of breaking out of existing problems and offering an optimistic future" (Ministerial advisor, Interview 7, Written comments, August 2016), and his limited interest in NETS,[28] in June 2013 the program was allowed to terminate. When the new Coalition government came to power some months later, it also failed to propose a replacement.

In the post-GFC fiscal environment, the shifting fortunes of the Labor leadership were a key factor in NETS' fate. Gillard was not a defender of interventionist industry and innovation policy – indeed in the 2010 election she was regarded as having "ignored industry policy completely" (Conley and van Acker 2011, 513). The equivocal credibility that had been achieved for nanotechnology's promissory claims (Chapter 4) and the lack of tangible

[28] Greg Combet's limited interest in NETS was noted by many interviewees.

commercial successes by the nascent Australian sector likely contributed to the decision not to renew the program (McGrail 2011, 67). Yet perhaps most significantly, in the absence of an "activist Minister" and without the support of a sympathetic Prime Minister, questions had been asked within government regarding NETS' purpose, value and justification and the program had been found wanting. This finding concurs with those of earlier studies showing the importance of personalities to Australian innovation policy settlements, and the vacillation that surrounds support for particular initiatives (Conley and van Acker 2011; Thurbon 2012, 2016).[29] It also affirms a key argument of the wider thesis: adoption by the state of policy to promote nanotechnology development was neither 'natural' nor inevitable, but rather a situated achievement. Conditioned by its economic, political and ideational environment, such support was importantly also the product of active work by intermediaries acting between science, policy and politics – in this case a small number of high-level politicians whose pro-technology policies enjoyed only qualified support from their colleagues.

The limits on state support for nanotechnology produced by disagreement within government regarding its role as technology sponsor were in the view of one Ministerial advisor a good thing. This interviewee stressed the value of having "people in government that give the argument that 'it's not government's role to be driving industry'... You know the fact is, no-one really knows what the future's going to hold. And politicians certainly don't have the monopoly on knowledge" (Ministerial advisor, Interview 46, December 2015).[30] Moreover, they cautioned that had nanotechnology proponents been more successful, the field could have received significant public funding yet delivered limited public benefit:

> "*I think in fact you could even point to it and say 'look thank god it wasn't a big industry policy' because… if we had had you know hundreds of millions of dollars invested in trying to nurture a nano industry of one kind or another here... there'd be a whole bunch of people that had done very nicely out of it, out of the whole government support. And the rest of us would be paying for it. And* if *it took off and there were all these spinoffs and so on, then it would have proved a great decision. But the odds would be against that. So in the likelihood – just thinking about the industry and the way it's developed globally – I actually think it would have been something that would have benefited a minority at the expense of a majority. So you know, thank god there*

[29] This phenomenon is not unique to Australia. On the influence of individuals in US post-war research policy and technology policy debates see Daniel Kleinman (1995), and in US and British biotechnology policy making see Susan Wright (1994).
[30] Wanna (2011) makes a similar argument for the value of the 'devil's advocate' role played by Treasury.

> *was that sentiment there. What I find peculiar – well not peculiar – but no-one had the gumption just to say 'well actually do we need this at all? Why are we spending – what was it, two million dollars a year*[31] *– why do we spend* anything *on this*?'" (Ministerial advisor, Interview 46, December 2015, emphases in original).

Funding nanotechnology research and development (R&D) is understood in this perspective not as an investment by an 'imagined community' (cf. B. Anderson 2006 [1983]) in an axiomatically 'better' future for all its members (eg as implied in Powering Ideas, DIISR 2009c, 56), but as the site of financial redistribution from one sub-set of society to another. The "science lobby" is viewed as "one special interest – among many" (Ministerial advisor, Interview 46, December 2015). This advisor emphasised the absence of any guarantee that collective benefit would result from state support for a field such as nanotechnology, only that wider publics would pay. They query why "no-one had the gumption just to say 'well actually do we need this [policy] at all?'" Marginalised by the scientistic and progressivist framing of NETS, this question was difficult for nanotechnology critics to raise.[32] However, it ultimately proved influential within government.

5.4.3 Renegotiating science-state-market relations

'Political' questions also recurred in government's relations with nanotechnology proponents, in particular regarding roles for the state, researchers and the private sector in promoting the field's commercial development. In arguing for greater 'leadership' by the federal government in coordinating the research effort and in supporting industrial capability building, proponents effectively supported a developmentalist policy approach that was at odds with that of the NNS and NETS. Conversely, politicians, their advisors and key bureaucrats expressed frustration with what they saw as the failure of scientists to work with industry to 'translate' their research for social and economic benefit. Several interviewees expressed the view that "a lot of researchers, the research leaders and the university professors and so on just take the money and run" (Ministerial advisor, Interview 7, September 2013).[33]

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[31] This underestimates government spending under both the NNS and NETS, see figures cited above.
[32] Critical social science and NGO interviewees spoke of their difficulty in finding forums in which they were "allowed" to critically question the purpose of NETS rather than "just tinker at the edges to make a few small changes" (Social scientist, Interview 38, December 2013).
[33] Such criticism is not new (eg see Aitkin 1996; Aitkin 1997).

In an interview for this research Carr described his efforts to forge a progressive new 'social contract' for science (see Part A Introduction) and his disappointment in scientists' failure to see their work as more directly relevant to the needs of industry, workers and the agenda for "social change":

> "*we tried to change a country... remember we are trying to reshape manufacturing and of course a lot of scientists say 'oh well I'm not much interested in what you did in the automotive industry'. You say, 'hang on a minute now, that technology has no relevance to the automotive industry? You're making a terrible mistake... that's what this is* for. *You're in the business of helping us transform this country. We've got a pact here, we provide you with the very best kit and resource we can as a country afford and in turn I ask you to give us every possible assistance in transforming Australia, building a richer, fairer, greener Australia... putting [scientists] in the centre on social change'. Now how many of them would have understood that? I think you'll find if you do the survey, you'll find very few. Because you see all they want to know is how much money they got*" (Kim Carr, Interview December 2013, emphasis in original).

Carr described a social contract or "pact" between science and society that was ambitious, explicitly aiming to put scientists "in the centre on social change" to "transform this country". Somewhat discordantly though, he suggested that "very few" scientists "would have understood" the terms of their "pact", and that "all they want to know is how much money they got".

A number of the Ministerial advisors and bureaucrats I spoke with translated Carr's vision for science's role in progressive social change into a renewed focus on promoting greater commercial relevance in publicly funded research. One senior public servant emphasised efforts under Labor to "improve the performance of the innovation system":

> "*... [we had] a desire to, if you like, get a better yield from the government's investment in science and research... particularly in the universities and the publicly funded research organisations to generate new jobs, new sources of income, and that sort of thing... we think there's significant barriers between the culture, quite often, and the reward system in universities compared to what you need from an industry perspective. We did quite a lot to try and work out how we could break that down, how we could change the incentives structures...*" (Public servant, Interview 10, November 2013).

This interviewee expressed expectations that “chang[ing] the incentives structures” for “universities and the publicly funded research organisations” would drive industry development, “generat[ing] new jobs, new sources of income”. That is, illustrating another site of policy convergence, as with the approach taken by the Howard government (Chapter 3) under Labor senior public servants still emphasised ‘supply side’ measures to foster innovation with an emphasis on the need to secure ‘cultural’ change among publicly funded researchers as the means to improving innovation outcomes.

Whereas government interviewees often held researchers responsible for the failure to commercialise their work, proponents criticised government’s unwillingness to offer support for capability development or industry uptake. The federal government did partner with the Australian Nanotechnology Alliance to raise the profile of Australian nanotechnology, for example through a series of promotional brochures (eg DIISR 2011b). However, government was largely unwilling to develop an industry strategy, or to offer the targeted assistance for commercialisation activities that industry bodies called for (eg Future Materials and Australian Nanotechnology Alliance 2009; Rankovic 2008). The NETS policy document touted initiatives that would *“*assist the development, commercialisation and adoption of enabling technologies in Australia”*,* “in particular, the new research and development tax credit, and Commercialisation Australia” (DIISR 2010, 3). Yet as a senior public servant observed, neither the R&D tax credit scheme nor Commercialisation Australia were designed to support selective sectoral intervention: “... we don’t say ‘if you’re in the biotechnology area you can have them, but you can’t have them if you’re in the TCF [textiles, clothing, footwear] area’. They’re generally available programs which support that sort of market failure or capability development” (Public servant, Interview 10, November 2013). Similarly, an advisor emphasised the intention of innovation policy to be sector neutral, improving the business operating environment through “...universal things. There was access to infrastructure, access to skilled people, access to capital, and access to commercial pathways, and that’s kind of technology neutral those things” (Ministerial advisor, Interview 57, November 2013). Indeed, illustrating a deep-seated aversion to ‘picking winners’, the advisor argued even that “the role of the Minister... is to be completely technology neutral” (Ministerial advisor, Interview 57, November 2013). This statement highlights the friction that recurred in government between its stated goal to grow the nanotechnology sector and widespread interpretations of ‘free market’ principles. It also underlines the (perhaps under-recognised) gulf in expectations for government's role in nanotechnology commercialisation held by nanotechnology proponents and political actors.

The very foundations of government's nanotechnology strategy, which posited metrology, regulation and public awareness as the basis for fostering industry development, and facilitation and information coordination as the Department's key roles, were seen by proponents as misguided. Criticising government's lack of "vision", one interviewee suggested that the: "[Australian] Office of Nanotechnology sounds more like a postal office than a leading office, and that was a little bit frustrating that the Office of Nanotechnology turned out to be a collating mechanism rather than a visionary and guiding mechanism" (Industry member, Interview 60, December 2013). Most damningly, the interviewee observed:

> "*it was almost like you've come to us and asked us a question which is 'where do we go with nanotechnology', and we've come back with an answer which is 'we're not going to worry about nanotechnology, we're going to put all of our effort on to the health and safety and the public awareness of nanotechnology – but don't worry about the industry, it'll just kind of happen by itself'*" (Industry member, Interview 60, December 2013).

Similarly, a senior scientist observed that "the investments which the government has made in terms of the Australian Office of Nanotechnology or the national NETS is mainly to enhance [public] awareness" (Technical scientist, Interview 31, November 2013). This interviewee viewed the introduction of nanotechnology to "the national agenda" as a positive thing, but criticised the lack of dedicated research funding allocated to nanotechnology and that of a clear, government-led development strategy. Such comments repudiate NETS' plan to achieve "economic and social benefits for Australia" by promoting "industry uptake" through regulatory and awareness measures to "creat[e] an optimal operating environment" (DIISRTE 2012c, 238). Industry stakeholders made even more pointed criticisms in the NETS review, warning that without targeted efforts to develop local commercial capabilities, this strategy could simply prepare the ground for the ready import of internationally-manufactured nano-products with no benefit to Australian industry (DIISRTE 2012c, 274).[34]

[34] For a different but related argument regarding the deficiencies of assumptions that *national* basic science programs will boost *national* technological competitiveness – the foundation of 'techno-nationalist' appeals for basic science funding (Edgerton 2007) – see Matthew Eisler (2013a).

Beyond disappointment in what proponents saw as government's failure to develop and fund *industry strategy*, they also criticised the absence of a coordinated *research strategy* that linked to innovation priorities.[35] One interviewee argued that "as a high-level strategy you couldn't argue with [NETS] strategically. But where were the detailed action plans? Where was the follow through?... I didn't see this was linking to either our national research or national innovation priorities" (Industry representative body, Interview 42, November 2013). Similarly, a senior scientist suggested that NNS and NETS statements regarding nanotechnology's importance to Australia and its transformational potential were "feel good stuff", arguing that "all that rhetoric has not been translated into a targeted, strategically targeted program" (Technical scientist, Interview 31, November 2013). This interviewee acknowledged that government could always point to the R&D funding provided through competitive grants, the National Collaborative Research Infrastructure Strategy (NCRIS) and the Australian National Fabrication Facility (ANFF) and say "'why are you so critical of us, we've put so much money into these things and you researchers are real bastards, you don't really give credit to us and show your appreciation'". Yet they insisted that funding for these initiatives was a product of researcher-driven, "bottom up approaches" to securing funding, the research sector's bids to "various standard government programs", and its lobbying for infrastructure, rather than part of a strategic effort on government's part. In their view, the fortunes and operation of facilities such as NCRIS or ANFF were effectively disconnected from those of the dedicated nanotechnology policy offices (Technical scientist, Interview 31, November 2013).

Proponents' appeals for developmentalist interventions by the state were at odds with the 'market failure' framing of nanotechnology policy and with the narrow view of government's role in sponsoring technological innovation shared by many policy makers and political actors. In a context in which nanotechnology enjoyed neither durable high-level political support, nor affiliation with an economically or electorally important industry sector, there was no opportunistic motivation for government to offer targeted support that breached – or required the favourable re-interpretation of – 'free market' policy principles. Earlier work has observed

[35] Proponents' expressed desire for an active, interventionist government role in developing both research and industry policy is striking. It contrasts with calls elsewhere for the protection of scientific and market autonomy, and the long-standing antipathy of the research sector towards priority setting and the development of coordinated research agendas (Kleinman 1995). Nonetheless, as shown by previous work, both industry (Vallas, et al. 2011) and scientists (Calvert 2006) make strategic appeals for state sponsorship which are characterised by the context-specific performance of work to define (Gieryn 1999; Jasanoff 1990) or to breach or blur (Bijker, et al. 2009) boundaries between science, the state, and markets. The extent to which the active role for government called for here is supported, and the conditionality of such support, would be interesting to explore further.

the interaction of 'free market' and scientistic commitments "limit[ing] the scope of government intervention in the economy to narrow, technical grounds that favor industry" (Moore, et al. 2011, 523). Yet, in the absence of the "self-propelling" momentum of technology or the market which NETS assumed, the policy settlement produced by these commitments did not unequivocally aid the nascent Australian nanotechnology sector. Indeed, it denied industry stakeholders avenues for potential political support and public funding and was therefore criticised by them.

5.5 Conclusion

Consonant with the wider argument of this thesis, this chapter challenges the assumed commitment of the state to actively fostering emerging technologies development. It shows that in addition to limited high-level political interest in nanotechnology, and scepticism regarding the economic value to Australia of new technology development more broadly, nanotechnology policy was plagued by Australia's hesitant approach to innovation policy. A narrow, 'market failure' rationale for the state's role in sponsoring technological innovation was apparent in policies adopted by both Coalition and Labor governments. Beyond providing public funding for research, government policy focused on metrology, EHS risk regulation, and public awareness initiatives. This policy architecture presented a barrier to appeals for government to play a more active role in fostering the nascent sector's commercial development. It also contributed to nanotechnology's enactment as a 'scientific' rather than a 'political' policy object, with depoliticising effects: many in government assumed the "natural sovereignty" of science in policy making. Nonetheless, 'political' questions regarding the purpose, legitimacy and value of the state's nanotechnology policy recurred internally to government and in its relations with the research and private sectors. Although scientistic policy framing had been amplified by 'market failure' rationales, in the straitened post-GFC fiscal circumstances, and with political instability undermining nanotechnology's Cabinet champions, the 'scientific' meaning of nanotechnology policy was ultimately subordinated. Judgements that the program breached 'free market' commitments contributed to its discontinuation.

This chapter has explored in detail the specificity of the forms in which state support for new technology development is expressed. Nanotechnology policy was a site at which the state's ambivalent relations with industry and innovation policy, and with the research sector and technology proponents, were tested and renegotiated. Both the NNS and NETS enacted nanotechnology as a scientific field whose commercial expansion was both inevitable and desirable; both also declared the intention of the state to foster nanotechnology development. Yet in a context in which nanotechnology enjoyed neither durable high-level political interest nor association with an electorally important industrial sector, public servants played a key role in developing modest policy interventions that were largely restricted to 'science-based' regulatory measures based on 'market failure' rationales. Despite proponents' appeals to government to develop detailed policy to connect the research investment to commercial capability development, and to provide targeted funding and practical support to foster nanotechnology's commercial expansion, there was no preparedness on the part of the Australian state to assume such an active role. The failure of Australian nanotechnology to match the predictions made for its commercial impact is attributed both by government and by proponents in part to the other, in a continuation of long-running recriminations (sees also Chapters 3 and 4).

Earlier STS work has shown that the enactment of public policy debates as 'scientific' rather than 'political' can 'close down' opportunities for sociopolitical critique and participation by wider publics. This chapter has shown that such framing also influences policy making within government. The enactment of nanotechnology as a 'scientific' policy object shaped the day to day interactions and relations of Ministers, their advisors, Department staff and regulators. It shifted the locus and epistemic basis of policy making from political to technical spheres, as governance of the nanotechnology 'revolution' and efforts to build a local industry were increasingly approached as a chemicals regulatory question for technical experts. To some extent scientistic framing 'closed down' questions from critics regarding whether Australia should pursue nanotechnology, the appropriate role for the state in industry development, and the value of public investment in the field. Yet such questions recurred within government, contributing to the decision not to renew funding for the NETS program. In this way, I find that a classic observation of earlier STS knowledge controversy studies – that despite the extensive efforts of policy makers to reduce the meaning of technoscience policy to questions of 'science' and risk, such narrow designations are routinely 'overflowed' – is also pertinent to the internal operations of government.

The common assumption in STS work that regulatory responses to emerging technologies are a site at which states pursue 'nation building projects' is given only qualified support by the empirical work of this chapter. Risk regulation, alongside metrological work and public awareness activities, was identified as a primary means by which government would create the "optimal operating environment" to foster nanotechnology's expansion. And yet this focus did not reflect a high-level political commitment to sponsoring nanotechnology development; indeed, it may be argued to result in part from the state's unwillingness to engage in a more fully-fledged capability building effort for the nascent sector. Further, rather than an uncomplicated channel between the government's dedicated nanotechnology policy office and the formulation of regulatory responses, relations between the NETS office and key regulators are described by interviewees as fractious. These findings point to a less straightforward co-production of epistemic, normative and political commitments in regulatory outcomes than is sometimes assumed. The influence of the Australian national nanotechnology policy architecture and the phenomena described in this chapter on political and policy responses to regulatory debates surrounding nano-sunscreens is investigated in Chapter 6.

Chapter 6: Nano-sunscreen regulatory debates

Amidst promissory claims that nanotechnology would 'revolutionise' industry, healthcare and defence, in the early 2000s state-backed nanotechnology programs were initiated internationally as previous chapters have described. Yet in this period questions also emerged regarding toxicological risks posed by the new nano-products entering commercial use. Partly as a consequence of a high-profile inquiry held by the United Kingdom's Royal Society and Royal Academy of Engineering (RS/RAE 2004), the potential risks of nano-ingredients used in quotidian products such as cosmetics and sunscreens attracted growing attention. Questions surrounding sunscreen safety proved particularly salient in Australia, where rates of skin cancer are very high (AIHW 2012) and sunscreen use is heavily promoted by government and anti-cancer groups. The safety of nano-sunscreens and the adequacy of their regulation became the subject of policy deliberation and academic inquiry, and a condensation point (cf. Kearnes, et al. 2006a) for critics' concerns regarding government oversight of the nascent field. This chapter investigates Australian political and policy responses to nano-sunscreen regulatory debates as a site at which the outworking of features identified in earlier chapters may be observed. I argue that the emphasis by public servants on propelling the closure of these debates, and the form and the expression of the interventions they made, can be understood only in the context of the 'market failure' rationales (cf. Dodgson, et al. 2011; Marsh and Edwards 2008)[1] and scientistic framing (cf. Doubleday and Wynne 2011; Kleinman 2005; Wynne 2006)[2] that constrained nanotechnology policy (Chapter 5). Fostering favourable public opinion, particularly by containing public perceptions of risk, was identified by public servants as one of the few sites at which they could properly seek to further the government's declared nanotechnology development objectives.

The science and technology studies (STS) literature shows how in addition to widely shared 'technologically progressivist' commitments that treat technology-enabled social 'progress' as linear, "self-propelling" and "always for the good" (Kleinman 2005, 5; see also Sarewitz 1996; Stirling 2009a, 2010; Part B Introduction), regulatory structures (Jasanoff 2005a; Kinchy, et al. 2008; Moore, et al. 2011; Stirling 2008a, 2010a; Winickoff and Bushey 2010) and the dominance and obduracy of risk discourse (Szerszynski, et al. 1996; Wynne 2001; 2002; see also Beck 1992) repeatedly reduce potentially rich dialogues regarding technology policy to scientistic terms. As a consequence, in earlier controversies such as that surrounding

[1] For an explanation of 'market failure' policy rationales see Chapter 1.
[2] For my treatment of scientism see Part B Introduction.

genetically engineered (GE) crops, debates regarding risk and regulation functioned as a locus at which to also contest normative questions and sociopolitical relations (Gottweis 1998; Jasanoff 2005a; Kearnes, et al. 2006a; Kearnes, et al. 2006b). This chapter shows that Australian political and policy responses to nano-sunscreen regulatory debates both reflected these general phenomena and were shaped by context-specific features. The latter included the constraints of 'market failure' rationales on policy designed to foster nanotechnology's commercial development, and, in the context of limited high-level political interest in developing more meaningful forms of industry support, the proactive role in fighting "battles over public opinion" (cf. Cormick 2011, 2) assumed by small numbers of public servants.

The chapter begins by exploring the particular significance of sunscreens in Australian preventative health initiatives. I then trace how the use of nanoscale active ingredients in sunscreens gained prominence in nanotechnology policy debates, first as an example cited by proponents of the field's 'revolutionary' promise and later as an object of anxiety. I show how debates surrounding the risks associated with nano-sunscreen became a site at which government's oversight of the field was challenged and defended, and how public opinion was identified by key public servants as a "battle" ground in efforts to both promote emerging technologies development and to defend 'science' itself (cf. Wynne 1982). I investigate the presentations of public servants and metrologists at the 2012 International Conference on Nanoscience and Nanotechnology, which marked a turning point in Australian nano-sunscreen regulatory debates. Finally, I briefly describe the aftermath of definitional disputes regarding the presence of nano-ingredients in Australian sunscreens, and the 'unsettled settlement' (cf. Jasanoff 2005a) the debate reached. The chapter's investigation spans the nano-sunscreen debate in 2005-2013, with particular focus on events in February 2012. It encompasses archival work, the observation of a consultative forum on nano-regulation, and interviews as described in Chapter 1.[3]

6.1 The sunburnt country

In the years following the 2004 RS/RAE inquiry, the potential environment, health and safety (EHS) risks posed by novel nano-ingredients used in industrial, household and environmental products attracted increasing attention from policy makers world-wide. Prominent scientists

[3] Requests for interviews with representatives of the Therapeutic Goods Administration, the Australian Competition and Consumer Commission, and the National Industrial Chemicals Notification and Assessment Scheme were ignored or denied.

warned that: “the spectre of possible harm — whether real or imagined — is threatening to slow the development of nanotechnology unless sound, independent and authoritative information is developed on what the risks are, and how to avoid them” (Maynard, et al. 2006, 267). Yet, in a phenomenon identified in earlier STS work (Jasanoff 2005a; Wright 1994), as governments began sponsoring EHS risk research and grappling with more or less similar sets of incomplete and uncertain risk data, their regulatory responses to the new nano-products varied. Illustrating the situated (re)constitution of policy meaning, whereas European policy makers introduced nano-specific regulation and labelling for sunscreens (Shelley-Egan and Bowman 2015),[4] in sun-loving Australia calls for similar measures were rejected and cast as a threat to skin cancer prevention initiatives.

Andrew Barry (2013, 8) urges analysts to “attend to the historically and geographically contingent ways in which diverse events and materials come to be matters of public dispute”. He suggests that individual technoscientific controversies “must be understood as elements of multiple political situations of which they form a part” (Barry 2013, 6). This chapter locates Australian nano-sunscreen regulatory debates within two key political situations. In one, government was seeking to promote nanotechnology development, with a particular emphasis on fostering favourable public opinion (DIISRTE 2012c). And in another, public health initiatives sought to reduce skin cancer by promoting ‘sun safe’ behaviour, in which sunscreen use featured prominently (Montague, et al. 2001). As subsequent sections of the chapter show, public servants charged with promoting nanotechnology were able to harness the considerable credibility and public status of anti-cancer advocates to depict calls for nano-sunscreen regulation as threatening publics’ confidence in sunscreens safety and therefore their likely sunscreen use. This strategy enabled policy makers to discredit calls for nano-specific sunscreen regulation as ‘putting lives at risk’, thereby diminishing what the industry department saw as a threat to the “community confidence” that would underpin nanotechnology’s expansion (see Figure 3, Chapter 5). Here, I provide a brief introduction to the centrality of sunscreen in Australian public health policy.

Sunscreen occupies an unusually important place in Australian public life. Following the 18th century British invasion, the unfamiliar climate encountered by colonists was often

[4] European regulation for nano-sunscreens and cosmetics was not unproblematic. Along with other nano-specific regulation its implementation faced significant technical challenges, while its core definitions, including for nanomaterials, were the subject of heated debate (see G. Miller and Wickson 2015).

experienced as hostile (W. Anderson 2002a). Yet, over time, both the warmth of the climate and the strength of the sun became celebrated. In Dorothea Mackellar's *My country*, perhaps the nation's best known poem, Australia's "wide brown land" is described affectionately as the "sunburnt country" (Mackellar 2011 [1908]). The healthfulness of an outdoors life and tanning which signified it was lionised (Fiske 1997), and beach culture played a strong role in myth making about Australian identity domestically and abroad (Perera 2009). Yet the nation's enthusiasm for sun exposure came at a cost. Australia has more than 12 times the average world rate of melanoma (AIHW 2012); in a population of 24 million skin cancer kills over 2,200 people each year (ABS 2015). The healthfulness of sun exposure has been reimagined in recent decades, in part reflecting the efforts of anti-cancer advocates.

'Sun safe' behaviour is vigorously promoted by the Cancer Council, a high profile national not-for-profit agency (Montague, et al. 2001). Since 1980 the Cancer Council has engaged in "population-based campaigning" and mass advertising with a "slip, slop, slap" message – "slip on a shirt, slop on some sunscreen and slap on a hat" (Montague, et al. 2001, 290, 291).[5] It is described as "one of the most successful health campaigns in Australia's history" (Cancer Council Australia 2016, unpaged). Since 1988 the Cancer Council has collaborated with state governments to deliver the 'SunSmart' program, which promotes behavioural change, and institutional and legislative action (Montague, et al. 2001). This has also been highly successful. Around 80% of schools have a written sun protection policy, requiring children to wear a hat and sunscreen before they are allowed to play outside (S. Jones, et al. 2008), commonly referred to as the 'No Hat, No Play' rule. Similarly, employers' responsibility to provide safe working conditions has been extended to limiting workers' UV exposure (ASCC 2008).

Rather than a simple cosmetic product, in Australia sunscreen has become the core of a state-sanctioned technological response to the very high national incidence of skin cancer. Indeed, sunscreen is "the most frequent method of sun protection used across all [Australian] age groups" (Stanton, et al. 2004, 369). Studies have found that wearing sunscreen may prompt individuals to stay longer in the sun, sunscreen may not filter all UV exposure, and insufficiently frequent or inadequate application of sunscreen may hamper its efficacy (see W. McCarthy 2004; Stanton, et al. 2004). This is reported to have influenced public education programs to emphasise the value of sunscreen as an *adjunct* to other sun protective behaviours such as seeking shade and covering up with clothing and a hat, rather than as a

[5] Since 2007, the message has been extended to include "seek" (shade) and "slide" (on sunglasses).

replacement (W. McCarthy 2004). Yet despite these recommendations most Australians use sunscreen as their preferred form of sun protection, helping to explain the emphasis of anti-cancer advocates on maintaining confidence in its safety.

The commitment to maintaining public confidence in sunscreen led anti-cancer advocates and other policy stakeholders interviewed for this research to be wary of public discussion of nano-ingredient risks. As explored above, ‘deficit model’ assumptions attribute publics’ technological ambivalence to their ignorance or misunderstanding of scientific ‘facts’ (Wynne 1991, 1993). Exhibiting such assumptions, many interviewees understood publics to be intolerant of scientific uncertainty, vulnerable to confusion, and reliant on unqualified assurances of sunscreen’s safety and efficacy in order to comply with prescriptions for its use (on the implicit identification by Australian policy makers of a "cognitive deficit" among publics, see Dietrich and Schibeci 2003; Harwood and Schibeci 2008). In this context, many interviewees located nano-sunscreen regulatory debates in a political situation in which such debates threatened public health initiatives.

In an interview with me then Chief Executive Officer of the Cancer Council of Australia Professor Ian Olver observed that nano-sunscreen regulatory debates could jeopardise public confidence in sunscreen:

> “*I think they’re unhelpful. Over 1800 people lose their lives from skin cancer [each year]. Now that’s a fact. People die and we’re trying to stop them dying. The fact that something might happen against that is important. How important is difficult to say, but if it stopped one person from using sunscreen, I’d be really concerned, and we know from [the government’s] research that it has stopped people... So I find it unhelpful to take a genuine concern into the public forum, and the public don’t understand the nature of evidence... So as I said before, you’d be far better for the people that want to convince the government [of the need for regulatory change] to get a whole bunch of well-credentialed scientists on their side to make the case*” (Ian Olver, Interview November 2013).

Olver recognised that “genuine concern” existed regarding risks associated with nano-sunscreen but cautioned that it was “unhelpful” to take such concern “into the public forum”, or to involve wider publics in policy debates, given the Cancer Council’s focus on “trying to stop them dying”. That is, Olver argued that public discussion of the need for nano-sunscreen regulation could jeopardise lives by dissuading people from using sunscreen. For publics' own good they must be insulated from scientific uncertainty, given they "don't understand the nature of evidence" (a position that accords very closely with that of the experts described by Callon, et al. 2009, 108). Instead, Olver suggested that "well-credentialed scientists" should be trusted to make the case to government, in private forums, for regulatory change.

Having shown the particular salience of sunscreens in Australia, in the following sections I trace the use by proponents of nano-sunscreen as an early emblem of nanotechnology's 'revolutionary' promise, before concerns emerged regarding its health risks.

6.2 Contesting the revolutionary through the quotidian

The regulation and labelling of nano-ingredients in sunscreen may seem an unlikely site to contest or to defend the promise of the nanotechnology 'revolution'.[6] So it is striking that alongside the perceived salience of the nano-sunscreen regulatory debate for public confidence in *sunscreen*, many Australian actors associated it with both challenges to the legitimacy of state support for *nanotechnology* and the fields' prospects for commercial development. The internal government correspondence I obtained under *Freedom of Information Act 1982* (FoI) requests, and the interview comments and public statements of a broad range of stakeholders, suggest such an operating assumption. The prevalence of this view among policy makers is in part explained by the architecture of national nanotechnology policy explored in Chapter 5.

In the context of the narrow 'market failure' rationales on which the National Enabling Technologies Strategy (NETS) was based, sponsoring metrological work, coordinating EHS risk regulation and undertaking "public awareness" activities were identified as the principle means by which government would promote nanotechnology development (DIISRTE 2012c, 238). The metrological work, which received roughly half the NETS budget (DIISR 2010), was undertaken by the National Measurement Institute (NMI). While a division of the industry department, the NMI was largely outside the purview of the NETS policy office. And whereas the NETS office coordinated dialogue between the regulators whose responsibility it was to determine regulatory responses to EHS risks, public servants felt limited agency over the

[6] Although of course product labelling was the focus of public debates in earlier technological controversies such as that surrounding genetically engineered crop (Gottweis 1998; Jasanoff 2005a).

outcomes of these activities (Chapter 5). This left "community confidence" not only as one of the key 'barriers to innovation' (cf. Balmer and Molyneux-Hodgson 2013; Molyneux-Hodgson and Balmer 2014; see also Kearnes and Wynne 2007) identified by the industry department (see Figure 3), but, with close to one quarter of the NETS budget (DIISR 2010), also a site at which public servants could pick and choose the "battles" they saw as useful to government's innovation agenda. The following sections explore how competing claims regarding the 'revolutionary' qualities of nano-sunscreens, and the adequacy of their regulation, became identified as such a "battle" site.

6.2.1 Revolution in a bottle

In the early 2000s, as proponents sought to consolidate state support for nanotechnology, they pointed to the commercial availability of nano-sunscreens as evidence of an imminent nanotechnology 'revolution', in which more sophisticated and spectacular products would soon appear.[7] At the United States (US) Congressional hearings investigated in Chapter 4, nano-sunscreens, cosmetics and computer hard disks were cited as evidence that "nanoscience and nanotechnology are not dreams but are here today in products and technologies we currently use" (Committee on Commerce 2002, 26). Similarly, in promotional material then Australian Minister for Industry Ian Macfarlane referenced Australian-made "clear UV-resistant sunscreens" to substantiate his assertion that the country was "equipping itself to be at the forefront of this technological revolution" (Invest Australia 2004, 2). In such claims, these everyday products were made to do political work. Proponents used nano-sunscreens to demonstrate the novel biophysical properties of the new 'miracle' materials – UV-absorbing zinc oxide and titanium dioxide that had a white and chalky appearance in bulk form became transparent in nano-form – but also to bolster their assertions that promissory claims for nanotechnology were based in commercially relevant 'science fact' rather than 'science fiction' or "dreams". That is, despite the quotidian nature of sunscreens and cosmetics, the 'miraculous' properties of the nanomaterials they contained were used to corroborate the more ambitious claims made for the coming nanotechnology 'revolution'.

Proponents' use of nano-sunscreen to legitimate their 'prospective techno-futures' (cf. N. Brown, et al. 2000) in part reflected their lack of options. In 2004 the RS/RAE estimated that

[7] This promise was later implicit in the 'four generations of nanotechnology' proposed by Mihail Roco (2007), in which the use of 'passive nano-structures' – such as those found in sunscreens – was characterised as 'first-generation' nanotechnology.

the skincare sector was the biggest commercial user of nanomaterials internationally, far in advance of any other (RS/RAE 2004, Table 4.1). Yet the mobilisation of novel materials used in apparently familiar products to support the speculative and spectacular promissory claims of technoscience also has historical precedents, for example as Alison Clarke (1999) shows in her study of the earlier 'miracle' material Tupperware. Clarke (1999, location 123) suggests that – as we see in relation to nano-sunscreens at the hearing cited above – a key component of Tupperware's appeal was that it was "at once mundane and extraordinary". Similarly, the contingent distinction between such attributes in Bakelite, the first wholly synthetic plastic, is shown by Wiebe Bijker (1995). Yet, just as with the new generations of plastics, in time nano-sunscreens also became a site of ambivalence and social critique. Concerns emerged regarding the novel EHS risks of nanomaterials, and the 'miraculous' qualities of nano-sunscreens themselves attracted critical attention.

The RS/RAE inquiry marked the beginning of a less straightforwardly positive image for nano-sunscreens. The report noted the novel physicochemical properties of nanomaterials and their poorly understood toxicological risks, the intimate nature of sunscreen and cosmetics use, and the lack of nano-specific product regulation (RS/RAE 2004). In particular, it observed the photoactivity of some nanomaterials which had been associated with "phototoxic effects on cultured mammalian cells and their DNA *in vitro*" (RS/RAE 2004, 44). The report recognised that the ability of nanoparticles to be taken up through skin was poorly understood, especially in relation to damaged skin. It recommended that ingredients in nanoparticle form be assessed by regulators as new chemicals (recommendation 18), required to pass safety testing before being permitted for use in products (recommendation 24), and listed on product labels to enable informed purchasing choice (recommendation 26).

As we saw in Chapter 5, policy makers in the industry department deferred to the Therapeutic Goods Administration (TGA)[8] on questions of nano-sunscreen regulation, and the TGA rejected the RS/RAE recommendations. In 2006 the TGA conducted a literature review on risks associated with nano-ingredients in sunscreens which concluded that:

> "*There is evidence from isolated cell experiments that zinc oxide and titanium dioxide can induce free radical formation in the presence of light and that this may damage these cells (photo-mutagenicity with zinc oxide). However, this would only be of*

[8] Under Australian regulation, sunscreens that have a Sun Protection Factor (SPF) rating >15 are regulated as therapeutic sunscreens by the TGA; sunscreens with SPF of ≤15 are regulated as cosmetic sunscreens by the National Industrial Chemical Notification and Assessment Scheme (NICNAS).

concern in people using sunscreens if the zinc oxide and titanium dioxide penetrated into viable skin cells. The weight of current evidence is that they remain on the surface of the skin and in the outer dead layer (stratum corneum) of the skin" (TGA 2006, 15).

The regulator argued that new, nano-specific assessment and labelling for nano-forms of zinc oxide and titanium dioxide was not warranted given "the weight of current evidence" that their uptake through dead outer layers of skin, and therefore their ability to reach "viable skin cells", was nil or very low. That is, the TGA judged the risks to sunscreen users posed by nano-ingredients to be low, irrespective of these ingredients' potential hazard, given the absence of evidence that exposure took place. The TGA elected not to introduce nano-specific regulation or ingredient labelling. This meant that as it had previously approved bulk forms of zinc oxide and titanium dioxide for use in sunscreens, the use of their nano-forms would trigger no new notification or regulatory assessment.[9] This position faced early criticism from environment and social justice group Friends of the Earth Australia (FoEA) in a report it produced with FoEUS (FoEA 2006b).[10] The groups argued that the novel properties of nano-ingredients warranted their precautionary treatment. They called for nanomaterials to be regulated as 'new chemicals' and subject to new notification, assessment and labelling requirements in line with the RS/RAE recommendations. However, the TGA's subsequent literature reviews reiterated its initial conclusion that there was no clear evidence of skin uptake, and so no need for new assessment procedures (TGA 2009, 2013). It reiterated its commitment to a "weight of current evidence" approach, despite uncertainties and knowledge gaps in the literature.[11]

The use by nanotechnology proponents of nano-sunscreens as a 'first-generation' exemplar of nanotechnology's revolutionary potential (cf. Roco 2007) was initially convenient. However, as concerns emerged regarding EHS risks, nano-sunscreens' identity was (re)enacted (cf. Law 2004; Mol 2002) in anticipation of new audiences – regulators and wider publics (on

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[9] On the regulatory 'gap' produced by much existing regulations' failure to distinguish between 'nano' and 'bulk' forms of a given substance see Karinne Ludlow and colleagues (2007). On the potential ramifications for the TGA's approach of applying the precautionary principle to the assessment of nano-ingredients in sunscreen, see Thomas Faunce and colleagues (2008).

[10] I was a co-author of this report. Friends of the Earth Australia (FoEA)'s interest in and criticism of nanotechnology was wide-ranging. The group argued for a moratorium on the commercial use of nanotechnology until precautionary management of EHS risks had been introduced, along with participatory forms of sociopolitical oversight (FoEA 2006a, c). FoEA explained its early interest in nano-sunscreens and cosmetics as reflecting the skincare sector's significance as "one of the primary early adopters of nanomaterials" (FoEA 2006b, 5).

[11] The TGA's position placed the burden of proof of skin uptake on advocates for nano-specific assessment. In this, its position affirmed dominant 'epistemic form' (cf. Kleinman and Suryanarayanan 2012) that marginalises recognition of scientific ignorance and uncertainty.

'audiencing' see Mahony 2015, 157).[12] Rather than a powerful new *technology*, nano-sunscreens were now enacted as familiar, essential skincare *products,* whose policy appraisal was properly the domain of technical experts (this reductive move is of course itself familiar, eg Jasanoff 1995). This was no doubt expedient for proponents who sought to limit the scope for sociopolitical dissensus to questions of toxicological risk (cf. Barry 2001; Callon, et al. 2009; Kinchy, et al. 2008; Moore, et al. 2011; Winner 1986). The focus on technical dimensions of risk management was also promoted by the RS/RAE inquiry, and by historical precedent as discussed previously. However, the enactment of nano-sunscreen as a 'scientific' policy object whose meaning would be arbitrated by 'science' alone (cf. Doubleday and Wynne 2011; Wynne 2006; Wynne 2014) was also a product of the framing and design of Australian nanotechnology policy (Chapter 5). This had implications for the interventions in policy debates of proponents and critics alike, as we will see.

6.2.2 The multivalence of risk debates

In a phenomenon well remarked in earlier studies (Jasanoff 2005a; Kearnes, et al. 2006b; Kinchy, et al. 2008; Moore, et al. 2011; Winickoff and Bushey 2010), members of unions and NGOs interviewed for this research described difficulties in challenging nanotechnology oversight and in communicating their concerns in terms other than those of EHS risk.[13] Nevertheless, the attention of NGOs and unions to issues of risk was not simply a product of such constraints. Regulatory responses to risk were themselves seen by these groups as materially important and inherently political.[14] Interviewees described regulators routinely

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[12] On subject-object co-construction and the imagined publics of science see Brian Wynne (2002, 2005). On relationality in promissory work see John Gardner and colleagues (2017).

[13] Asked what they thought of calls for public interest management of non-EHS aspects of nanotechnology, for example in relation to public health, privacy or military concerns, one interviewee replied bluntly: "Utopia really, because in terms of EHS there's some specific stuff that can be – that you can actually tie it to. So there's regulation there... in terms of these other areas... there might be something there, but in terms of the broader – wow" (Community sector, Interview 17, September 2013). Suggesting some acceptance of technology or market-determinism, this interviewee viewed as impossible any attempt to challenge the trajectory of nanotechnology's commercialisation and its governance in terms other than EHS risk. Another interviewee observed that despite having broader sociopolitical concerns, their work had focused on safety issues because these were more easily communicated: "I think it's true that we did focus on the safety issues because the political critique would be incomprehensible to people basically" (Community sector, Interview 39, September 2013).

[14] For example, one interviewee remarked that given industry pressure it was difficult to secure regulatory action even when the health harms of particular substances had been shown. They emphasised that asbestos was not banned until 2003 "after centuries of knowing [its effects]... government reacts to public opinion and if you can't mobilise the public – well you can't go there with confidence and say 'we represent 50%' or 'we represent – and this will make a difference to the voting of these people', it's just too easy to be swept aside I think" (Community sector, Interview 17,

succumbing to pressure from industry to reduce the stringency of EHS risk management – pressure that was openly acknowledged by one regulator at the consultative forum which I observed (see Chapter 1).[15] Given this, I argue that union and NGO campaigns on nano-safety must be understood as multivalent – simultaneously embodying concerns regarding material risks, and (often implicit) challenges to the social relations in which risk is produced, experienced, appraised and managed (cf. Wynne 2002). However, somewhat differently from previous STS work, in this chapter I stress that such multivalence was not specific to the activities of nanotechnology critics, but was characteristic of all participants' contributions to nano-sunscreen regulatory debates.

Just as dominant discourses and regulatory structures often channelled the interventions of nanotechnology critics into scientistic terms, so too did they shape the advocacy of nanotechnology's proponents. 'Market failure' and scientistic policy framing made it difficult for public servants charged with promoting nanotechnology's expansion to acknowledge their own industry development agenda (Chapter 5). This resulted in their pursuit of innovation objectives through interventions whose meaning was framed as 'scientific' and whose focus was often on questions of risk and their perception, such as those investigated in this chapter. Indeed, illustrating the influence of scientistic commitments, even politicians whose advocacy for the emerging sector was explicit sought to promote and defend their aspirations for *nanotechnology* by delegitimising concerns regarding *nanomaterial risks*. In this way, albeit tacitly, both nanotechnology's proponents and critics accepted risk issues as a key terrain on which questions regarding the social license of the emergent technology would be resolved, and identified "public opinion" as a strategic site in this struggle.[16] The next section explores the multivalence of political responses to nano-sunscreen risks, including the identification of risk concerns as a threat to efforts to actualise nanotechnology imaginaries.

September 2013). In this statement, in the face of unequal power relations, "public opinion" is a source of democratic authority for advocates for workplace and public safety who seek to "mobilise the public" to secure regulatory outcomes resisted by industry.

[15] At this event a regulator (whose institution I do not identify) decried industry pressure and the inadequacy of resourcing for their activities: "As [a regulator] it is very difficult for us to reject a product, to say that it should not be on our register. We have to look at the data more closely when we reject a product, it's a lot more work. Our intent is to approve most products… We're given a set of data from the sponsor. We get a lot of sponsors who will push back and take legal action if you reject them. It can get quite ugly. If we are going to reject an application we have to look at it very carefully before we reject anything". Significantly the inadequacy of resourcing for regulators to properly address nanotechnology was observed by both industry and community sector interviewees.

[16] On nanotechnology critics' emphasis on "public opinion" as necessary to secure regulatory outcomes resisted by industry see community sector interviewee statements cited in previous footnotes.

6.2.3 Nano-sunscreen regulation vs social progress

As the Minister for Innovation, Industry, Science and Research, Kim Carr depicted concern regarding nano-sunscreens as a form of "anti-science" that threatened the realisation of nanotechnology's progressive potential. At a 2013 ceremony to turn the first sod for the new $131 million Australian Institute of Nanoscience (AIN), of which the federal government had contributed $40 million, Carr explicitly celebrated the AIN's construction as a triumph in this struggle:

> *"Three years have passed since I announced the funding for this facility...this was the sort of research guaranteed to bring out the anti-science crowd... It was as if the Enlightenment had never happened. It was as if nanoscience was some kind of global conspiracy to kill us all with sunscreen. But I saw this project differently... The great potential of nanoscience was already abundantly clear to me, and anyone else who was serious about asking these questions. We were seeing sensors to make workplaces safer. New treatments for disease, including cancer and AIDS. New clean energy solutions, from solar cells to carbon storage*..." (Carr 2013, unpaged).

Scepticism of technological innovation agendas and critique of particular technologies has in the past often been "stigmatised as indiscriminate 'anti-science'" (Stirling 2009a, 10; see also Kinchy, et al. 2008; Kleinman 2005; Wynne 2014, 2016). In this vein, Carr associated concern regarding nano-sunscreen risks with a "global conspiracy" theory among those for whom "the Enlightenment had never happened". In this account, the heroic quest to cure disease and to confront climate change via "the great potential of nanoscience" required the casting aside of anxieties regarding nano-sunscreen, and active disregard of "the anti-science crowd".

Carr's location of calls for nano-ingredient labelling in a political situation in which the greater potential for nanotechnology-enabled social progress was at stake (see also Chapter 5) was underscored in an interview for my research. In response to a question asking whether he would "support labelling of manufactured nanomaterials added to industrial or consumer products", Carr replied that:

> "...*the focus on labelling in the public debate tends to obscure the real issue. What we need is a genuine understanding about this emerging science, and the defining role it will play in the century ahead. It is incredible to me that nanotechnology has the capacity to rebuild fractured spinal cords, clean up toxic waste, revolutionise the modern motor car – and we spend all our time arguing about labels on sunscreen. We*

> *have people demonising the very notion of nanoparticles without heed to the scientific evidence or understanding of what the science actually entails. Labels can only be helpful if people have a genuine understanding of what the label represents"* (Kim Carr, Written comments, February 2014)

In this statement, Carr unfavourably compared debates regarding "labels on sunscreen" with "the defining role [nanotechnology] will play in the century ahead". Ironically, with sunscreens no longer serving as a useful instantiation of nanotechnology's promise, Carr suggested that calls for nano-sunscreen labelling constituted a distraction from "the real issue" of nanotechnology's potential. Carr mobilised both public ignorance and "the science" – scientific knowledge regarding nano-sunscreens' safety – as reasons not to label nano-ingredients. Yet in support of this position he simultaneously leveraged another kind of 'science': expectations of the transformative potential of a hoped-for future nanotechnology (cf. Borup, et al. 2006; N. Brown and Beynon-Jones 2012). In his reply Carr sidestepped questions regarding how the much-touted novel properties of 'first-generation' nano-products would be regulated, and whether information regarding nanomaterials in commercial use should be available to wider publics, workers, employers and product manufacturers. Instead, Carr counter posed calls for nano-product labelling with efforts to realise what he suggested was the technology's great social promise.

The characterisation by government actors of nanotechnology critics as "anti-science" and as threatening societal advance was most palpable in their use of 'war on science' discourse.[17] In 2011 Carr wrote a newspaper opinion piece accusing nanotechnology critics (among others) of engaging in a "war on science" that threatened to "turn back the Enlightenment" (2011, 14). The opinion piece depicted a 'one-track race' (cf. Stirling 2009a, 2010a) in which the choice faced by Australians was to embrace nanotechnology or "to stay in the caves of mediocrity" (Carr 2011, 14). In the same period, a series of workshops and conference presentations by the manager of the NETS Public Awareness and Community Engagement (PACE) program Dr Craig Cormick were titled "The war on science". Cormick characterised public debate surrounding emerging technologies as "a war of **values** and world views" (Cormick 2011, 1, emphasis in

[17] The 'war on science' discourse was popularised during President George W. Bush's administration. Having already alienated large swathes of the scientific sector with his policies on climate change and stem cells research, Bush supported moves to introduce 'intelligent design' to schools' curriculum, at the same time as Chris Mooney's (2005) best-seller *The Republican War on Science* was being published. Two interviewees linked Kim Carr's 'war on science' language to his anger at attacks on climate science.

original), in which the epistemic authority of 'science' itself was at stake (cf. Wynne 1982). The following section investigates the engagement of NETS-PACE staff in this "war".

6.2.4 "Battles over public opinion"

Chapter 5 illustrated how, in the absence of political preparedness to offer more direct forms of industry support, NETS emphasised building "community confidence" as a means to foster nanotechnology's commercial development (DIISRTE 2012c). Guided by this strategy, yet motivated also to defend what they saw as 'science under siege', the staff of NETS-PACE engaged proactively in what Cormick (2011, 2) identified as "battles over public opinion". They were informed by occasional public statements and cues from the Minister, and by NETS' broadly articulated policy objectives (DIISR 2010). Nonetheless, as NETS-PACE staff sought to fight a "war" on behalf of the government's nanotechnology development agenda and of 'science' more broadly, they exercised a high degree of autonomy. To contextualise their interventions in nano-sunscreen regulatory debates, I make some brief observations regarding the engagement of NETS-PACE in these "battles".

As NETS-PACE manager, Cormick argued that: "**public sanction** is needed for new science and technologies, but public sanction needs to be based on **fair** and **balanced information** and **discussion**" (Cormick 2011, 1, emphases in original). That is, even though he and his colleagues were charged with promoting emerging technologies, Cormick assumed the prerogative to determine what constitutes "fair and balanced" public discussion. This position raises difficult questions regarding the standards by which "balance" in public debate is to be judged and applied, not least in relation to questions of "values and world views", and the plurality of potential development pathways (cf. Stirling 2009a, 2010a; Vallas, et al. 2011). Cormick had previously been manager of public awareness for Biotechnology Australia, precursor to NETS and model for its development (Chapter 5). In this capacity he acknowledged intervening in public discussions to "seek balance" by supporting promotional interventions, when in his view "there was a strong anti-line dominant" (Cormick 2002; see also Salleh 2005).[18] That is, in Cormick's view, in debates regarding whether Australia should accept GE crops and food and on what terms, achieving "balance" required public servants to orchestrate interventions to

[18] On a conference list-serve Craig Cormick (2002, unpaged) wrote: "In seeking balance, back in 2000, when there was a strong anti-line dominant the strategy adopted at the time had been to seek more input from the other side. The public debate has changed a lot since 2000 of course and we are less likely to need to recruit anybody to seek balance through polarised replies to public statements".

‘correct the record’, even if such interventions were not themselves ‘balanced’ (cf. Callon, et al. 2009, 108). Analysts have observed that Biotechnology Australia sought “to manage community concern and opposition to biotechnology... by depoliticising issues and/or alleviating [concern], with more ‘facts’” (Harwood and Schibeci 2008, 154). Some years later, the NETS-PACE opinion polling on nano-sunscreens investigated later in the chapter seemingly illustrates the use of this strategy.

The apparently passionate participation of some NETS-PACE staff in the “battles over public opinion” did not mean that these debates attracted substantial interest from the wider industry department or from high-level politicians. Just as nanotechnology proponents interviewed for this research observed the absence of political leadership for nanotechnology industry development (Chapter 5), critics identified the policy debates surrounding emerging technologies – in which they participated – to be of marginal interest to most of government. Some interviewees observed a disjuncture between the ostensibly progressive NETS objectives and their experiences of NETS-PACE activities (see also Civil Liberties Australia, et al. 2010; Lyons and Whelan 2013). One interviewee suggested that despite some positive NETS initiatives, such as the Science and Technology Engagement Pathways program (see Marks and Russell 2015; Russell 2013) and some of the EHS training, many of the public materials produced by NETS-PACE were “appalling”. They attributed this to the lack of “consistent oversight by the responsible Minister or his staff” (Community sector, Interview 17, September 2013). Similarly, another interviewee suggested that: “I think it’s a few bureaucrats taking it upon themselves to do stuff. I don’t think government at the government level, at the executive level, only really got engaged [unless] we made them, otherwise they wouldn’t really care, they would just – ‘yes, sounds good, tick’” (Community sector, Interview 39, October 2013). The form in which public servants intervened in public debates was constrained by the ‘market failure’ and scientistic framing of nanotechnology policy – their interventions were necessarily couched in the language of ‘science’, and aimed to advance the (sometimes tacit) nanotechnology development goals of government. Yet the high degree of latitude possessed by NETS-PACE bureaucrats was an expression of the lack of high-level political engagement in nanotechnology policy implementation. With a risk debate rumbling on, and a Cabinet and industry department largely disinterested in nanotechnology, the dedicated nanotechnology policy office was effectively left to pick and fight its own “battles”, among which it identified the nano-sunscreen regulatory debate.

Having shown the particular salience of sunscreens to Australian public health initiatives, how the 'revolutionary' promise of nanotechnology became associated with questions of nano-sunscreen safety, and the emphasis by public servants on public opinion as a "battle" ground, in the next section I explore the events and activities that led to nano-sunscreens becoming the focus of a minor public debate.

6.3 Making things visible

6.3.1 Roofs, textiles and unexpected observations

Policy discussions surrounding nano-sunscreen regulation were given impetus by a surprise discovery by industrial scientists. Philip Barker and Amos Branch were researchers at BlueScope Steel, a major Australian metal manufacturing company that produces popular roofs and fencing. They reported that from mid-2006, the company had observed unusually accelerated weather damage in its newly installed pre-painted metal roofs (Barker and Branch 2008). In some instances damage that would ordinarily take fifteen years had occurred in six weeks. Barker and Branch traced this to workers installing the roofs wearing nano-sunscreen and leaving behind a residue on the roof surface. The weathering was highly localised; in some places individual fingerprints could be observed. A controlled study demonstrated that some nano-ingredients exhibited an "aggressive, photocatalytically initiated, free-radical degradation mechanism" (Barker and Branch 2008, 313). The weathering of surface gloss caused by sunscreen active ingredients varied: organic chemicals did not catalyse much reduction; the one nano zinc oxide tested resulted in 50% more surface gloss loss in 12 weeks than no sunscreen application; and the most potent effect was exerted by a mix of anatase and rutile crystal forms of nano titanium dioxide, which accelerated weathering 100-fold (Barker and Branch 2008).

An industry interviewee for this research described a comparable and unexpected observation following the first commercial sales of their nano-product. When the same nano-ingredient was used in different formulations applied to outdoor textiles, its behaviour was highly variable:

> "*...in some instances you could improve the colourfastness by a factor of 10, and in other instances you could bleach the colour in a few minutes and we thought 'what's going on, we don't understand it'. And then some work that we'd done on coatings also had shown [weathering] effects, but some neutral and some negative and of*

> *course you can't market a product like that if you don't have the understanding... And that was probably about the same time as when Friends of the Earth sort of said 'we really don't know enough about this'. So I made a conscious decision of withdrawing [our personal care products] from the market at that stage*" (Industry member, Interview 35, November 2013).[19]

Subsequent testing also established a photocatalytic degradation mechanism for the textile weathering observed by the company. As the new nano-products reached the market, this interviewee's statement shows that industry was struggling to understand and to predict the physicochemical behaviour and photocatalytic effect of nanomaterials, and their interaction with a range of coatings and surfaces. At the time, this interviewee viewed the calls for caution of FoEA's campaign as reasonable – indeed, they withdrew from the market their own personal care products.[20]

The results of the BlueScope Steel study could not be extrapolated to interactions with human skin. Specifically, the key issue of whether or not nanomaterials could be taken up through skin, in what quantities, and what the impact of skin condition on such uptake may be, remained contested.[21] Nonetheless, as the "free-radical degradation mechanism" identified by Barker and Branch was also one associated with UV-induced damage to human skin (eg see Scharffetter-Kochanek, et al. 1997), the research prompted new concerns regarding the hazards of nano-sunscreens, especially those containing anatase forms of titanium dioxide. In media comments a CSIRO scientist warned that in a worst case scenario nano-ingredients in

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[19] Subsequent questions established that the company had withdrawn their personal care products from the market: "We left the industrial there, but the industrial wasn't going anywhere because no one could see consistent positive results" (Industry member, Interview 35, November 2013).

[20] Conversely, at the time of interviews for this thesis, the interviewee's attitude had changed. They stressed that after considerable research, "we're now back in the market but we're still now grappling with perceptions that had been built over the last five or ten years that were not unfounded five or ten years ago, but now you've got to start an education process and get people to understand the work [that has been done to improve understanding of nanomaterial behaviour]" (Industry member, Interview 35, November 2013).

[21] The TGA's conclusions and its "weight of current evidence" approach to skin penetration research remained subject to question in the literature. Some reviews backed the TGA view that uptake into viable skin cells was nil or very low (eg Nohynek, et al. 2007). Others emphasised that relevant research had been predominantly short-term, *in vitro* or both, and had largely not investigated the role of skin condition (eg Osmond and McCall 2010). In 2010 a 6-day *in vivo* study on intact, adult skin showed that small amounts of isotope-labelled zinc from sunscreens could be found in the blood stream of volunteers, although it was not possible to tell if the zinc had been absorbed in nanoparticle or ionic form (Gulson, et al. 2010). Equivalent work was not undertaken for titanium dioxide due largely to its cost. In an interview for this research, the then director of CSIRO's nano-safety work estimated that using titanium dioxide enriched with a stable titanium isotope would have cost three times as much as zinc oxide (Maxine McCall, Interview November 2013).

sunscreens could themselves increase the risk of skin cancer, but cautioned that this potential remained largely unknown (K. Murray 2008). That year, FoEA expanded its nano-sunscreen campaign.

6.3.2 The 'Safe Sunscreen Guide'

In the summers of 2008-9 through to 2011-12, FoEA collated and published information regarding the use of nano-ingredients in sunscreens. Based on information provided by sunscreen brands in response to an annual survey it conducted, FoEA produced a 'Safe Sunscreen Guide' (SSG). The SSG listed sunscreen brands in red ("use nano"), amber ("may use nano"), or green ("nano-free" and "nano and chemical-free") categories (FoEA 2011).[22] In order to be listed in the green section, representatives from each sunscreen brand signed a statement that their products did not contain manufactured nanoparticles 1-100nm in size, or aggregates or agglomerates of such nanoparticles (ACCC 2014; FoEA 2012a, b). Many companies gave FoEA certificates of analysis regarding their products' 'nano-free' status, or particle size graphs provided by their suppliers, to substantiate claims that their zinc oxide or titanium dioxide active ingredients were in non-nano form (ACCC 2014; FoEA 2012a, b).

The SSG responded to the 'negative knowledge' (Frickel, et al. 2010; Gross 2007) or 'strategic ignorance' (McGoey 2007, 2012) produced by the federal government in relation to nanomaterials' commercial use, and the absence of mandatory requirements for nano-ingredient labelling. In the context of FoEA's campaign, the SSG had a performative effect. It created a new, 'nano-free' sunscreen category which individuals, organisations and sunscreen companies could choose, in so doing raising the visibility of concerns regarding nano-sunscreens and nanotechnology oversight more broadly. The 2011-12 SSG included over 130 brands, including 33 who were listed as 'nano-free' (FoEA 2011). 'Nano-free' brands included the Cancer Council, the 'own brands' of national pharmacy chains and major supermarkets Woolworths and Coles, and a range of boutique brands. In 2011 many of these brands were marketing their nano-free status, had voluntarily labelled their products, and were providing links on their websites to the SSG. Between December 2011 and mid-February 2012 more than

[22] Elsewhere, the NGO called for case by case nano-specific regulatory assessment, given the diverse physicochemical properties that influence the toxicity of nanomaterials even of the same chemical composition. Nonetheless, its SSG used colour to signify that nano-free sunscreens were 'safe' and nano-containing sunscreens were 'risky'. This representation of nanomaterials as a unitary category is simplistic and in some respects problematic, but it was also a simplification made by other stakeholders including the industry department, nano-safety researchers and the Cancer Council.

10,000 hard copies of the SSG were distributed, and 50,000 online copies downloaded from the FoEA website; additional copies of the SSG were made available from the websites of two television stations (FoEA 2012a).

A range of other NGOs and unions took action on the nano-sunscreens issue, some using information from the SSG to support their own activities. While positive about nanotechnology's application in consumer products, the Australian consumers' association CHOICE called for greater regulation of nanomaterials, and for mandatory labelling of nano-ingredients (CHOICE 2012). In 2010 CHOICE commissioned its own testing of sunscreens for nano-content. In formal policies passed in 2007 and 2011, the Public Health Association of Australia called for precautionary regulation of nano-products, public involvement in decision making, and for 'right to know' measures, including labelling (PHAA 2011). In 2012 the group officially endorsed a report published by FoEA on the need for nano-specific sunscreen regulation (FoEA 2012c). In the context of a wider campaign that focused on efforts to control workplace exposure to nanomaterials (eg see ACTU 2009; Hall 2009), several unions also distributed copies of the SSG. Of greatest political impact on nano-sunscreens was action by the teachers' union.

A 2011 motion that schools "use only nanoparticle-free sunscreen", and that a copy of the SSG be sent to each, was initiated by the Victorian branch of the Australian Education Union (AEU) and subsequently passed by the AEU Federal Executive, becoming a national policy (AEU 2011a, unpaged; AEU 2011b). The union represents teachers at public schools across the country and the resolution attracted media attention in Australia and internationally. Following the motion being passed, FoEA worked with the union to supply schools around the country with a copy of the 2011-12 SSG, planning to distribute a further 50,000 copies to teachers that summer (FoEA 2012a). Spokespeople for the AEU emphasised that the action was precautionary and complementary to the school's SunSafe Program (AEU 2011b). In the context of uncertainty surrounding the potential risks of nano-sunscreens, and given the existence of alternatives, the AEU would prefer that their members used and provided non-nano sunscreens. Yet some suggested that the AEU's action could undermine confidence in sunscreen, potentially jeopardising children's safety (Maynard 2011). In the months that followed, the same accusation was made more forcefully of FoEA's campaign, while the SSG was itself criticised as inaccurate.

6.4 Sunscreen scandal

The chapter has so far illustrated the importance of sunscreen to Australian public health policy, the early focus on sunscreens in nanotechnology policy discussions, the defence of and challenge to nanotechnology oversight through risk debates, and the growing attention to nano-sunscreen regulatory issues in 2008-2011. In this section I explore in detail the events of February 2012 at Australia's largest and highest profile nanotechnology gathering, the biannual International Conference on Nanoscience and Nanotechnology (ICONN). In the midst of an emerging debate over the safety of sunscreens, it was at this conference that government metrologists presented research showing that FoEA's SSG was inaccurate (Coleman, et al. 2012) and that the NETS-PACE manager presented the results of an online poll suggesting it threatened public health (Cormick 2012d; DIISRTE 2012e). These presentations led to FoEA recalling its guide and marked a turning point in the nano-sunscreen regulatory debate.

6.4.1 The NMI product testing

It was product testing by the National Measurement Institute (NMI), a division of the industry department, which showed that the SSG was inaccurate: the guide's list of 'nano-free' sunscreen brands included those whose products were based on nanomaterials. Accurate methods to measure nanomaterials in complex matrixes were then widely sought but remained in development (Linsinger, et al. 2012). Given the domestic profile of the nano-sunscreen debate, it is perhaps unsurprising that the attention of the NMI turned to characterising nanomaterials in sunscreens as it sought to boost its own nanometrological capability. Working with colleagues in the US and using ultra-small-angle X-ray scattering (USAXS), the NMI researchers tested six sunscreens sold by brands listed in FoEA's SSG as 'nano-free'. The metrologists' ICONN presentation, the PowerPoint of which I obtained under FoI (Coleman, et al. 2012), shows that five of these six products contained nanomaterials. It was not that the sunscreens had been found to contain traces of nanomaterials. According to USAXS, the sunscreen's primary particles were *all* nanoscale, ranging in mean primary particle size from 24 to 35 nm (Coleman, et al. 2012, 56). The metrologists found a good comparison with testing by Transmission Electron Microscopy for particles extracted from one of the sunscreens (29nm vs 31nm mean particle size), confirming their USAXS measurements (Coleman, et al. 2012, 61). The testing was inconclusive regarding whether these primary particles were present as 'free' nanoparticles or in clusters of 'secondary nanoparticles' – that is, as agglomerates or aggregates. Nonetheless, they were ‘nanomaterials’ according to all common definitions of the term, including that recently released by the European Commission (2011), and the ‘working definition’ of Australia’s chemicals regulator (NICNAS 2010).[23] Within the parameters of FoEA’s SSG, these sunscreens were definitely not ‘nano-free’.

Friends of the Earth Australia’s campaigner Dr Gregory Crocetti was present in the audience at ICONN when NMI’s Dr Victoria Coleman presented the results of NMI’s work. The PowerPoint presentation contained a photograph of the sunscreen products tested, and information regarding the weight fraction of their active ingredients, along with the particle size detected by USAXS (Coleman, et al. 2012, 56, 60). Crocetti had coordinated the survey for the most recent SSG and had had extensive contact with many sunscreen brands regarding their ingredients and suppliers. He was able to make an educated guess correlating the products displayed in Coleman’s PowerPoint with the results of nanomaterial content that she presented, as emails show NMI metrologists belatedly realised.[24] Moreover, from Crocetti’s previous communications with the sunscreen brands whose products were tested by NMI, he knew the identity of two of the companies that had supplied them with active ingredients. Crocetti knew also that other brands listed in the SSG as ‘nano-free’ sourced their active ingredients from these same two suppliers, meaning that these other brands would similarly discover that their products were based on nanomaterials. Indeed, subsequent work by FoEA identified a minimum of thirteen sunscreen brands whose products, while having been listed as ‘nano-free’, were in fact based on nano-structured zinc oxide (ACCC 2014; FoEA 2012a, b).[25] In the days following the NMI presentation, FoEA withdrew and recycled over 50,000 physical copies of the SSG that were in circulation, and suspended the guide’s online distribution (FoEA 2012a), acknowledging in media interviews that the information in the guide was inaccurate (Lauder 2012). For the NGO’s campaign, it was a dire blow. In the context of efforts to obtain information regarding the commercial use of nano-ingredients by Australian sunscreen manufacturers, it was the first of a series of new twists, as we will see.

[23] Public statements referred to the NMI findings as identifying “nano-structured materials”.

[24] In an update to the General Manager of Physical Metrology two days subsequent to the NMI ICONN presentation, metrologist Jan Herrmann (2012d, 64) wrote that the presentation “did not correlate explicitly specific products with specific results, but it contained a photograph of the six products tested and had a table with the nominal active ingredients as listed on the packaging. For people who know the market, it would, in principle, be possible to deduce what set of results corresponds to what product. FoE’s representative, Dr Gregory Crocetti, who was present at the presentation and is very familiar with the industry, seemed to have been able to do so, at least partially”.

[25] Brands identified by FoEA as affected were the Cancer Council, ChemMart, Coco Island, Coles, Grahams Sunclear, Invisible Zinc, Mukti Botanicals, Natural Instinct, Pharmacy Choice, Terry White chemists, Woolworths, WotNot and Sunzapper (FoEA 2012a, b).

The NMI's actions subsequent to ICONN suggest an organisation surprised and challenged by the unforeseen political dimensions of metrological work, and struggling to justify a series of decisions regarding the selective concealment and display of the knowledge it had produced by appeals to the norms of 'science' (cf. Bijker, et al. 2009; Hilgartner 2000). A draft Ministerial brief on these events prepared by NMI and obtained under FoI emphasised that "accurate and objective information dissemination to the public is a core NETS activity" (Johnson 2012, unpaged). Yet whereas the unique ability of the NMI to provide accurate particle measurement data appeared to be appreciated by all stakeholders in the debate, the selectivity of this information's "dissemination to the public" became controversial. Amidst media attention following the NMI ICONN presentation, senior NMI staff decided not to release copies of Coleman and colleagues' original PowerPoint. Emails show that the NMI released only a redacted version of the slides to FoEA (Herrmann 2012b), journalists (Warrington 2012b), one of the suppliers whose clients' sunscreen products were characterised in the ICONN presentation (Herrmann 2012c), and even to one of the sunscreen brands whose products had been the subject of NMI testing (Herrmann 2012a).

The redacted presentation lacked the image of the tested sunscreen products and information regarding the weight fraction of active ingredients which could be used to identify the products (Herrmann 2012e), but retained images of the FoEA guide and references to the AEU's decision to support nano-free sunscreens' use in schools. This meant that there was no public identification of the brands whose own inaccurate responses to FoEA's survey had led to their listing in the SSG as 'nano-free' – including the Cancer Council – until the original presentation was obtained from NMI by FoEA under FoI several months later. Among other reasons, the NMI's decision not to release the original slides was initially justified to FoEA on the basis that the work had not yet been subject to formal peer review (Herrmann 2012d). However, a Ministerial briefing stated that "NMI conducts rigorous internal review of research results prior to presentation, and does not anticipate any significant change to results as a consequence of external peer review" (in Warrington 2012a, 241). That is, there was a clear and tactical disjuncture in representations of robust 'scientific' practice, and the NMI's conformance with it, to different audiences (cf. Mahony 2015). Interestingly, given the prominence of PowerPoint presentations in this story, another reason given for not releasing the non-redacted ICONN presentation was that "printed slides are only a partial representation of an interactive presentation given at a conference session, where the speaker can also provide additional explanations and clarifications" (Warrington 2012c, 244). This observation is undeniable.[26] And yet, such a rationale does not account for the selective retention and redaction of information and images from the original presentation.

Underscoring the seriousness with which the political dimensions of the NMI ICONN presentation was belatedly approached, internal email correspondence shows that senior NMI staff and the managers of both NETS policy and PACE divisions were involved in preparing rejections to repeated FoEA requests[27] to access the non-redacted presentation (Warrington 2012c). Without access to the original presentation, FoEA and other parties were left to trace the source of the supply chain misinformation without the ability to reference the NMI study. Perhaps most intriguingly, for reasons that are not clear, this selective withholding of the NMI test results extended even to the TGA. In response to interest from the TGA in obtaining a copy of the NMI ICONN presentation, the NETS-PACE manager urged his colleague in the NETS policy office to provide the TGA with a redacted version: "make sure there are no sunscreen product photos in the ppt – very, very important" (Cormick 2012b, unpaged). In this way, the knowledge produced by one set of public servants was actively brokered (cf. Meyer 2010; Meyer and Kearnes 2013) and selectively distributed among others – including the regulator charged with making decisions regarding product assessment, and to whose 'scientific' expertise the NETS office was ostensibly deferent.

6.4.2 The NETS-PACE polling

The finding that FoEA's SSG was inaccurate precipitated a minor scandal, led the NGO to recall its guide from ever-widening distribution (FoEA Undated; Lauder 2012), and appears to have ended the AEU's efforts to support the use of nano-free sunscreen in schools. Yet the NMI's presentation was not alone at ICONN in turning the tide of the nano-sunscreen regulatory debate. The accusation that the campaign for nano-specific safety testing and labelling of sunscreens was putting lives at risk was arguably more influential in propelling the 'unsettled settlement' (cf. Jasanoff 2005a) of the regulatory debate. That accusation was implicit in the keynote address the NETS-PACE manager gave on the second day of ICONN, the slides of which were obtained under FoI (Cormick 2012d), and was more stridently articulated in a Departmental media release issued to coincide with the presentation, headed: "Concerns

[26] On the circulation and interpretation of PowerPoint presentations separate from their original delivery see David Stark and Verena Paravel (2008).

[27] Including my own.

about sunscreen nanoparticles put Australians at risk of skin cancer" (DIISRTE 2012b, unpaged). Underpinning this dramatic claim was an online poll of 1000 people which Cormick had commissioned. The poll found that of the 33% of respondents who had heard media stories regarding the risks of nano-sunscreens, 13% were "completely" or "mostly" less likely to use sunscreen (DIISRTE 2012e). The final slide of Cormick's ICONN presentation stated that "messages can have inadvertent outcomes, and if there are indications of danger to human health or the environment from the message, then the precautionary principle should be observed" (Cormick 2012d, unpaged). The presentation included a photo of a recent FoEA sunscreen action under the heading: "Sunscreen study findings and implications – is the Precautionary Principle needed?", next to a screen shot of a media article titled "Sunscreen concern reaches into the school grounds" (Cormick 2012d, unpaged). The object of Cormick's warning and his call for "precaution" was clear: it was the NGOs' appeals for people to choose 'nano-free' sunscreen and its calls for nano-specific regulation that were the "danger to human health", and "the precautionary principle" demanded a cessation of their campaign.

The presentation and the media release were reported widely. Most influentially, so too was strong criticism of FoEA by the Cancer Council. In the days following the NETS-PACE polling's release, Cancer Council spokespeople argued that the campaign for nano-sunscreen regulation had been exposed as a "scare campaign" that was "very dangerous" (P. Murray 2012). Terry Slevin, chair of the organisation's Occupational and Environmental Cancer Risk Committee and its National Skin Cancer Committee, wrote that the poll's findings: "translate to 4% of Australians choosing to reduce or stop using sunscreen altogether" (Slevin 2012, unpaged). Slevin stressed the uncertainties associated with the "at best, speculative" research "suggesting harm from nanoparticles in sunscreen". He stated that: "A key question is whether people reducing their use of sunscreen would result in more cases of skin cancer. If this is an (inadvertent) outcome of the FOE campaign, it would be tragic and a major setback to cancer prevention efforts" (Slevin 2012, unpaged). On the basis of the online poll, Slevin backed Cormick's call for "precaution" to be exercised by FoEA campaigners.

Nonetheless, despite the impact of the NETS-PACE polling, and its apparent acceptance as a 'scientific' study, the conclusions drawn from it were not supported by the questions it had asked. As John Law and John Urry have shown, surveys and polling do not objectively sample a pre-existing reality but rather enact the social realities that they purport to describe (Law 2009; Law and Urry 2004; on social interaction in interviewing more broadly see Chapter 1).

Yet I emphasise here a further point. Although it was touted by the Department as showing that concerns regarding nano-sunscreens had led people to reduce their use of sunscreen and to put themselves at increased risk of skin cancer (DIISRTE 2012b), the questions asked by the poll did not permit either claim.[28] Polling and focus group work has played an influential role in recent Australian emerging technologies policy (Dietrich and Schibeci 2003; Salleh 2005; Schibeci 2008). Yet Renato Schibeci (2008, 42) has cautioned that despite their results being used to justify nanotechnology and biotechnology policy, surveys conducted by the industry department are not subject to independent review and may be "statistically and conceptually flawed" (Schibeci 2008, 42). This may be particularly problematic when, for example, small percentage changes in measured public opinion have been cited as evidence of trends in favour of particular technologies (eg see Salleh 2005).The NETS-PACE polling presented at ICONN which contained prompting, inadvertently omitted to ask its respondents about their use of alternative 'sun safety' measures (Cormick 2012a; see detail in previous footnote), and made strong claims on the basis of small percentage changes (4.29%) in respondents' preparedness to use sunscreen, is seemingly open to such criticism. What is of particular interest to this study is the NETS-PACE polling's rapid journey from 'claim' to 'fact' (cf. Latour 1987), and its being held to a far inferior evidentiary standard than other contributions to the nano-sunscreen regulatory debate. This suggests its findings' alignment with the deficit model assumptions and the professional allegiances of scientists, science communicators, anti-cancer advocates and parliamentarians, who located themselves on the side of the industry department in a "war on science", efforts to create favourable conditions for nanotechnology's future development, or – as proved increasingly influential – the quest to maintain publics' use of sunscreens.

[28] The Department's media release claimed that "Australians are putting themselves at increased risk of potentially deadly skin cancers by cutting sunscreen use because of concerns about sun-protecting nanoparticles" (DIISRTE 2012b). However the poll had not asked people whether they had in practice reduced their sunscreen use but rather "if you have heard or read stories about possible risks of using sunscreens with nanoparticles in them, do the stories make you any less likely to use sunscreens in general" (DIISRTE 2012e). Questions about actual behaviour would likely have produced different results, particularly if they had not contained prompting; polling commissioned by the Department six months previously had shown the strong influence of prompting on its results (DIISR 2011a, 3, 4). Moreover, in the rush to get data that could be used at ICONN, Cormick had overlooked the need to ask respondents about their use of alternative 'sun safety' measures, such as wearing a hat and protective clothing or seeking shade – measures that health authorities recognise as vital to effective sun protection (W. McCarthy 2004; Stanton, et al. 2004). Cormick later recognised this in email correspondence: "I think we've missed one issue... if people who have heard about nano sunscreen and don't use any sunscreen as a result (about 13% of those) – do they turn to another form of skin protection instead?" (Cormick 2012a). By omitting to ask this question, the survey had no way of determining whether respondents were experiencing greater UV exposure and hence risk of skin cancer.

Strikingly, while the industry department had become focused on prosecuting a sun safety message as the means to pursue its innovation objectives, the Cancer Council emerged as the government's most effective opponent of calls for nano-specific regulation. The polling commissioned by NETS-PACE, and the ICONN presentation and media release based upon it, drew together the two principal political situations in which the nano-sunscreen regulatory debate had meaning (cf. Barry 2013). Now, calling for nano-specific sunscreen regulation was cast by the NETS office not only as a threat to the nascent nanotechnology sector – regarding which most publics, journalists and even policy makers had little interest – but more significantly as jeopardising skin cancer prevention programs. The convergence in these political situations was not a fortuitous yet unforeseen development for the NETS office, but rather the product of its active work.

In the lead up to the release of the NETS-PACE polling, Cormick had undertaken extensive brokering activities. The Cancer Council, along with CSIRO and university researchers and the TGA, had been provided with advance access to the polling results (Canning-Menon 2012) "to ensure they [we]re able to prepare complimentary [sic] statements" (DIISRTE 2012a, unpaged). In an internal email obtained under FoI, Cormick celebrated the success of this strategy, and the extensive media coverage the polling had received: "I have had almost no calls on it from media, which I think shows our strategy was very sound of us just providing data and referencing/ working with the cancer council who are known 'talent' – maximise our impact and minimise our risk" (Cormick 2012c, unpaged). By releasing polling that was based on a facsimile of the practices of 'science' – "just providing data" – the Department had been able to satisfy its charge under NETS of providing "balanced and factual information" (DIISR 2010, 3), thereby "minimis[ing]" its "risk". At the same time, its leverage of the Cancer Council's public profile and gravitas, and its reliance on that body for more overt criticism of the FoEA campaign, boosted the credibility of the poll while guaranteeing the intervention's newsworthiness. According to a logic that identified 'public opinion' as the key 'barrier to innovation', NETS-PACE had advanced the government's nanotechnology development objectives through a new alignment with efforts to safeguard publics' compliance with prescriptions for sunscreen use.

The core purpose of NETS-PACE work was to build "community confidence" to enable "industry uptake of emerging technologies", as shown in Chapter 5 (see Figure 3). Yet the events surrounding the NETS-PACE polling illuminate the lack of straightforward relations between this branch of the industry department and industry. Chapter 5 identified that NETS' primary stakeholders, or 'clients' (cf. Pusey 1991), were within the research sector. Similarly, as Cormick designed his survey and prepared for its public release, his major contacts outside government and the Cancer Council were with nanoscience researchers.[29] The *industry* that was of central interest for NETS-PACE was not the one directly affected by nano-sunscreen regulatory debates, that is the skincare sector, but one whose emergence was still speculative – the 'nanotechnology' industry. The skincare sector's representative body had lobbied government (ACCORD 2010a, 2) and made public comments (ACCORD 2010b) regarding regulatory settings for nano-sunscreens and cosmetics.[30] Industry groups had also been vocal participants in the consultation held by the national chemicals regulator for mooted new nano-specific assessment. Yet this was not a *nanotechnology* industry and many sunscreen companies had marginal interest in the field. In turn, the interest of NETS-PACE in the skincare sector was itself marginal (although this was certainly not true for the regulators). The industry that NETS sought to support was largely unformed. Indeed, through its own activities, and consonant with the overarching NETS strategy, NETS-PACE sought to create favourable conditions for the wished-for nanotechnology industry to emerge.

6.4.3 "A great job given the NETS review!!"

Neither the NETS-PACE polling nor the NMI testing had reflected a top-down direction from senior Departmental staff or Ministerial offices, nor coordination across the two wings of the Department.[31] The respective ICONN presentations were the initiatives of a small number of public servants – although the polling media release was approved by the Department's Secretary and Acting Deputy Secretary (Pettifer 2012) and formed the focus of prior Ministerial briefings, including an unsuccessful attempt by NETS-PACE for then Minister Greg Combet to himself release the results (DIISRTE 2012a).[32] Yet illustrating the perhaps surprising emphasis

[29] Cormick's correspondents included the Chief of CSIRO's Division of Materials Science and Engineering, nano-safety researchers from the CSIRO and two universities, the Cancer Council, the TGA and one redacted recipient (Canning-Menon 2012). The earlier release of these documents, as reported by Katherine Wilson (2012), mistakenly included this recipient, who was identified as an employee of Ego Pharmaceuticals. That is, only one of the people Cormick consulted worked for a sunscreen company.
[30] The body backed ingredient labelling to bring Australia into line with Europe, although it stopped short of supporting calls for nano-specific safety assessment.
[31] Although despite the separate origins of their studies, correspondence obtained under FoI shows a high degree of collaboration between the NMI and NETS-PACE in their release and promotion to media, and subsequent distribution to other parties.
[32] The handwritten note on the document, apparently from the Minister, states: "Not appropriate for a Ministerial release – please issue as a Departmental release" (DIISRTE 2012a, 1). It is unclear if this

the industry and innovation department placed on the nano-sunscreen debate, its Senate Estimates brief for the Minister two weeks subsequent to the ICONN conference focused predominantly on sunscreen issues. The brief touted the NETS-PACE polling, the NMI's measurement work, and the recall of FoEA's guide as demonstrating "that the Government is positively engaging in a debate on the safety and application of nanomaterials and sunscreens" (DIISRTE 2012d, 229). Indeed, as NETS neared the completion of its four-year term and faced review, internal correspondence suggests a perception that the sunscreen controversy – and the ways in which NETS staff had coordinated Departmental responses to it – would reflect well on the program as a whole.[33]

The emergent focus of the industry department on promoting sunscreens use makes sense only in the context of the 'market failure' rationales and the scientistic framing that constrained Australian national nanotechnology policy. As a strategy to foster nanotechnology's commercial expansion, it was modest at best. But as a means to derail public debate regarding the uncertain EHS risks of nano-products, it was effective. Calls for the nano-specific safety assessment and labelling of sunscreen ingredients could now be dismissed by policy makers as a threat to public health – even as some of the key 'scientific' questions remained unresolved, and there was lingering evidence of community unease.

6.5 Duelling definitions

In the aftermath of the ICONN 2012 conference, the results of the NMI testing reverberated in a series of increasingly technical debates.[34] At stake were both ontological and epistemological questions – what is a 'nano' material, how should it be measured, and what particle size distribution in a sample should trigger its treatment as 'nano'? As the companies whose products were characterised in the NMI's ICONN presentation sought to manage public and commercial responses to the findings, and as FoEA sought to determine how at least thirteen products it considered to be 'nano-free' were found by NMI to contain nano-structured materials, the definition of what constituted a nanomaterial for the purpose of product identification and labelling was subject to challenge on multiple fronts.

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rejection was a product of what many interviewees saw as Greg Combet's disinterest in nanotechnology, or a more specific response to the poll.

[33] Cormick was congratulated by the Assistant Manager of the NMI's Canberra branch on "doing a great job given the NETS review!!" (Dessi 2012).

[34] As Bruno Latour observes, "when controversies flare up the literature becomes technical" (1987, 30).

Through its correspondence with sunscreen brands, FoEA established that nanomaterials manufacturer Antaria was the zinc oxide supplier for three of the products tested by the NMI which were identified as based on primary nanoparticles, and Ross Cosmetics was the formulation supplier of a fourth: between them, these suppliers provided the active ingredients (zinc oxide) for at least thirteen of the sunscreen brands incorrectly listed in the SSG as 'nano-free' (FoEA 2012a, b). In a bid to hold these two suppliers to account, FoEA made complaints to the fair trading regulator the Australian Competition and Consumer Commission (ACCC; FoEA 2012a, b).[35]

The ACCC rejected FoEA's complaints of the companies' deceptive conduct. FoEA's SSG survey had asked specifically about primary particle size and the presence of aggregates or agglomerates. In its appraisal, obtained under FoI, the ACCC stated that: "Given that it is factually correct that Antaria and Ross Cosmetics formulations are made up of aggregates or 'agglomerates' composed of primary nano-scale particles (ie particles <100 nm in size), it is arguable that those responses [to the survey] were false" (ACCC 2014, 11). Nonetheless, in its judgment and in the internal correspondence that preceded this, the ACCC did not support FoEA's assertion that the companies' representations of their products as 'nano-free' had been misleading. The ACCC stated that: "Both Antaria and Ross Cosmetics acknowledge that their zinc oxide formulations contain 'aggregates' or clusters of nano-scale primary particles but... They do not agree with FoE's allegation that their 'nano-free' representations are misleading" (ACCC 2014, 9). Aggregates and agglomerates of primary nanoparticles were regarded as 'nanomaterials' in the definition released by the European Commission (2011) and in the working definition used by Australia's chemicals agency (NICNAS 2010). However, in the absence of a formal Australian regulatory definition, the ACCC accepted the companies' right to describe formulations based on aggregates or agglomerates of primary nanoparticles as 'nano-free'. That is, following the position taken by the active ingredient suppliers, the ACCC accepted that the distinction between a product containing nanomaterials and its being 'nano-free' was itself problematic and subject to dispute.

The suppliers' selective use of measurement instruments to produce graphs that depicted an absence of primary nanoparticles in their products was also found by the ACCC to be legally

[35] The complaint against Antaria was supported by eleven other community groups: the Australian Education Union, the Australian Council of Trade Unions, the State Public Services Federation Group of the Community and Public Sector Union, the Public Health Association of Australia, the Consumer Advocacy Law Centre, The Australia Institute, the National Toxics Network, the Victorian Trades Hall Council, the Ethical Consumer Group, GeneEthics and MADGE (FoEA 2012a).

acceptable. The laser scattering instruments used by these companies to produce graphs depicting their particles as 1,000nm or larger (eg ACCC 2014; Antaria 2009) were only able to 'see' larger, secondary particles. That is, these instruments were unsuited to the task of detecting primary nanoparticles – unlike the USAXS employed by NMI. Illuminating both what Barry terms "'the fragility of metrological regimes' and the 'inventiveness of measurement'" (Barry 2002, 268), and the significance of 'audiencing' in subject-object co-construction (Mahony 2015; Wynne 2002, 2005), the companies' use of these instruments in this setting was strategic, supporting a claim regarding the absence of nanoparticles. And indeed, different measurement techniques were adopted for knowledge production for different audiences. For example, in its patent application Antaria used a range of alternative measurement techniques to demonstrate the nano-structure of its zinc oxide, on which its claims of novelty rested (Table 1, McCormick and Trotter 2010). Nonetheless, as the companies had stated the measurement techniques on which the graphs and measurement data used to substantiate 'nano-free' claims were based, and which they provided to investors, their customers and FoEA (FoEA 2012a, b), ACCC did not agree that the suppliers had engaged in deceptive conduct. Finally, the ACCC found that the advice provided by the sunscreen brands to FoEA in the context of producing its product guide, and even the advice provided by the suppliers to the sunscreen brands to support their listing in the SSG, was not made in "trade or commerce", and was therefore exempt from fair trading provisions (ACCC 2014, 10-12).

Uncertainty among sunscreen companies regarding the nature of their products' active ingredients was consolidated by the non-intervention of policy makers. In addition to the ACCC's decision not to prosecute Antaria or Ross Cosmetics for deceptive conduct, the TGA continued to reject calls for a regulatory definition for nanomaterials. The NETS office, while publicly stating that the controversy revealed a need for clear definitions (DIISRTE 2012b), did not propose any of its own. Meanwhile, affected sunscreen brands provided a range of sometimes conflicting public explanations about what had occurred and whether their products should be considered 'nano' or 'nano-free'. Combined, these uncoordinated actions limited the future prospects for individuals, organisations or companies to obtain information regarding the presence of manufactured nanomaterials in the products they worked with, used or sold, short of commissioning testing by the NMI. At a bureaucratic level, the conditions had been created for 'strategic ignorance' (McGoey 2007, 2012) regarding the extent and location of nanomaterials in Australian sunscreen supply chains.

NGOs, sunscreen companies and ingredients suppliers had sought to generate and to display information regarding products' nano-content. Ultimately, such efforts were plagued by the politics of transparency interacting with the politics of measurement (cf. Barry 2002, 2013), and the information produced was increasingly contested. In the aftermath of the events described here, strategic ignorance was a "productive asset" for policy makers (cf. McGoey 2012, 553). Amidst contested interpretations of the emergent risk data, highly technical arguments regarding nanomaterials definition and measurement, and accusations from heavy-hitting actors such as the Cancer Council – based on the government's own work – that public discussion of the need for nano-specific sunscreen regulation was itself a threat to public health, ignorance enabled policy makers to put space between themselves and the heat of a messy and politically fraught series of debates. Yet even as new political skirmishes surrounded the proliferating series of technical disputes, the potential for broader sociopolitical critique and dissensus appeared to dwindle. Whereas FoEA and other community groups had entered the nanotechnology debate seeking to 'open up' (Stirling 2008a) its 'revolutionary' ambition to collective reimagining (FoEA 2006a, c), they became ensnared in a metrological argument that was inaccessible to most people.

6.6 An 'unsettled settlement'

The events investigated in this chapter did not mark the end of the nano-sunscreens regulatory debate in Australia, but they did precipitate its diminution. Following the widely repeated claim that FoEA's campaign was putting lives at risk, even scientists and other NGOs who had previously supported calls for more EHS research and new, nano-specific regulation, expressed their hesitation to publicly discuss nano-sunscreen safety (Armitage 2013). No longer confident in the reliability of company-provided measurement data, and, in the wake of new NMI work it commissioned showing nanomaterials in each of the several sunscreens it had tested, FoEA did not publish another product guide (FoEA Undated). After its failed effort to prosecute companies for deceptive representations regarding the nano-free status of their products, the group's campaign on sunscreens receded.

Some interviewees suggested that whereas FoEA's campaign had raised important questions at a time of scientific uncertainty, helping to boost support for needed nano-safety research, risk issues had since been 'settled'. As one industry interviewee asked rhetorically: "When is there enough evidence to say 'yes'? You know, the collective view now has changed..."

(Industry member, Interview 35, November 2013). Indeed, several interviewees from industry and the research sector suggested that nano zinc oxide and rutile forms of titanium dioxide had been shown to be 'safe', although they strongly criticised the ongoing use in sunscreens of anatase titanium dioxide.[36] Yet in a testament to the influence of social closure mechanisms in scientific controversies and the impact of the government interventions explored above, in 2012 the space for dissensus in the nano-sunscreens regulatory debate was greatly diminished without some of the most contentious 'scientific' questions having been answered – including the *in vivo* behaviour of anatase titanium dioxide, and the conditions in which skin uptake of nanomaterials from sunscreen may occur.[37] Indeed, despite the demonstrated behaviour of anatase titanium dioxide as an aggressive photocatalyst (Barker and Branch 2008), when NMI testing commissioned by FoEA some months subsequent to ICONN 2012 identified it in several sunscreen and cosmetic products (NMI 2012), the apparent interest of media and other actors was considerably reduced. Calls for nano-specific sunscreens regulation, even criticism of the TGA's failure to withdraw anatase titanium dioxide from use in sunscreens, had become difficult to sustain.

Controversies are often seen as being resolved by some kind of definitive political or scientific settlement. Conversely, in relation to nano-sunscreen, key issues remained unsettled in the context of the regulatory debate's apparent closure. Indeed, whereas the debate was ostensibly settled in 2012, at the time of writing the TGA (2017) has recently published a new literature review assessing nano-sunscreen safety, the Australian consumers' association CHOICE continues to back calls for nano-specific labelling (Bray 2017), and a recently updated

[36] Strikingly, despite the TGA's repeated arguments that there was no evidence of nano-ingredients uptake through skin, many interviewees pointed to the 'real-world' findings of BlueScope Steel that anatase titanium dioxide was an "aggressive photocatalyst" in objecting to its use in sunscreens. For example, one industry member observed bluntly: "It's an extreme photocatalyst, it takes the coating off paint, how is that not a problem?" (Industry member, Interview 24, October 2013). Similarly, another interviewee argued that: "I don't think p25 anatase [titanium dioxide] should be in any sunscreens, passivated or otherwise, I am against that line" (Nano safety researcher, Interview 6, December 2013). Such statements reject the TGA's privileging of a particular "epistemic form" for its assessment (cf. Kleinman and Suryanarayanan 2012), and the regulator's assumption that where exposure is nil or very low (as judged by a "weight of current evidence" assessment), risk is negligible irrespective of hazard. Nonetheless, one of these interviewees expressed their support for nano zinc oxide: "the nano [zinc oxide] sunscreen is the best sunscreen out there... we now know that there is not an issue, the UV known risk far outweighs anything that can possibly occur from now the known effects of [zinc oxide nanoparticles]" (Nano safety researcher, Interview 6, December 2013).

[37] Highlighting the persistence of 'undone science', uncertainty persisted regarding whether 'absorption enhancers' in product formulations, impaired skin condition, or physical activity significantly enabled nanomaterials' uptake through skin. In January 2013 a senior NICNAS staff member advised the ACCC that "Science about the safety of nano sunscreens is evolving. Current thinking is that nanoparticles may penetrate the very thin skin (such as for babies) and compromised skin (eg where the skin has burns or wounds)" (ACCC 2014, 3).

Cancer Council blog states that "Cancer Council sunscreens do not contain nanoparticles" (Cancer Council ACT 2017, unpaged). This suggests that the settlement remains vulnerable, and that institutions continue to feel the need to counter arguments about nano-sunscreen risks.

6.7 Conclusion

Political and policy responses to Australian nano-sunscreen regulatory debates reveal the outworking of features of Australia's innovation policy environment identified in earlier chapters. The emphasis placed by public servants on propelling the closure of these debates, and the form and the expression of their interventions in them, were strongly shaped by the scientistic framing and 'market failure' rationale for NETS. Dampening nano-sunscreen regulatory debates was seen by many stakeholders as necessary to secure publics' compliance with state-backed prescriptions for sunscreen use. Yet given the constraints on government activities thought to be imposed by 'free market' commitments, and ambivalence regarding the state's role as sponsor of technological innovation, creating favourable public opinion surrounding nanotechnology also formed a key component of government's strategy to foster its development. For the public servants charged with implementing nanotechnology policy, maintaining public confidence in nano-sunscreen became a means to nurture the commercial prospects of the wished-for future industry, while also defending what they saw as 'science under siege'. And yet, despite some bureaucrats' spirited engagement in what they identified as "battles over public opinion", this did not reflect the commitment of wider government; the lack of high-level political engagement in these debates is consonant with that observed elsewhere in this thesis.

The dominance of scientistic policy framing, and the approach to nanotechnology as a 'scientific' rather than a 'political' policy object shaped the form in which political and policy responses to nano-sunscreen regulatory debates were articulated. The framing by public servants of their interventions in these debates as 'scientific' reflected their assumptions that 'science' held "natural sovereignty" for policy meaning (cf. Wynne 2014, see also Chapter 5), their judgment that it would "trump political difference" and dissensus (cf. Doubleday and Wynne 2011, 248; see also Harwood and Schibeci 2008; Jasanoff 2005a, 288), and their uneasiness in acknowledging normative and political motivations for their own activities. The pursuit of 'politics' through 'science' is commonly observed to be a tactic deployed by technoscience critics. Yet I find an unexpected array of government actors using the language and a likeness of the practices of 'science' to pursue more or less apparent sociopolitical aims. This offered public servants the means to leverage epistemic authority, but also the ability to better navigate the tensions produced by the government's equivocal commitment to its role as innovation sponsor.

Previous work has shown the influence on the evolution of technology policy of actors' shared normative commitments and sense-making frames, particularly in the absence of explicit political leadership or a clear and well-developed industry policy (Berman 2008; Vallas, et al. 2011). The primary motivations of actors in the events investigated here differed – the manager of NETS-PACE was focused on "battles over public opinion", NMI metrologists on characterising nanomaterials, nano-safety researchers in developing knowledge of nanomaterials behaviour, and the Cancer Council on promoting sunscreens' use, Yet I find an emergent alignment of their interests and actions based in part on shared assumptions and normative commitments, including to maintaining publics' confidence in sunscreen safety. The critical response of public servants, metrologists, nano-researchers and anti-cancer advocates to NGOs' campaign for nano-sunscreen regulation ultimately converged, driving the 'unsettled settlement' of the debate.

It has been suggested that "the larger political challenge of nanotechnology is to find ways to make invisibility visible — if not materially, at least politically, economically, and philosophically" (Frodeman 2006, 386). Yet this chapter demonstrates that whereas proponents worked hard to raise the visibility of *nanotechnology* for innovation policy, a series of uncoordinated actions by policy makers consolidated the conditions in which the identity and location of *nanomaterials* in commercial use would remain obscure. This rendered the "political" and "economic" relations in nanotechnology's application even more opaque, and undermined the "philosophical" argument of critics that nano-sunscreen (and by implication nanotechnology) was neither necessary nor inevitable. It created the bureaucratic conditions for strategic ignorance by the state and served to enforce public compliance with the normative choices woven into both innovation policy and state-backed prescriptions for sunscreen use. Ironically, if unsurprisingly, this did little to ensure the successful emergence of an Australian nanotechnology sector.

Part B conclusion

Following Part A's exploration of how particular areas of technoscience come to attracted political attention and prioritised public funding, Part B has examined the specific ways in which state support for such fields' development is subsequently expressed, using Australian nanotechnology policy as a case study. Despite proponents' appeals for the state to play an active role in fostering the 'next industrial revolution', Chapters 5 and 6 reveal a lack of high-level political engagement in Australian national nanotechnology policy, and reservations regarding state sponsorship for technological innovation among both major political parties. Constrained by 'market failure' rationales (Dodgson, et al. 2011; Marsh and Edwards 2008, 2009) and scientistic framing (Doubleday and Wynne 2011; Kleinman 2005; Wynne 2006; see also Part B Introduction), policy designed to foster nanotechnology development centred on metrology, risk regulation, and public awareness. The emphasis by public servants on efforts to propel the closure of nano-sunscreen regulatory debates was in part a product of this limited policy focus, and the identification of 'public opinion' as a key 'barrier to innovation' (cf. Balmer and Molyneux-Hodgson 2013; Molyneux-Hodgson and Balmer 2014).

The scientistic framing of nanotechnology policy exerted a depoliticising influence on policy making, to some extent 'closing down' (cf. Stirling 2008a) opportunities for sociopolitical critique. Whereas this has been widely remarked in previous studies of public knowledge controversies and technology policy debates (Callon, et al. 2009; Gottweis 1998; Jasanoff 2005a; Kleinman 2005), I show its influence also within government. Policy makers and political actors assumed the "natural sovereignty" of science in the appraisal of 'scientific' policy objects (cf. Wynne 2014, 61), and this contributed to shifting the locus and epistemic basis of policy making towards the technical sphere (cf. Barry 2001). Yet despite the enactment (cf. Law 2004; Mol 2002) of nanotechnology as a 'scientific' policy object, 'political' questions regarding the purpose, value and legitimacy of nanotechnology policy recurred internally to government, in its relations with the research sector, and in proliferating risk debates, including those associated with nano-sunscreen regulation.

The design and implementation of Australian nanotechnology policy, and political and policy responses to nano-sunscreen regulatory debates, reveal a messier picture of co-production (cf. Jasanoff 2004) and of the relationship between regulatory policy and the pursuit of innovation objectives than has been previously recognised. Responsive to political cues but largely lacking high-level political direction, public servants charged with implementing nanotechnology policy sought to advance the state's (assumed) emerging technologies agenda, within the constraints of their environment. Rather than regulatory work being guided by them, public servants felt limited agency over the actions of regulators with whom they had sometimes fractious relations. The sphere in which public servants enjoyed the most autonomy was in "battles over public opinion" (cf. Cormick 2011, 2), where they sought to both advance the government's nanotechnology development objectives and defend the epistemic authority of 'science'. Nonetheless, there was a sharp disjuncture between the expressed government aims of promoting nanotechnology's expansion, the activities of public servants, and the expectations of technology proponents. Whereas government posited metrology, risk regulation and public awareness as key to achieving its innovation objectives, this policy approach was strongly criticised by proponents. In turn, proponents' calls for targeted measures to support commercial capability building and a strong government role in developing industry strategy were dismissed by those who assumed narrow 'market failure' rationales for public policy. In the wake of the global financial crisis, and with the political displacement of nanotechnology's few key champions, 'market failure' logics ultimately subordinated even nanotechnology policy's 'scientific' meaning to one associated with 'market' thinking. The view that government had no proper role in sponsoring technological innovation, even through policy whose meaning was framed as 'scientific', contributed to the 2013 disbanding of Australia's dedicated nanotechnology policy apparatus.

Chapter 7: Conclusion

It was never inevitable that governments in the United States (US) and in Australia would single out nanotechnology for priority funding and political patronage. The two countries' decisions to establish national nanotechnology policies reflected technical developments in the field, but also particular political and fiscal circumstances, the active work of intermediaries acting between science, policy and politics (cf. Guston 2000; Meyer and Kearnes 2013), and chance. Complicating the assumed commitment of the state to promoting technology development, in both the US and in Australia the creation of nanotechnology policy, and the policy object 'nanotechnology' itself, were situated achievements (cf. Balmer, et al. 2016). In contrast to the techno-positivity of the state frequently depicted in the literature (Barry 2001; Jasanoff 2005a; Wynne 2016), 'technological progressivism' (Kleinman 2005; see also Sarewitz 1996; Stirling 2009a, 2010a) was not universal among politicians and policy makers, particularly in Australia. The state's role in sponsoring technological innovation was contested among Australian political elites, and the scope of the policy designed to promote nanotechnology development was modest. Rather than attempting to directly support capability building in the nascent sector, Australian nanotechnology policy focused on metrology, risk regulation and public awareness initiatives. By 2013, although research funding for the field continued, the federal government allowed its nanotechnology policy program to lapse. Rather than a 'hegemonic' force this thesis finds that science-state-market relations, and the science policies that reflect and reinscribe them, are themselves the "(co-)products of contingent interactions and practices" (cf. Jasanoff 2004, 36).

7.1 Chapter summaries

Part A of this thesis (Chapters 2-4) explored intermediaries' varyingly successful efforts to bring nanotechnology to the attention of political actors as a worthy object of innovation policy. Part B (Chapters 5-6) investigated the design and implementation of the policy via which the Australian government subsequently sought to promote the field's development.

Chapter 2 illuminated how the creation of the US National Nanotechnology Initiative (NNI) reflected the 'buzz' surrounding nanoscience, the presence of favourable political and fiscal conditions, and chance, but was also substantially brokered by federal agency officials, with support from White House staff and entrepreneurial academics. It showed that the success of NNI proponents may be understood only in light of their constitutive work to ensure that the policy object 'nanotechnology' was responsive to the imperatives of its policy environment. Chapter 3 explored the central role of science-policy intermediaries in the nomination of nanomaterials as one of Australia's research priorities, a decision which gave the (false) impression of state orchestration. It showed how prioritising nanotechnology reflected elite research sector representatives' attempts to demonstrate their willingness to promote commercially relevant science, and that nanotechnology's enactment (cf. Law 2004; Mol 2002) by them as 'commercially relevant' came despite limited industry engagement in the field, and doubts regarding its Australian commercial prospects. Chapter 4 compared the efforts of nanotechnology proponents in the two countries to make promissory claims "sound credible" (cf. Sunder Rajan 2006, 114) to political audiences as they sought to consolidate policy for the field. It showed that even in the US, a site rich with discursive resources that emphasise technology's centrality to the strength and success of the nation-state, proponents worked actively to build an emplaced rationale for enduring nanotechnology support. Lacking such resources, Australian nanotechnology proponents struggled to make salient to political audiences claims that state-supported nanotechnology offered the means to future prosperity. Chapter 5 investigated the design and implementation of Australian nanotechnology policy, showing how this was constrained by political actors' long-standing objections to interventionist innovation policy in light of 'free market' commitments, scepticism regarding technology's relevance to the Australian economy, and limited political interest in nanotechnology itself. Treating nanotechnology as a 'scientific' object, policy focused on metrology and regulatory measures – even as 'political' questions regarding such policy's purpose and value recurred within government and in its relations with proponents. Chapter 6 showed how the features of the policy environment identified in earlier chapters were articulated in debates surrounding the regulation of nano-sunscreen. The uncoordinated attempts by public servants to propel the closure of these debates reflected the 'market failure' rationales (cf. Dodgson, et al. 2011; Marsh and Edwards 2008, 2009) and scientistic framing (cf. Doubleday and Wynne 2011; Kleinman 2005; Wynne 2006) of nanotechnology policy, and, in the absence of political preparedness to offer more direct forms of industry support, its emphasis on building "community confidence" as a means to foster the field's commercial development (DIISRTE 2012c).

7.2 Scientific and social ordering

Tracing the arc of nanotechnology's enactment from innovation policy to regulatory debates reveals it to be a policy object whose identity and meaning was continually remade in anticipation of its new subjects (cf. Mahony 2015; Wynne 2002, 2005; see also Gardner, et al. 2017). The name 'nanotechnology' was effective in coordination work, patching together a semblance of singularity from among the multiple versions of the field (cf. Mol 2002). It helped to forge a disciplinary community, enabling an articulation of its collective vision for future impact, and a research agenda for which it could advocate (cf. Balmer, et al. 2016; N. Brown 2003; Hedgecoe 2003; Molyneux-Hodgson and Meyer 2009; A. Powell, et al. 2007). It also facilitated the policy object's trade amongst different stakeholder groups (cf. Star and Griesemer 1989). Yet the category's 'interpretative flexibility' (Pinch and Bijker 1984) was also a key asset (cf. Bowker and Star 1999). A coherent, powerful and disruptive technology for the purposes of the *innovation policy* investigated in Part A, proponents in the US and in Australia argued (with mixed success) that state support for nanotechnology was vital to each country's economic and geopolitical interests (Chapters 2, 4). As Australian science-policy intermediaries negotiated the politically fraught process of *research priority setting*, nanotechnology was a 'package' that could be used to demonstrate responsiveness to political demands for commercially relevant research (Chapter 3). Conversely, in the context of Australian *regulatory policy* investigated in Part B, the existence or relevance of 'nanotechnology' was largely denied, and nanomaterials were approached as a new generation of chemicals, perhaps not even worth the introduction of nano-specific risk assessment regimes (Chapters 5-6). These varying enactments of 'nanotechnology' were central to its propitious positioning for research funding, political patronage, commercial advantage, favourable public opinion and the disinterest of regulators. The enactment of particular versions of nanotechnology in particular policy contexts did political work; it was a site at which science and social order were co-produced, and through which constitutive work responded to the imperatives of its political, economic, institutional and ideational environment (cf. Jasanoff 2004; see also below).

The reduction by policy makers of the complex sociopolitical questions associated with the projects of technoscience to a focus on environment, health and safety (EHS) risks and their public perception[1] has been revealed by science and technology studies (STS) researchers as a consistent pattern in the (non)resolution of political conflicts over science. Indeed, there is a

[1] On the impossibility of separating these see Jack Stilgoe (2007); on the inextricable location of risk in broader sociopolitical relations see Brian Wynne (2002).

recurrent attempt to offer risk as the only site at which the social meaning of emerging technologies may be contested (Doubleday and Wynne 2011; Wynne 2014). In practice this has proved to be a strategy vulnerable to counter movements, and to the 'overflow' (Callon 1998; Callon, et al. 2009; Wynne 2002) of sociopolitical critique from its attempted reduction to narrow, technical grounds. This reductionism has often been understood in terms of the "presumption, projected onto society, that science has natural sovereignty over public meanings" (Wynne 2014, 61). Yet I extend this by observing that many Australian policy makers considered that 'science' has, or should have, "natural sovereignty" over their *own* appraisal of 'scientific' policy objects. That is, it was not simply that policy makers assumed and projected limited *public meanings* for nanotechnology policy, but that many also assumed its limited *political meanings* (see Part B Introduction). Indeed, the focus on risk in Australian nanotechnology policy was in part a reflection of the "transparently impoverished" resources possessed by policy makers to consider the sociopolitical dimensions of 'scientific' policy objects and technology policy making (cf. Stirling 2009a, 17; see also Kleinman 2005).

Australian national nanotechnology policy was shaped not only by scientistic commitments but also by 'market failure' policy rationales, based on the assumed limits that 'free market' commitments impose on the state's sponsorship of innovation (Chapter 5). Given narrow 'market failure' policy rationales, metrology, risk regulation and public awareness activities were identified as some of the few sites at which government could properly work to create an "optimal operating environment for enabling technologies to develop and grow" (DIISRTE 2012c, 238). Indeed, highlighting a site of synergy between scientistic and 'free market' assumptions, policy makers attributed to nanotechnology "self-unfolding deterministic power" (cf. Wynne 2014, 61). Both the National Nanotechnology Strategy (NNS) and its successor the National Enabling Technologies Strategy (NETS) reflected the influence of linear models of innovation that presuppose technology's natural expansion from the laboratory to commerce (cf. Callon 2007; Godin 2006; Guston 2000; Marsh and Edwards 2008; Sarewitz 1996; see also Stirling 2009a; Stirling 2010a). Implicit in both policies was the assumption that the greatest potential barrier to nanotechnology's expansion lay not in demand-side factors, or even scientists' ability to 'scale up' and 'translate' their research into commercial products, but rather a lack of "community confidence" (DIISR 2012; cf. Balmer and Molyneux-Hodgson 2013; Molyneux-Hodgson and Balmer 2014; see also Kearnes and Wynne 2007).[2] Government effectively looked to regulatory measures and public awareness initiatives to pursue its

[2] On publics as incipient 'threats' to innovation see David Hess (2015); Ian Welsh and Brian Wynne (2013).

industry policy – a strategy that was critiqued by nanotechnology lobby groups who sought more concrete form of "industry support" (Rankovic 2008, 6) and "a clear and articulated vision" from government for industry development (Future Materials and Australian Nanotechnology Alliance 2009, 4).

The approach to nanotechnology as a 'scientific' or 'technical' rather than a 'political' policy object (cf. Jasanoff 1990) performed both epistemic and political ordering. It privileged the role for scientific 'experts' in policy appraisal (cf. Gottweis 1998; Jasanoff 2005a) and diminished the space for sociopolitical dissensus and critique (cf. Barry 2001; Callon, et al. 2009; Stirling 2008a) – not only for wider publics but also for politicians, their advisors and public servants in the industry department (Chapter 5). Earlier work has highlighted the depoliticising influence in policy debate of the synergistic employment of scientistic and 'free market' discourses (Kinchy, et al. 2008; Moore, et al. 2011; Swyngedouw 2010; Wynne 2016). Yet within the Australian government 'free market' commitments were not the only source of depoliticising scientism. Even a self-identified "socialist" Minister deferred to 'science' as the sole legitimate basis for nano-product appraisal – not to protect the 'free' operation of the market but rather to defend technology's assumed ability to effect desirable societal transformation.[3] Nonetheless, 'political' questions regarding the purpose and value of nanotechnology policy recurred within government, in its relations with nanotechnology proponents, and in the proliferating risk debates associated with 'first-generation' nano-products (Chapters 5-6). That is, despite the distortionary effects of enacting nanotechnology as a 'scientific' policy object, its depoliticisation as a policy object was always incomplete (cf. J. McCarthy 2013). Nanotechnology's sociopolitical dimensions routinely overflowed its designation as a chemicals management question best answered by technical experts – including, influentially, in its treatment by politicians and senior bureaucrats within government. Indeed 'political' judgments contributed to the lapsing of Australia's dedicated nanotechnology policy apparatus, as nanotechnology policy's 'scientific' meaning was ultimately eclipsed by 'free market' reservations regarding government's role in technology development.

[3] Indeed, the convergent implications for science and technology policy of 'free market' and "social democratic" policy logics suggest that their assumed opposition should itself be subject to more critical inquiry. As earlier work (Jasanoff 2005; Kleinman 2005; Sarewitz 1996) has shown, conviction in science as the means to 'truth' and technology as the means to social progress is found across the political spectrum.

I have taken processes of co-production internal to science policy as key sites for this study. I have not approached nanotechnology policy as a reflection of the field's compelling material claims, the expression of a 'natural' state commitment to fostering new technologies development, or a reaction to the interests of capital – that is, I have not looked to 'internalist' or to 'externalist' explanations for such policy's creation (cf. Shapin 1992). Instead, I have shown the production of nanotechnology policy, objects, and their meanings, to be co-constituted with situated, sociopolitical relations. In this is a possibly surprising observation. Work to forge the objects and ideas that animate science policy is reliant on reinscribing the boundary between the natural and the social to secure its own claims. Indeed, as a form of "imposition of 'society' on 'nature'" (Calvert 2010, 95), such world-making poses and responds to deep metaphysical concerns (Jasanoff 2004). I show that the purposes, pursuits and achievements of this constitutive work cannot be understood without illuminating its responsiveness to the pragmatic political demands and epistemic conflicts of the environments in which it takes place.

This thesis shows that interactional co-production is present at the heart of constitutive work. The "*emergence and stabilization* of new technoscientific objects and framings" which Sheila Jasanoff (2004, 38, emphasis in original) describes as "the staple concern of constitutive co-production" is repeatedly shown to anticipate or respond to interactional needs – to "resol[ve] scientific and technical *controversies*" or to render "the products of technoscience... *intelligible and portable* across boundaries" (Jasanoff 2004, 38, emphases in original). Scientists, research agency officials, bureaucrats and politicians produced and brokered (cf. Meyer 2010) scientific knowledge, objects and promissory claims to more propitiously situate nanotechnology's prospects, their own research agendas, and the (apprehended) interests of the state or future industries. Such constitutive work repeatedly and directly responded to the epistemic and political conflicts taking place in government, the research sector and to a lesser extent business. Put differently, the 'nature' constructed by nanotechnology's proponents not only reflected political controversies in wider 'society', but sought to act upon them. The inscription of normative concerns, political interests and epistemic conflicts in such constitutional work underscores its attendant stakes (cf. Mol 1999). The political work and choices associated with forging, bounding and attaching particular objects of technoscience to particular 'prospective techno-futures' (cf. N. Brown, et al. 2000) is manifestly apparent. This thesis suggests that the strategic interests that inform the representations of 'reality' at the centre of science policy, and the connections between this ‘reality’ and attempts “to resolve scientific and technical controversies” that are in themselves politically charged, merit much closer attention.

7.3 Coaxing capital and science-state-market relations

The differing expectations for science-state-market relations observed in this thesis in Australia and the US underscore the divergent policy settings that may be accommodated within late-modern, capitalist states, even given ostensibly similar commitments to ‘free market’ ideology (cf. Ong 2007; Weiss 2012). Indeed, they show the heterogeneity, even incoherence (Birch 2015; Birch and Siemiatycki 2016; Ryan 2015), of ‘neo-liberalism’ itself, and the interpretative flexibility of its prescriptions for science policy. Science policy settlements in Australia and in the US evince different theories of capital and of the power and limits of the ‘free market’, implying also different roles for the state and its bureaucrats in stimulating, supporting and directing capital’s activities, including in technoscience.

In the US, described by Kaushik Sunder Rajan (2006, 112) as the “hegemonic center” of “free-market ideology”, there was state support not only for ‘basic’ science[4] but also for broader measures to promote technological innovation (Chapters 2, 4). In the period examined by this thesis (mid-1990s to 2003), there was widely expressed agreement among US scientists, government officials, technology industry lobbyists, venture capitalists and political actors that government should actively nurture the nation’s ‘innovators’ and their international competitiveness. Beyond the high-tech sector’s military significance – a common justification for state support (Block 2008; Weiss 2014) – stakeholders argued that the economic success of the country’s high-tech firms was key to the ‘national’ interest (Chapters 2, 4). Yet even as the dot-com boom and the huge profits it generated were leveraged to argue for the high-tech sector’s public value, there was a concomitant expectation that government would aid its recovery following the boom’s demise. That is, there was an expectation that whereas profits would be privatised, losses would be publicly shared (Block and Keller 2011). In contrast to the risk-seeking “lively capital” of some depictions (Sunder Rajan 2006, 2012), in the aftermath of the dot-com bust, the venture capital sector was described by nanotechnology lobbyists as “stagnant” and the US “nanotechnology market” “ in need of serious attention and assistance from the Federal Government” (Committee on Commerce 2002, 67). Appeals were made –

[4] On the flexible and strategic use of this term see Jane Calvert (2006); for my qualified use of it see Part A Introduction.

and sympathetically received – for government to entice capital's interest in nanotechnology by preparing an environment favourable to its investment and by reducing the attendant risks. Despite discursive deference to "a high-risk, free-market frontier ideology" (Sunder Rajan 2006, 113), US nanotechnology stakeholders routinely expressed their expectation that the state would provide the budgetary, legal and policy environment within which the field's 'high risk' would be reduced to 'acceptable' and 'attractive' risk, and the "free market" structured on terms favourable to future US firms (Chapter 4; cf. Vallas, et al. 2011). In this way, the NNI aimed to coax capital to colonise a new field in which its 'natural' interest was not assumed.

The leadership role assumed by US government actors in fostering nanotechnology's commercial expansion is noteworthy. Advocates within government engaged in promissory work that fostered expectations for nanotechnology's economic prospects (cf. Borup, et al. 2006; N. Brown 2003; N. Brown and Michael 2003; Petersen and Krisjansen 2015; Pollock and Williams 2010), but also sought to construct a policy and market environment (cf. Callon 2007; Garcia-Parpet 2007 [1986]; Mirowski and Nik-Khah 2007) that would encourage its commercial development.[5] The initiative was predicated on nanotechnology's future 'revolutionary' economic impact and always envisaged the state's withdrawal from the field. Nonetheless, a key claim made in support of the NNI was the necessity of government's present-day funding for high-risk research that was unattractive to industry, in the interests of as-yet speculative future industries that were cast as central to maintaining US economic strength.[6]

This assumed imbrication of the interests of US science and the state contrasts with previous STS work which identifies a constitutional commitment to their separation. In the *regulatory* sphere Jasanoff (2005a, 288) has emphasised the need for science to "stand apart from the contaminating touch of politics" to maintain its epistemic authority. Moreover, she observes the commitment to the "Mertonian vision of disinterested science" by even "corporate science's most ardent American critics" (Jasanoff 2005a, 288). Yet, perhaps unsurprisingly given the common attribution among policy elites of US economic strength and geopolitical power to its scientific competitiveness and technological success, in the context of *innovation* policy a divergent set of assumed social relations is apparent. Publicly funded science, US firms' competitive prospects and the national interest were commonly understood to be

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[5] Ironically then, proponents' claims for the NNI's industrial relevance were initially a rhetorical strategy to leverage greater funding for basic science (Eisler 2013a; Eisler 2013b; Gallo 2009).

[6] The NanoBusiness Alliance declared in 2002 that: "Since its inception, the National Nanotechnology Initiative has proven to be an incredible instance of Government outpacing the imagination of the private sector" (Committee on Commerce 2002, 11).

mutually dependent. Rather than 'innovation science'[7] being seen as "disinterested" and "stand[ing] apart from the contaminating touch of politics" as Jasanoff observes is required for 'regulatory science', it was assumed to be thoroughly social, commercially necessary, and politically responsive. Indeed, the credibility of innovation science was achieved not by the social distancing required to perform 'objectivity' (cf. Jasanoff 2011c) but by its demonstration of ineluctable sociopolitical and economic ties. State support for such science was an important – if sometimes less explicit – component of a US imaginary of technology's centrality to (imperilled) national strength (Chapter 4). This underscores the heterogeneity of meanings for which 'science' is made or assumed to speak, and points to a site of friction in relations between innovation and regulatory science and related policy that merits further inquiry. STS has in the past focused primarily on processes of the attempted purification of 'science' from 'society' (Latour 1993), and has developed a conceptual vocabulary to explore these themes, for example in studies of boundary work (Bijker, et al. 2009; Gieryn 1999; Jasanoff 1990). What has been less considered is where science is explicitly – and willingly – engaged in sociopolitical promising which requires demonstration of hybridisation, and the connections that exist between these two science policy spaces. Such sites warrant closer STS attention, even as making sense of this reverse image of science may require new conceptual tools and terms

In Australia, government leadership was also called for by the research sector to encourage nanotechnology's emergence, although with more ambiguous results (Chapters 3-6). As in the US, the commercial prospects of nanoscience were touted by Australian scientists and science-policy intermediaries, largely in the absence of active industry engagement in the field (DISR 2001; Ernst & Young 2002). In a period of funding instability, and beset by accusations that researchers were not delivering a sufficient 'return on investment' (Hazell and Coloe 2002), scientists sought to demonstrate to government their commitment to pursuing commercially relevant research (Chapter 3). Nanotechnology benefited from these circumstances and was nominated among Australia's research priorities in 2002. Nonetheless, the federal government did not commit to developing dedicated policy for the field until 2005, which then took a further two years to release. Even then, its policy was constrained by 'science push/ market failure' framings (cf. Dodgson, et al. 2011; Marsh and Edwards 2008, 2009), and resistance to the provision of targeted resources to support industry development.

[7] As noted in Chapter 1, this term is employed by Sheila Jasanoff (2005a, 108) to distinguish it from 'regulatory science' but she credits it without citation to Brian Wynne.

Despite routine concessions to political pragmatism, in recent decades Australian industry and innovation policy has been constrained by the adherence of high-level bureaucrats and many political actors to neo-classical economic theory. This policy commitment is hostile to strategic interventions to promote the development of particular industrial sectors, sceptical of particular sector's 'special pleading', and aims to limit industry and innovation policy to that which can be justified by 'market failure' rationales (Conley and van Acker 2011; Pusey 1991; Thurbon 2012).[8] It dictates that: "innovation should be driven by the market… if the market does not support innovation, so be it" (West 2004, 33). The ideological purity of Australian public policy and the constrained role for the state it envisages is frequently compromised by electoral opportunism, and by favoured treatment for influential sectors such as mining and agriculture (Chapter 5). Yet such privileged treatment was not available to nanotechnology given the limited credibility that had been achieved for the field's promissory claims (Chapters 3-4). Even when a dedicated apparatus to create nanotechnology policy had been established, it focused on measures that could be justified by 'market failure', and whose meaning was cast as 'scientific', as discussed above. Ultimately, reservations regarding the state's role as sponsor of technological innovation, and the adverse political fortunes of nanotechnology's key champions, contributed to the demise of the policy itself.

Innovation scholars have warned that the conflation of 'innovation' with the capital-intensive high-tech sector dramatically over-values the role of emerging technologies in wealth creation (K. Smith 2004). Following earlier critique by postcolonial and feminist scholars of the deficiency, partiality and misplaced assertions to universalism of Northern science's accounts of 'knowledge' (Chakrabarty 2007 [2000]; Haraway 1988; Harding 1998; Nandy 1989), recent STS work has criticised the insufficiency of 'knowledge economy' accounts of both 'knowledge' and 'economy' (Borup, et al. 2006; Stirling 2009b). The qualified salience of the 'knowledge economy' to Australian policy elites highlights an important and under-recognised point. It is not just critical scholars and wider publics who show ambivalence, even scepticism, towards the assumed meaning of technology development as a 'one-track race' whose direction or plural nature cannot be questioned (cf. Stirling 2009a, 2010a). For political audiences familiar with an imaginary that lauds Australia's 'competitive advantages' as based in minerals, fossil fuels, agriculture and real estate, and who were to some extent culturally estranged from the research sector (see Chapters 3-5), the enactment of nanotechnology as 'the future' was not unequivocally credible. Australian nanotechnology proponents touting an imaginary of

[8] A position broadly supported by the 'science push' focus of Australia's core science policy institutions (Marsh and Edwards 2008).

prosperity through state-supported nanotechnology faced resistance from both ‘free market’ enthusiasts and those who would support a(n ostensibly competing) “fossil fuels forever” imaginary (cf. Levy and Spicer 2013; although see Chapter 4 regarding the high-tech nature of Australia's extractive industries).

Rather than the universal triumph of global technoscience, I observe a messier picture of co-production, contingency and vacillation in science and technology policy. This underscores Andrew Barry’s observation that the sites of resistance within a technological society, and the forms in which opposition is expressed, should not be assumed to be “more or less romantic and utopian” (2001, 6). It remains striking that the most influential critics of Australian nanotechnology policy – and of selective support for technology development more generally – were found amongst the ‘economic dries’ (cf. Watson 2002) of government. This highlights the unevenness of the convergence that has taken place between science, the state and markets (cf. Kleinman and Vallas 2001; Vallas and Kleinman 2008), and the frictions that recur between competing sources of policy authority. The challenge posed by ‘the market’ to the state’s capacity to sponsor technological innovation is conspicuous, as is its periodic usurpation of the “natural sovereignty” of ‘science’ as the source of epistemic authority and policy meaning (cf. Doubleday and Wynne 2011; Wynne 2016).

7.4 The situated (re)constitution of global technoscience

Appeals for state support to develop nanotechnology were necessarily tailor-made (Chapter 4). In both the US and Australia, proponents seeking priority funding and political patronage constructed forms of the policy object and rationales for its support that they hoped would be salient to their respective political audiences. As a consequence there was no “unmarked” (cf. Haraway 1988) or ‘non-provincial’ (cf. Chakrabarty 2007 [2000]) ‘nanotechnology’: its meaning was always enacted *in situ* (cf. Balmer, et al. 2016), shaped by and for a particular time and place (cf. N. Brown, et al. 2000), and particular scientific and political audiences. I have eschewed treating Australia and the US as a straightforward example of ‘periphery’ and ‘centre’. Nonetheless, and consonant with postcolonial STS work that emphasises the ever present “local” within “the ‘centre’”, I observe that the ‘nanotechnology’ enacted in the US was “just as local” as that enacted in Australia (cf. W. Anderson 2002b, 652).[9] Indeed, US

[9] Similarly, Bruno Latour (1993, 117) emphasises that “even a longer network remains local at all points”.

intermediaries' effective efforts to build an 'American' nanotechnology, and to posit state support for it as vital to the nation's future economic and geopolitical strength, may be understood as a key source of their policy success (cf. Felt 2015; Hecht 1998). Conversely, Australian proponents struggled to enact a compelling 'Australian' nanotechnology, a result in part of the 'absent imaginary' that they encountered regarding technology's importance to the nation-state and the state's role as technology sponsor.

The capacity and the outcome of proponents' efforts to make ostensibly similar promissory claims for nanotechnology 'sound credible' differed substantially in the two countries (Chapter 4). That is, despite the international circulation of promissory claims for nanotechnology's future economic impact, their meaning was remade anew among each political audience. In the US, predictions of a trillion dollar nanotechnology market were judged to 'sound credible' although not understood to be literally 'true'; in Australia such claims were dismissed as "a bunch of words" (Chapter 4). The *sociopolitical* dimensions of promissory claims, particularly the implied role for the state in bringing 'prospective techno-futures' (N. Brown, et al. 2000) into being, were influential in whether such claims were judged to 'sound credible'. US nanotechnology proponents drew heavily on collective 'memories' of state-sponsored technology's contribution to the nation's wealth, health and military might, and of past displays of its spectacular power that evoke national pride. Importantly, US proponents were also able to leverage expectations that the federal government should assume the burden of funding high-risk research to unleash the 'unique' entrepreneurial capabilities of its private sector. Australian proponents lacked comparable discursive resources. Not only did they lack salient stories of technology's role in nation building, but also the ability to recall collective memories of technological triumphs underwritten by the state. Unable to make government-backed Australian technological success 'sound credible', proponents' predictions of future nanotechnology-driven wealth creation were not persuasive (Chapter 4).

Despite international regulatory efforts responding to similar sets of risk data, Australia's nano-sunscreen regulatory debates (Chapter 6) also illustrate how policy meanings are shaped by their location within context-specific 'political situations' (cf. Barry 2013; see also Gottweis 1998; Jasanoff 2005a). Whereas Europe adopted nano-specific regulatory measures for nano-sunscreen and cosmetics (Shelley-Egan and Bowman 2015), in Australia calls for similar measures were cast as a threat to public health. Given very high skin cancer rates, and conceptions among Australian policy elites of publics as suffering a 'cognitive deficit' (Dietrich and Schibeci 2003; Schibeci and Harwood 2007; cf. Wynne 1991; Wynne 1993), many stakeholders viewed debates surrounding the adequacy of nano-sunscreen's regulation as undermining initiatives that promoted sunscreen's use. However, the emphasis by public servants on quashing these debates was shaped also by the architecture of nanotechnology policy. Given the constraints of 'market failure' policy rationales, the limited capacity of the NETS office to direct the activities of regulators, and the allocation of nearly one quarter of the NETS budget to its 'public awareness and community engagement' wing, intervening to manage publics' risk perceptions was one of the principal means identified by policy makers to foster conditions favourable to the nascent sector's development. Ironically, as the two political situations converged, the industry department became focused on maintaining publics' compliance with prescriptions for sunscreen use, while anti-cancer advocates were influential in delegitimising calls for nano-specific regulation.

7.5 The enduring effects of (nano)technology world-making

Nanotechnology proponents' storylines both drew on and contributed to imaginaries of future worlds that demand greater funding for (certain kinds of) scientific research, favourable policy settings, and particular science-state-market relations in the present. Their efforts helped to galvanise governments' preparedness to (attempt to) conjure nanotechnology futures, and a future nanotechnology, into being, while marginalising or silencing alternative futures, and indeed presents and pasts (cf. N. Brown 2003; Stirling 2009a). By some measures, this effort was highly successful**:** nearly US$24 billion in public funding for R&D has been invested by the US alone since the NNI's establishment (NSTC 2016, although see Chapter 4 regarding the contingency of such estimates)**.**[10] At the time of writing, the nanotechnology 'story' appears to hold receding salience for public policy. And yet, the appeal of the imaginaries on which this story drew is apparent in more recent US initiatives supported under President Barack Obama surrounding precision medicine, synthetic biology, and artificial intelligence – although President Donald Trump's treatment of science and technology policy is as yet unclear, and Australia's recent National Innovation Statement remains ambivalent in its view of the state's role. STS has always held in tension its capacity for interpretative analysis and normative intervention (see Prologue). Having shown the central role played by science-policy intermediaries in shaping generative imaginaries of the future, in this section I ask what we can

[10] In a more sceptical view, Matthew Eisler (2013b, 27) observes that research funds allocated under the "rubric" of the NNI constitute a "tiny fraction" of the US investment in basic science, and that the initiative did not substantially alter the funding imbalance between biomedical and physical sciences.

learn from these observations, and what relevance they hold for our conceptualisation of world-making in science policy more broadly.

Andy Stirling (2010b, 1031) emphasises that technological "lock in is not evidence of inevitability but of the 'crowding out' of potential alternatives". I suggest that whereas the policy focus on nanotechnology has demonstrably not resulted in "lock in", it has affirmed an imaginary among policy elites in which capital-intensive emerging technologies constitute 'the future', thereby 'closing down' (cf. Stirling 2008a) consideration of their multiple alternatives. One Australian interviewee suggested that there was "no downside" to the investment in nanotechnology, "even if nanotech went nowhere":

> "*...they knew that a lot of it would actually be spent on good causes – even if nanotech went nowhere, then the universities would end up with some really good equipment that they could use for 20 or 30 years, and some people would get to complete PhDs and do postdocs which would undoubtedly help the schools' development. So there was no downside to it. It was a clumsy effort, but most of these things are. They rarely work, but that shouldn't stop people trying*" (Industry member, Interview 60, December 2013).

Yet rather than having "no downside", the imaginaries that make such initiatives "sound credible" to political audiences even though "they rarely work" play an influential role in foreclosing consideration of alternative sociotechnical pathways and forms of 'innovation'. As Susan Leigh Star (1991) observes, world-making requires the destruction of alternate worlds – even though it is never entirely successful.

The repetition of technologically progressivist storylines which posit a narrow set of development pathways has a performative effect (cf. Gibson-Graham 2008). By asserting the inevitability of a particular future, these storylines conceal from view alternate futures. This is a powerful form of 'coordination work' (Mol 2002). By patching together into a semblance of singularity 'the future' available to us, technological progressivism prevents the proliferation of alternative futures, and the pluralisation of the objects, ideas and sociotechnical imaginaries that are actually available to innovation policy (cf. Stirling 2008a, 2009a, 2010a). It limits the range of options which policy makers and others consider to be credible, thereby shaping "the ways our progress actually unfolds" (cf. Stirling 2009a, 5).

The powerful influence of stories about the future in limiting science and innovation policy is apparent in many fields, among them agricultural research and development. For example, one Australian interviewee for this research argued that there is:

> "...*absurd inequity between where funding goes compared to where funding could go. Like we've brought certain worlds into being because we've invested so much in bio[technology] and nano – despite not investing in organics for example, or other kinds of food systems. They're still there and they're still flourishing but imagine if we flipped that funding and dropped it in to organics and other sustainable agriculture, how different the world would look*" (Social scientist, Interview 38, December 2013).

Yet storylines that foreground high-tech as 'the future' shield the "absurd inequity" in agricultural research funding allocations from critical scrutiny. In earlier work Anna Salleh found that Australian journalists were unwilling to "raise the issue of the money that is pouring into biotechnology versus other [agricultural] options" because, as one senior interviewee explained, such alternatives have "a whiff of incense about it... you know what I mean? ... The alternatives aren't canvassed because they aren't within the polygon of a 'biotech-led recovery' or a 'computer-led reality'. 'That's 1970s stuff, that's hippy stuff, that's out of fashion'" (Salleh 2005, 294). Where high-tech is enacted among policy makers as "ontologically inevitable" (Stirling 2009a), competing framings of both 'problems' and 'solutions' become relegated to 'the past' – "'1970s stuff... hippy stuff'". Such options, despite their material or normative merits, no longer 'sound credible' and their very canvassing brings a compromising "whiff of incense". Faced with a putative 'one-track' route to 'the future', the only choice available becomes high-tech or the "caves of mediocrity" (cf. Carr 2011, 14). For many observers, despite recognition that high-tech promotional initiatives "rarely work", the only 'credible' policy questions become scalar rather than directional or evaluative ('how much' rather than 'which direction'; Stirling 2009a), or pertain to safety.

It is perhaps unsurprising that the 'worlds' (re)created by nanotechnology may outlast the field's own appeal. Whereas nanotechnology proved effective in marshalling interest, enthusiasm and funding for physical science research, some interviewees suggested that the apparently diminishing enthusiasm for it meant simply that as an object of innovation policy it had reached the end of its useful service life. One US analyst observed that:

> "...*in the same way that TV shows have a half-life, and music has a half-life, these things lose their appeal after successive repetition. I think nano lost its appeal... you*

need a continuous refresh of having broad aspirational goals to pursue in science and technology, in pursuit of social or policy aims, and that message has to be fresh. It means that the message itself, it sometimes may be arbitrary. I don't think the nanotechnology message actually was arbitrary... I actually do think there was a toolset that did specifically have to do with nanoscale dimensions and size-dependent properties that mattered a lot. But even if it didn't there would have needed to be some other banner under which to push for more science and engineering funding and research. And I happen to think it was a good one" (Technology analyst, Interview 29, May 2014).

In this statement, the leverage of "fresh" stories (in which the object "sometimes may be arbitrary") is vital to the ongoing (re)constitution of future worlds that demand greater science funding in the present. The interviewee emphasised that the value of any one "message" or "banner" will diminish with "successive repetition". But the project of articulating "broad aspirational goals to pursue in science and technology, in pursuit of social or policy aims" – that is, the affirmation of sociotechnical imaginaries (Jasanoff and Kim 2009, 2013, 2015) that privilege technology as the means to achieve social aims – is in this view largely immune to cycles of disappointment, disillusion or ennui. Jasanoff (1996) observes that US conviction in a disinterested and objective mode of scientific enquiry has proven resilient to routine attacks on the imperfections of its practitioners. As I conducted interviews, the credibility of storylines that depict imminent technology-driven 'revolution' appeared to be comparably robust among US policy elites despite perennial disappointment or boredom with the revolution's vehicles – although the picture is more complex in Australia, as it is possibly now under the Trump administration in the US.

The question of *whose* imaginations and *whose* judgments of what "sounds credible" are conditioning the world-making of innovation policy is clearly of great significance. In cloistered environments, the stories told by entrepreneurial scientists about 'reality' and 'the future' exert a significant influence on policy making. A brief vignette from an Australian social scientist describing the black-tie dinner that followed celebrity entrepreneur Craig Venter's public address on synthetic biology is illustrative:

"*I looked across the sea of tables, the politicians, all the notable figures were there... And then it really hit home, just the links in the science community. Do you know what I mean, the links from the scientists and the policy makers. This huge momentum there,* *and I think a lot of the key decisions are made at a dinner, over golf, or an ALP function. The things that you and I... don't get invited to, do you know what I mean? I certainly wouldn't want Friends of the Earth there*" (Social scientist, Interview 21, September 2013).

This interviewee highlighted the strength of links between "notable figures" in science and in politics and the "huge momentum" they generate. They emphasised the physical disconnection of critical NGOs and social scientists from the sites at which science and technology policy agenda setting takes place, in their view "at a dinner, over golf, or an ALP function".[11] They suggested that such absences are not only a product of structural dynamics, and the socioeconomic synergies and networks that exist between these "notable figures", but also strategic inclusions and exclusions: "I certainly wouldn't want Friends of the Earth there".

That we seem to be entering an era that is seen as repudiating the 'third way' politics and the 'new economy' (Romer 1990, 1994) so closely identified with Clinton's administration, and which underpinned the NNI, is all the more reason to (again) question the proximity of science to particular conceptions of social order. STS scholarship has long highlighted publics' ambivalence regarding the projects of technoscience (Callon, et al. 2009; Chilvers and Kearnes 2016; Felt, et al. 2007; Irwin and Wynne 1996; Jasanoff 2003, 2005a; Wynne 1991, 2001, 2014) and their "loss of belief in science, when coupled to neo-liberal logics, as guaranteeing social progress" (Macnaghten, et al. 2015, 1). Such work has shown that the 'problem' of publics' ambivalence to technological innovation lies not in their deficient understanding of scientific risk and its regulation but in their questioning of the normative assumptions and political ambitions of projects justified in the name of objective 'science' (Doubleday and Wynne 2011; Wynne 2014). This thesis adds to that work by illuminating similar ambivalence towards the claims that underpin science policy among policy makers, political actors and even researchers. In so doing, it reveals fissures within what appear to be obdurate policy settlements, and sociopolitical contingency in the 'centres of calculation' (Latour 1987) of global technoscience. Amidst contemporary disillusion with the promises of the 'new economy', the casting of particular economic and technological trajectories as 'inevitable' (even though favoured initiatives "rarely work"), and the inequality produced by past policies' conflating particular sectors' and firms' competitiveness with the broader achievement of public good, there is growing recognition that we need to approach technoscientific world-making differently. I

[11] This vignette may underestimate the contribution to agenda setting of public servants and other "working level" intermediaries who may similarly not receive invitations to golf or private dinners.

conclude this study by suggesting some new opportunities for both scholarly analysis and political intervention.

7.6 Future directions

This thesis finds a role for the state in shaping technological futures that is at once greater, more diffusely organised, more variable, and more characterised by friction than is commonly recognised in the literature. This is important to the understanding that STS has of science-state-market relations and its common assumption of coordinated, pro-technology policy settings within government. More pragmatically, it is also of significance both to advocates for a more strategic interventionist innovation policy, and to those who would 'open up' (Stirling 2008a) such policy to greater democratic accountability and participation. To recognise that states play an active if sometimes uncoordinated role in forging the objects, ideas and stories that animate science and innovation policy, and which recursively (re)enact what we understand to be 'reality', is not to damn it, but rather to cast into sharp relief the political stakes of such work and the "democratic deficit" that is produced through such activities being "hidden" (Block 2008). Similarly, to find that even governments paying discursive deference to 'free market' commitments pursue industry policy is not to suggest that all industry policy is alike (Vallas, et al. 2011). Instead, it raises questions about the purpose, efficacy and opportunity costs of public investment in one sector at the expense of others, and how questions of social value may be more accountably and inclusively considered in an environment where uncertainty and unpredictability is inescapable (Calvert 2014).

My research highlights barriers within late-modern, capitalist countries' science policies to pluralising visions of possible futures, and to reimagining 'innovation' through a lens that foregrounds public good. The internalisation of apprehended 'market logics' by scientists, policy makers and political actors, their limited resources to consider or engage with the sociopolitical dimensions of science policy, and the often uncoordinated implementation of such policy in practice, are significant obstacles to doing innovation policy differently. Yet I suggest that doing innovation policy differently has never been a more urgent task. At the time of writing, there is a palpable backlash to the imaginaries that this thesis has investigated, and disillusion with the socio-economic inequity produced by technological innovation and the automation it enables. Yet this is concomitant with calls for governments to take a greater leadership role in harnessing new technologies to shift away from carbon-intensive economic systems to avoid catastrophic climate change, and to take a more active role in managing automation's disruptive effects. If we want a more critical, socially engaged and ecologically responsive science and technology policy, the challenge is formidable. Present-day advocates for interventionist innovation policy must: articulate a proactive role for the state in developing industry and innovation policy that is not limited by 'market failure' rationales; prioritise the pursuit of equity in a time of rapid and unequal technological change; foster a plurality of development pathways that explicitly recognises uncertainty; and 'open up' the cloistered world of science and technology policy making to countervailing imaginaries, critiques and aspirations. Perhaps most challenging for scientistic notions of science and technology policy, such policy making must explicitly recognise and engage with the "social, cultural and technical processes" with which it is intertwined (Irwin 2008, 584), rather than defending long-discredited claims to its disinterest and objectivity.

This thesis suggests opportunities for both scholarly and political work. The impoverished apparatus and the fragility of Australian government support for 'innovation' is striking. A series of Australian governments has been resistant to supporting technology development on the basis of both 'free market' and 'comparative advantage' ("fossil fuels forever") principles. Future research could fruitfully explore these tensions within other governments who ostensibly adopt 'free market' policy settings, and whose political economies show a strong reliance on extractive industries. Are Australian political audiences exceptional in their scepticism towards the knowledge economy's claims, or has its appeal for political actors been over-stated? If it is the case that in addition to publics' disillusion with the promissory claims that accompany technological innovation, policy elites are also ambivalent towards them, how vulnerable is the 'reality' of emerging technologies proponents to remaking? How might we enact alternative worlds that foreground values such as justice and care (cf. Gibson-Graham 2008; R. Pearse 2015; Verran 1998), and how can we best explore the role for science and technology policy in creating them? I suggest that 'opening up' our sociotechnical pathways for collective reimagining requires not only analytic but explicitly political work – an insurrection of both "*subjugated knowledges*" (Foucault 1980 [1972], 81), and also the stories and the imaginaries with which they are intertwined. It requires creating avenues and spaces within which the assumptions, values and tradeoffs shaping innovation policy may be explicitly contested, importantly including how we should understand or evaluate 'innovative' knowledge and behaviour. It demands that we re-examine the appropriate roles and responsibilities of government, industry, the research sector and wider publics in fostering a plurality of development pathways. And it requires affective storylines and imaginaries that amplify the ‘reality’ of the already-existing ‘truth’ that there is no pre-existing, unitary path to ‘the future’. This is a challenge whose structural, material and discursive dimensions are interlinked.

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Appendix A: List of interviewees

Interviewee number	Interviewee description (role or former role most relevant to interview)	Interview Date
1	Social scientist (US)	January 2014
2	Social scientist (US)	January 2014
3	Social scientist (Au)	October 2013
4	Regulator (US)	February 2014
5	Neal Lane, Presidential advisor (US)	March 2015
6	Safety scientist (Au)	December 2013
7	Ministerial advisor (Au)	September 2013
8	Regulator (US)	May 2014
9	Kim Carr, Minister for Innovation, Industry, Science and Research (Au)	December 2013
10	Public servant (Au)	November 2013
11	Technical scientist (Au)	December 2013
12	NNCO staff member (US)	February 2014
13	CEO R&D body (Au)	November 2013
14	Regulator (US)	February 2014
15	Technical scientist (Au)	November 2013
16	Social scientist (Au)	December 2013
17	Community sector (Au)	September 2013
18	Social scientist (US)	May 2014
19	Ian Olver, CEO Cancer Council Australia (Au)	November 2013
20	Federal agency official (US)	May 2014
21	Social scientist (Au)	September 2013
22	Social scientist (US)	May 2014
23	Social scientist (Au)	December 2013
24	Industry member (Au)	October 2013
25	Safety scientist (US)	March 2014
26	House Committee on Science staff member (US)	May 2014
27	Regulator (Au)	November 2013
28	Public servant (Au)	March 2014
29	Technology analyst (US)	May 2014
30	Public servant (Au)	November 2013
31	Technical scientist (Au)	November 2013
32	Community sector (Au)	November 2013
33	Industry member (US)	May 2014
34	Mihail Roco, chair NSTC NSET (US)	May 2014
35	Industry member (Au)	November 2013
36	Social scientist (Au)	November 2013
37	Social scientist (Au)	October 2015
38	Social scientist (Au)	November 2013
39	Community sector (Au)	October 2013
40	OSTP staff member (US)	May 2014

41	Safety scientist (Au)	November 2013
42	Industry member (Au)	November 2013
43	R&D Manager (US)	March 2014
44	Technical scientist (Au)	December 2013
45	Ministerial advisor (Au)	November 2013
46	Ministerial advisor (Au)	December 2015
47	Community sector (Au)	October 2013
48	Social scientist (Au)	March 2014
49	NSF staff member (US)	May 2014
50	Public servant (Au)	October 2013
51	Ministerial advisor (Au)	February 2014
52	Social scientist (US)	February 2014
53	Regulator (Au)	January 2014
54	Community sector (Au)	February 2014
55	Community sector (US)	May 2014
56	Safety scientist (Au)	December 2013
57	Ministerial advisor (Au)	November 2013
58	OSTP staff member (US)	May 2014
59	Journalist (Au)	November 2013
60	Industry member (Au)	December 2013
61	Science advisor (Au)	December 2013
62	Technical scientist (Au)	April 2015
63	Industry member (Au)	April 2015
64	CEO major research institution (Au)	November 2015
65	Robin Batterham, Chief Scientist (Au)	April 2015
66	Community sector (Au)	December 2014
67	CEO R&D body (Au)	May 2015
68	Public servant (AU)	June 2015
69	Vijoleta Braach-Maksvytis, co-director of CSIRO Centre for Nanotechnology (Au)	June 2015
70	Vicki Sara, CEO Australian Research Council (Au)	September 2015

Appendix B: Sample Participant Information Statement and Consent form

UNSW

<u>School of Humanities, Faculty of Arts and Social Sciences</u>

Approval No 13095

THE UNIVERSITY OF NEW SOUTH WALES

PARTICIPANT INFORMATION STATEMENT AND CONSENT FORM

"Science, values, policy and politics:
How have boundaries been constructed and contested in nanotechnology governance debates"[1]

Dear X,

You are invited to participate in a study of nanotechnology governance debates and policies. My name is Georgia Miller and this is my doctoral research project. I hope to learn about the emergence and unfolding of public and policy debates about governing nanotechnology in the Australian context, and to compare this to experiences internationally, particularly in the United States. Given your role in nanotechnology policy as X, your perspective would be of great value for my study.

If you decide to participate, I will interview you for approximately 1 hour at a time that is most convenient for you, either in person, if we can find a mutually convenient time, or via telephone. The interview will be audio-recorded for transcription purposes only with your consent. Notes may also be taken during the interview. All notes and audiotapes will be stored securely to safeguard confidentiality.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission, except as required by law. If you give me your permission by signing this document, I plan to analyse the results as part of my thesis, and to publish the analysis in subsequent papers. In any publication, including the thesis, information from this interview will be provided in such a way that you cannot be identified, except where you have explicitly granted me permission. If you grant me permission to identify you as an interviewee (by ticking the box below near your signature), I will not attribute any particular quotation to you without first showing it to you and receiving your permission to reproduce that quote..

Complaints may be directed to the Ethics Secretariat, The University of New South Wales, SYDNEY 2052 AUSTRALIA (phone +612 9385 4234, fax +612 9385 6648, email

[1] Please note that the title of the thesis changed following fieldwork.

ethics.gmo@unsw.edu.au). Any complaint you make will be investigated promptly and you will be informed about the outcome.

A summary of the research findings will be offered to research participants at the completion of this study in document form.

Your decision whether or not to participate will not prejudice your future relations with the University of New South Wales. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice. We cannot and do not guarantee or promise that you will receive any benefits from this study.

If you have any questions, please feel free to ask us. If you have any additional questions later, I will be happy to answer them – you can email at g.miller@student.unsw.edu.au

You may also contact my supervisor Dr Matthew Kearnes with any queries or for further information on + 612 9385 1010 or email m.kearnes@unsw.edu.au

You will be given a copy of this form to keep.

THE UNIVERSITY OF NEW SOUTH WALES

PARTICIPANT INFORMATION STATEMENT AND CONSENT FORM (continued)
"Science, values, policy and politics:
How have boundaries been constructed and contested in nanotechnology governance debates"

You are making a decision whether or not to participate. Your signature indicates that, having read the information provided above, you have decided to participate.

………………..……………………… ………………………...…………….
Signature of Research Participant Signature of Witness

……………………………………..…… …………………………………….
(Please PRINT name) (Please PRINT name)

………………………………………… ....……………………………………….
Date Nature of Witness

☐ I consent to being interviewed on the basis that my permission will be sought prior to attributing any information or quotes from this interview to me ________________________ (initial)

☐ I consent to being interview on condition of anonymity; that is, that no information from this interview that can be identified with me personally will be cited in the thesis or publications or communicated to anyone outside the research team (ie student and supervisors) _________________(initial)

REVOCATION OF CONSENT
"Science, values, policy and politics:
How have boundaries been constructed and contested in nanotechnology governance debates"

I hereby wish to **WITHDRAW** my consent to participate in the research proposal described above and understand that such withdrawal **WILL NOT** jeopardise any treatment or my relationship with The University of New South Wales, *(other participating organisation[s] or other professional[s])*.

……….................…………....………… …………………………………….
Signature Date

…………………………………………………….....................…
Please PRINT Name

The section for Revocation of Consent should be forwarded to *Georgia Miller* (*g.miller@student.unsw.edu.au*), or c/o Dr Matthew Kearnes, School of Humanities, University of NSW, Kensington NSW 2052 AUSTRALIA [p3/3]

Appendix C: United States archival work

In research for this thesis, I conducted multiple searches of the Clinton Digital Library, "a virtual research room and digital repository that provides free and open access to the digitized collections of the William J. Clinton Presidential Library & Museum".[2]

Following my examination of many documents, the following references are cited in the thesis:

Brock, Horace "Woody" (1995) *Resolving the US Productivity Paradox: Innovation versus Investment in Global Competition. Prepared for President William J. Clinton, The White House. September 7, 1995* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Clinton, William J. (1999) *Memorandum for the Heads of Executive Departments and Agencies: Use of Information Technology to Improve our Society. December 17, 1999* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Gore, Albert (1998) *Remarks by Vice President Al Gore. "Creating new jobs for the 21st Century: Investing in research and technology". Announcement of R&D tax credit extension, Genentech. Thursday, January 29, 1998* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Kalil, Thomas (1999) *National Nanotechnology Initiative. Draft September 27, 1999* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Kohlenberger, Jim (1998) *High-Tech Outreach Meeting, St. Louis Science Center. 2:50- 3:50 pm, Friday, October 16th 1998* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Lane, Neal (1999) *Memorandum for Maria Echaveste from Neal Lane. Subject: State of the Union Messages. November 23 1999* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

NEC Staff (1997) *Memorandum for Gene Sperling from NEC Staff. Potential new policy initiatives: Some preliminary ideas. October 30, 1997* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Penn Schoen Berland Associates (1999) *State of the Union Polling. Monday, December 20, 1999. FOIA Number: 2006-0458-F* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

PPI (1998) *The case·for technology, in the knowledge economy: R&D, economic growth, and the role of government. Policy briefing, June 1998* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

Sperling, Gene (1999) *Memorandum for John Podesta from Gene Sperling re FY 2001 budget ideas. November 23 1999* (Little Rock, AR: William J. Clinton Presidential Library & Museum).

[2] https://clinton.presidentiallibraries.us/about

Appendix D: Australian *Freedom of Information Act* requests

In research for this thesis, I submitted a request to the Department of Industry and Science under the *Freedom of Information Act 1982* (FoI), from which I obtained and examined documents on the evaluation of past national nanotechnology policy, for which I was given reference DIISR14/19152.

Additionally, I obtained documents from the Department of Industry and Science that were previously sought and released under FoI following requests by other parties, pursuant to those requests being registered on the Department's FoI Disclosure Log.[3] These were:

- Disclosure Log 11-010 (Policy responses to and regulatory assessment of nano-silver)
- Disclosure Log 12-012 ("Documents relating to the NETS survey of public attitudes towards sunscreen with nano-particles - February 2012")
- Disclosure Log 12-018 ("A Presentation given at a nanotechnology conference in February 2012 and associated documents. This includes an additional information letter related to the Presentation")
- Disclosure Log 13-004 ("Incoming briefs for Minister Craig Emerson as Minister for Tertiary Education, Skills, Science and Research; and Minister Greg Combet as Minister for Industry and Innovation")
- Disclosure Log 14/002 ("Review of materials produced through the national Enabling Technologies Strategy Public Awareness and Community Engagement Program").

I also examined documents associated with a previous FoI request to the Australian Competition and Consumer Commission, reference D14/11469, that had been made publicly available by Friends of the Earth Australia.[4]

From this research, the following references are cited in the thesis:

ACCC (2014) 'Request for access under the *Freedom of Information Act 1982* D14/11469', http://www.emergingtech.foe.org.au/wp-content/uploads/2016/03/FOI-Friends-of-the-Earth-Australia-ACCC-to-Applicant-re-Transmittal-of-Documents-Letter-2.pdf Accessed 9 January 2017.

Canning-Menon, Penny (2012) 'Email: Sun Screen Study [SEC=IN-CONFIDENCE]. Tuesday, 7 February 2012 6:43 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 112.

Cormick, Craig (2012a) 'Email: FW: Sunscreen survey [SEC=UNCLASSIFIED]. 24 January 2012, 4:38 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 41.

--- (2012b) 'Email: Re: Nano Sunscreens in the news [SEC=UNCLASSIFIED]. 9 February 2012 3:23 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 224.

--- (2012c) 'Email: Re: Nano Sunscreens in the news [SEC=UNCLASSIFIED]. 9 February 2012 12:18 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 198.

[3]https://industry.gov.au/AboutUs/InformationPublicationScheme/Pages/FreedomofInformationDisclosureLog.aspx

[4] http://www.emergingtech.foe.org.au/wp-content/uploads/2016/03/FOI-Friends-of-the-Earth-Australia-ACCC-to-Applicant-re-Transmittal-of-Documents-Letter-2.pdf

--- (2012d) 'What does the public really, REALLY think about nanotechnology? And what impacts does information have on their attitudes? 8 February 2012', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 146.
Dessi, Patrick (2012) 'Email: RE: Foe scraps safe sunscreen guide. 20 February 2012 10:52 AM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 253.
DIISRTE (2012a) 'IISRTE-In-Confidence-Brief: Release of online survey on public behaviours as a result of messages on possible dangers of nanotechnology in sunscreens. Slipstream version: 23 January 2012', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: Australian Government): Document 57.
--- (2012b) 'Media release: Concerns about sunscreen nanoparticles put Australians at risk of skin cancer', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: Australian Government): Document 94.
--- (2012c) 'Review of the National Enabling Technologies Strategy (NETS) September 2012. DIISR-In-Confidence', in, *Freedom of Information Act Disclosure DIISR14/19152* (Canberra: Australian Government): 230-433.
--- (2012d) 'Senate Standing Committee on Economics 2011-12 Additional Estimates', in, *Freedom of Information Act Disclosure Log 12-018* (Canberra: DIISRTE): 228-29.
--- (2012e) 'Study of public attitudes towards sunscreens with nano particles. February 2012', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: Australian Government): Document 65C.
Herrmann, Jan (2012a) 'Email: FW: ICONN 2012 [SEC=IN CONFIDENCE]. Tuesday, 21 February 2012 11:08 AM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): 269-70.
--- (2012b) 'Email: NMI ICONN presentation [SEC=UNCLASSIFIED]. Monday 13 February 2012 10:36 PM', in, *Freedom of Information Disclosure Log 12-018* (Canberra: DIISRTE): 218.
--- (2012c) 'Email: NMI ICONN presentation. 13 February 2012 10:36 PM', in, *Freedom of Information Disclosure Log 12-018* (Canberra: DIISRTE): 218.
--- (2012d) 'Email: RE. Further to ICONN nanoparticle presentation [SEC=IN-CONFIDENCE NMI]. 8 February 2012 10:14 AM', in, *Freedom of Information Disclosure Log 12-018* (Canberra: DIISRTE): 64.
--- (2012e) 'Email: RE. presentation [SEC=UNCLASSIFIED]. 13 February 201 10:36 PM', in, *Freedom of Information Disclosure Log 12-018* (Canberra: DIISRTE): 216.
Ipsos (2012) 'NETS-PACE Materials Discussion. Prepared for Department of Innovation, Industry, Science, Research and Tertiary Education', in, *Freedom of Information Act Disclosure DIISR14/19152* (Melbourne: Ipsos Social Research Institute): 200-28.
Johnson, Craig (2012) 'Email: FW: Draft brief on nano material in sunscreens from NMI [SEC=IN CONFIDENCE]. 14 February 2012 1:59 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 287.
Murray, Paul (2012) 'Mornings, 6PR (Perth), 9 February 2012, 9:18AM', in, *Freedom of Information Act Disclosure Log 12-012* (Perth, WA: DIISRTE): Document 269.
Pettifer, Ken (2012) 'Email: RE: MR-781 Concerns about sunscreen nanoparticles put Australians at risk.doc [SEC=UNCLASSIFIED]', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): Document 134.
Warrington, Bruce (2012a) 'Email: FW: Draft brief on nano material in sunscreens from NMI [SEC=IN-CONFIDENCE]. 15 February 2012 8:38 AM', in, *Freedom of Information Disclosure Log 12-018* (Canberra: DIISRTE): 239-42.
--- (2012b) 'Email: Re: Conversations with ABC journalists regarding sunscreen study [SEC=IN-CONFIDENCE]. Thursday, 9 February 2012 11:35 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): 170-72.

--- (2012c) 'Email: RE: Request for copy of Victoria's actual ICONN presentation [SEC=IN-CONFIDENCE]. 16 February 2012 1:51 PM', in, *Freedom of Information Act Disclosure Log 12-012* (Canberra: DIISRTE): 244-45.