Managing uncertainty and risk in science, innovation and preparedness

Why public policy should pay more attention to geopolitical and financial considerations

A Discussion Paper prepared for the Federation of Australian Scientific and Technological Societies

by

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Preface

The Federation of Australian Scientific and Technological Societies (FASTS) has commissioned this Discussion Paper, aimed at extending the scope of how we think about the nature and extent of the returns sought from public support for science and innovation. The purpose is to stimulate debate over how we should define what we are seeking to achieve from public support for science and innovation in Australia, and how we should go about achieving these objectives. This Discussion Paper does not necessarily reflect the agreed position of the Federation of Australian Scientific and Technological Societies.

The paper highlights a missing factor in why R&D is funded - *preparedness in an uncertain world*. It sets out to raise the profile of this concept and to tries to articulate what a framework for addressing "science, innovation and preparedness" (SIP) might look like. In so doing, it draws upon insights from finance and geopolitics – two inter-linked bodies of knowledge that focus on handling the uncertainties and risks generated by the modern global economic and political order.

The arguments presented in this paper are not new, indeed they are rather "obvious". They simply seek to re-state and integrate some commonsense principles that are tacitly accepted within government and the business community but do not sit easily within the current science and innovation policy framework. The current framework downgrades the status of "preparedness" as an outcome class relative to "innovation".

The proposals put forward in this paper are primarily aimed at the Government policy community. They have been stimulated by experience gained from actual practice in policy consulting on science and innovation over the last decade in which both academic and business perspectives have been engaged with. Over this period, it has become more and more apparent that there is a gulf between what practitioners seek from the policy framework and what they actually get once specific rules, guidelines, and evaluation principles have been rolled-out.

Recommended citation:

Matthews, M. L. (2006) *Managing Uncertainty and Risk In Science, Innovation and Preparedness: Why Public Policy Should Pay More Attention To Geopolitical and Financial Considerations,* Discussion Paper prepared by Howard Partners. Canberra: Federation of Australian Scientific and Technological Societies.

If this paper is cited, an email notification to mark.matthews@howardpartners.com.au detailing the citing document would be greatly appreciated.

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Acknowledgements

I would like to thank Bradley Smith for encouraging me to develop these arguments and for critical feedback, advice and very useful suggestions throughout the research, drafting and paper finalisation process. Other useful feedback was provided by (in alphabetical order): Andrew Boulton; Lawrence Cram; Katherine Morton and Tom Spurling. I would also like to thank Linda Butler, Kevin Croft, and John H Howard for useful discussions and advice on evidence used in the paper.

Executive Summary

This paper advocates a significant re-alignment of contemporary public policies towards science and innovation. The proposed re-alignment is designed to improve governments' ability to use publicly supported research and experimental development (R&D) to handle the uncertainties and risks that markets cannot cope with effectively. Handling uncertainties and risks is a long-established and widely recognised principle in public policy that remains as pertinent today as in the past – perhaps more so given the global challenges of climate change, environmental degradation, energy, poverty, pests and diseases, threatened pandemics and the proliferation of weapons of mass destruction.

The general community, and the private sector, expect publicly funded R&D, together with privately funded R&D carried out in the public sector, to identify, assess and develop contingency plans and responses to such uncertainties and risk factors. Business executives recognise that decision-makers in markets must apply relatively high discount rates to investment decisions. This limits seeking very long-term outcomes and/or highly uncertain outcomes even when commercial opportunities exist. Governments' "insurance" role in handling major threats is, largely, unquestioned. The private sector looks to the public sector to handle such concerns. Consequently, the wide-spread research on, and dissemination of, knowledge on *what* may happen in the future, *why* this may happen and *which actions, by whom and when,* can be taken *now* to mitigate these risks, provides a powerful means via which public R&D generates useful private and social benefits.

The central tenet of the paper is that we should move to introduce the concept of "preparedness" to complement the more familiar concepts of science and innovation – resulting in a policy framework that focuses on *science, innovation and preparedness (SIP)* policy. "Preparedness R&D" deals with risks and options in an uncertain world, a world in which contingent events determine whether or not specific options should be taken up. Characteristically, decision-makers throughout the economy seek access to, and an understanding of, preparedness options. The concept of "preparedness" relates both to the ways in which fundamental knowledge helps us to be prepared for the *unexpected* and to being prepared to handle specific *expected* threats and challenges. The concept of preparedness R&D applies to expected challenges - whilst most scientific research helps us to be prepared for the *unexpected* by identifying and diagnosing new and emerging challenges, in so doing stimulating preparedness R&D.

The principle is not dissimilar to that of "rational expectations" models in economic theory – in the sense that all decision-makers adjust their views of the world, and how to react, based on the best available models and information. Decision-makers seek to maximise opportunities relative to risks. The findings from public R&D play a critical role in shaping understanding of these opportunities and risks. In so doing, public R&D helps all markets be more efficient in allocating resources *today* in the face of *future* uncertainties, risks and consequences. As in financial markets, options and contingencies addressing future risks and opportunities can have a present day value based on the levels of potential damage faced in the future. *The greater the uncertainty over, and severity of the consequences of, what we face in the future - the greater the value of possessing options for responding to these uncertainties in a cost-effective and timely manner.* The growing levels of preparedness in the business sector to reduce greenhouse gas emissions or use water more efficiently, are topical examples of this "distributed decision making" outcome from public R&D. It is public R&D that has been identifying and assessing climate change risks – providing early warning of what might otherwise be far more costly shocks in the future.

Unfortunately, this uncertainty and risk-aware aspect of public R&D has become harder to justify because it sits awkwardly in relation to contemporary policy thinking. The current perspective seeks a "smoking gun" audit trail linking public R&D and wealth creation, often via formal intellectual property. It focuses largely on the "upside" and tends to neglect the important, and costly, "downside" to modern economic and political development. Furthermore, this narrowly focussed upside perspective is problematic because it can overlook: (a) the value of possessing fundamental computationally based theoretical understanding as core preparedness infrastructure, and; (b) the human capital value of the people trained in scientific research methods that work in many areas of the economy and society. These people play a critical role in helping markets and resource allocation decisions to be more efficient than would otherwise be the case. The computationally based theory applied (and, often, improved) by these agents is a significant shaper of market behaviour because it factors opportunities and risks into prices.

Public R&D seeks to generate fundamental theoretical understanding of phenomena and new ways of applying this understanding. "Contested knowledge" - the strong emphasis placed on peer review mechanisms to validate theoretical claims on the basis of factual data - is not simply a quality control process that benefits academic promotions. Contested claims of veracity subject to formal scrutiny of the relationship between theory and evidence also serve as a means of generating valuable human capital skilled in defining and solving complex problems quickly and cost-effectively *throughout* the economy. This is why leading investment banks recruit physicists, mathematicians and engineers – a rigorous scientific training generates valuable generic skills in problem definition and problem solution in complex situations in which timeliness is critical. Better theory, and the skills in applying this theory, allow given objectives to be achieved with a fewer number of iterations, thereby generating competitive advantages in both cost-effectiveness and lead-times.

Characteristically, better theory results in a tractable definition of a problem that is more likely to avoid wasted effort in proceeding to solve that problem. The competitive advantages that stem from this are as important in business as they are in academic research. Public science and industrial R&D exploit the same epistemological capabilities. Science seeks to develop ever more parsimonious explanations of complex phenomena (critical to tractable problem definitions) via experimental testing aimed at selecting and evolving theory. Peer review plays a critical gate-keeper role in reducing the incidence of limited or incorrect theoretical propositions that risk wasted time and cost in future research if not spotted by the "epistemological immune system". Similarly, industrial R&D uses experimental development to test theory and simulation models in order to avoid wasted time and cost in both future R&D and market introduction processes. Consequently, the differences between public science and industrial R&D are not epistemological (at the cutting-edge both share a concern with continuously advancing computationally based theoretical power via contested knowledge), rather they lie in the subtleties over what the theory seeks to achieve. For instance, experimental development in industrial R&D seeks to use theories and formal models that can handle the added complexities of "scale-up" and related issues of less relevance to public science.

The paper puts forward a geopolitically and financially-based perspective on how policies toward preparedness R&D might be approached. This framework seeks to recognise that the science and technology gaps between nations are not just a matter of differential "catch-up" – they are also the product of deliberate constraints to international flows of scientific and technological knowledge. These capability gaps are actively managed by the science powers by controlling cross-border flows of scientific and technological knowledge. Differential access to leading-edge technologies is granted on the basis of political and military alliances but also with regard to the potential for industrial competition. This creates the scope for trade-offs to be made and therefore a space in which diplomacy can be critical to effective international engagement in science, innovation and preparedness. In the more peripheral economies, such as Australia, a far greater emphasis in science and innovation policy is placed upon economic factors (principally trade and "research commercialization") than geopolitical and (rather strangely) financial concerns over how investment risk is managed.

Effective international engagement is particularly important because one impediment to innovation in smaller economies is that there may be an insufficient supply of both public and private funding for demonstrating "bankable feasibility" (acceptable levels of investment risk) relative to the demand for this critical, but costly, activity. This generates a major comparative advantage for the large 'science powers' that are able to accumulate the necessary, but expensive, R&D and technology demonstration infrastructure that generates bankable feasibility. This accumulated infrastructure of facilities, R&D tools and the skills to use them, are the basis of powerful economies of scale in innovation. As a result, actually realising the potential gains from science, innovation and preparedness R&D may require sophisticated "scientific and technological diplomacy" that trades access to niche areas of science and technology that smaller economies *can* afford to develop for access to the more expensive knowledge that smaller economies cannot afford – but which can be critical to achieving bankable feasibility for new technologies.

Recognising the important role of "preparedness", along with the geopolitical and financial dimensions to preparedness, would help to focus attention on the diverse and pervasive ways in which the returns to public support for R&D arise – and which extend way beyond "innovation" per se.

Preparedness

Why preparedness is a missing concept in the current policy framework

We accept it as a given that governments handle the uncertainties and risks that markets cannot cope with. We also accept that the strategies via which governments respond to these uncertainties and risks are informed by academic research. Concerns over climate change provide a topical example of one area of uncertainty and risk that has been informed by academic research – but there are many others.

Indeed, public responses to previous challenges over which initial uncertainty over cause and effect was reduced via public science (e.g. HIV-AIDS and dryland salinity) indicate that the general community recognises the importance of the "preparedness" dimension to public support for R&D. From that perspective, science and innovation does not just offer the potential to contribute to national income and wealth. These efforts are also concerned with identifying and preparing to handle a wide range of threats and risks that markets may not handle very well – from the consequences of pests/diseases and environmental degradation through to those faced in the national security domain. Characteristically, the concern is with how the likelihood of a threat or challenge eventuating *combines* with the economic and social *consequences* should the situation eventuate. Uncertainty and risk matter most when the consequences are severe.[2]

This type of research seeks to improve our understanding of what *may* happen in the future and *why* – and seeks to develop responses to these concerns. Characteristically, this work is *forward-looking*, *risk-mitigating* and the benefits sought are *contingent* on other factors that may, or may not, happen. In this sense, spending on this type of research is similar in nature to an insurance premium. Indeed, there are growing inter-connections between this type of research and insurance and other risk-hedging investments in the financial services sector.

Although the necessity for governments to invest in research that mitigates future risks is obvious and not controversial there is, rather puzzlingly, no generic "label" applied to this type of research. Policy thinking about public research in Western market democracies tends, nowadays, to focus on the notion of "science and innovation". Broadly speaking, this refers to the potential for science to generate *innovation* – to add to national income and national wealth by doing new things and by doing existing things in new ways.

This line of thinking about where to look for useful outcomes from public spending is dominated by "upside" considerations. Far less attention is paid to the ways in which public research generates benefits by helping governments, business and the general community reduce "downsides" by making smarter resource allocation decisions in an uncertain and risky world.

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2 A useful discussion of current thinking on how governments can handle uncertainty and risk from the perspective of the possible *consequences* can be found in: Prime Minister's Strategy Unit (2002) *Risk: Improving Government's Capability to Handle Risk and Uncertainty*. London: Cabinet Office.

The purpose of this paper is to try to redress this imbalance in the policy framework by:

- highlighting the importance of public, and private sector, *preparedness* research and experimental development (R&D);
- advocating a more explicit use of the preparedness concept in public policy by adopting the notion of "science, innovation and preparedness" (SIP);
- considering the geopolitical dimension to science, innovation and preparedness;
- arguing that innovation, as currently construed, and preparedness are not mutually exclusive - on the contrary, many innovations are derived from preparedness R&D;
- promoting a perspective toward preparedness that highlights the role of computationally based theoretical understanding in science and technology in achieving cost-effective and timely responses;
- suggesting ways in which financial tools based on the management of uncertainty and risk can be used to inform resource allocations and appraisal in the public sector, and;
- proposing an approach to valuing the human capital critical to R&D on the basis of the capability to achieve cost-effectiveness and timeliness in executing both preparedness and/or innovation based responses via the use of computationally based theoretical knowledge.

As such, the purpose of the paper is essentially to promote the use of a label that we can use to classify R&D in both the public and private sectors and also in the increasingly important civil society/philanthropic sector (which now accounts for a significant proportion of identified global R&D funding).

The concept of preparedness R&D is similar to accepted notions of capacity building in R&D – that is, investment in the capability to both identify and respond to the unforeseen.[3] One feature of the current "science and innovation" policy framework is that capacity building is, at best, considered a derivative outcome. This may be because capacity building can also be represented as a justification for "disengaged" R&D driven primarily by researchers' own interests - something that many OECD governments now view unfavourably.[4] Perhaps the time has now come to recognise that the "derivative" outcome associated with the preparedness dimension to capacity-building should be given a more prominent place in our policy framework.

Understanding preparedness R&D

The concept of "preparedness" in the context of R&D relates both to the ways in which fundamental knowledge helps us to be prepared for the *unexpected* and to being prepared to handle specific *expected* threats and challenges. The concept of

[3] I am grateful to Lawrence Cram for highlighting the relationship between preparedness and capacity building in relation to fashions in policy thinking.

[4] One of the best discussions of shifts in OECD government thinking on this issue, specifically in relation to the rise of the "grant-tract" can be found in Paul David (1999) The Political Economy of Public Science, in (ed) Helen Lawton Smith. *The Regulation of Science and Technology* Macmillan: London.

"preparedness R&D" applies to expected challenges - whilst most scientific research helps us to be prepared for the *unexpected* by identifying and diagnosing new and emerging challenges in so doing stimulating specific areas of preparedness R&D.

Consequently, preparedness R&D covers concerns over a range of natural hazards and environmental impacts, national security, pest and disease threats through to social disruption like pandemics. In more generic terms, preparedness also addresses areas in which it is important to reduce uncertainty over cause and effect in complex situations in which there might possibly be beneficial outcomes but over which there are high levels of uncertainty – such as potentially disruptive technologies. These are the situations in which the uncertainties and risks, and the consequences of these risks eventuating, are sufficiently great that markets cannot allocate sufficient resources to developing contingency options, although markets still do allocate substantial resources to this aspect of preparedness.

From this perspective, preparedness constitutes a distinct outcome class. It is concerned with generating the under-pinning capacity and understanding to identify new threats and challenges and then to develop, evaluate, and select portfolios of *options* to respond – a range of contingencies for handling the unexpected in an uncertain world. The value of investments in the fundamental research that generates preparedness, and specific areas of preparedness R&D that target identified threats, stems from:

- possessing the human capital able to handle uncertainty in complex situations via the advanced problem definition and solution development skills that work on fundamental theoretical understanding generates;
- the benefits of possessing a portfolio of knowledge-based options in order to mitigate future risks and exploit future opportunities.

The value of these options often lies in the ability to *integrate* the knowledge and capability associated with different options quickly and cost-effectively in response to emerging opportunities and threats.

In market democracies outside of the United States we hear relatively little about "preparedness R&D". In the United States, the concept of preparedness R&D has a distinct focus on the fast moving and catastrophic threats of natural disasters, terrorism and weapons of mass destruction. Whilst the contemporary use of the term in the United States is relatively recent the underlying policy principle can be traced back to the end of the Second World War. However, once the general principle of preparedness is accepted, as this paper seeks to show, a far wider longer-time frame and less pessimistic role is opened up.

Similarly, the geopolitical dimension to science policy is a relatively uncontroversial topic within the US policy community - as is the related issue of the critical role of theory-oriented basic research in a modern science power. However, outside the United States, policy communities tend be wary of, and uncomfortable about, highlighting the links between power in the geopolitical sense and the power of advanced scientific theory associated with the domination of the global R&D effort.

In these more peripheral economies a far greater emphasis in science and innovation policy is placed upon economic factors (principally trade and "research commercialization") than geopolitical and (rather strangely) financial concerns over how investment risk is managed. This is particularly evident in the policy frameworks of two of the United State's closest geopolitical allies: the United Kingdom and Australia. In both of these economies the game is "science and innovation" policy with little reference to preparedness. This contrasts with the emphasis on preparedness and global reach in synergy with geopolitical and economic objectives evident in the US policy framework.

Lessons from the United States in managing preparedness R&D

The modern governance movement may have played a significant role in directing policy thinking away from the preparedness outcome class. Output-outcome budgeting tends to be "risk-averse" – it is not well suited to handling things that *might possibly* happen. This characteristic is not inherent in the concept itself (preparedness can be, and is, treated as an outcome class in the public sector) but risk-aversion does now tend to be a feature of how governments choose to actually implement output-outcome budgeting outside of national security and other high-profile preparedness policy areas.[5]

One consequence of the move toward a modern governance agenda in market democracies that do not possess a strong military-industrial R&D capability is that appropriate constraints are not placed on how output-outcome thinking influences the nature and extent of the benefits we expect from support for science and innovation.

The United States led innovation within government in adopting and refining output-outcome budgeting.[6] It was subsequently promoted internationally and has become a norm for "good governance" in the public sector. Although the United States continues to develop its application of output-outcome thinking to public R&D[7] - it does so with the additional benefit of a counter-balancing emphasis on preparedness concerns – albeit with a dominating focus on fast moving threats.

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5 Part of the explanation may lie in the tendency for governments to draw upon lessons from compliance oriented financial accounting in the business sector rather than on the more risk-aware approaches used by investment banks. Accountants have traditionally been trained to generate "point estimates" that are represented as "the right answer". When governments hire large accounting firms to advise them they tend to be provided with 'risk-averse" approaches that are at odds with the core business of government (managing the uncertainties and risks that markets cannot cope with). In contrast, professionals in investment banks are expected to engage with far more complex opportunity exploitation and risk mitigation concerns in which there is no "right answer" – only uncertainty and risk that must be managed for profit – this is exemplified in the bank's "value at risk" analyses.

6 The genealogy of the currently used methods lies in the tools implemented within the Ford Motor Company under the championship of Robert McNamara. These were subsequently introduced into the US Department of Defense by McNamara and, later, into the World Bank. The line of thinking then spread to OECD governments.

7 Congressional concern with the accountability for the use of public funds is reflected in the Competition in Contracting Act of 1984 (P.L. 98-369), the Chief Financial Officers Act of 1990 (P.L. 101-576) and the Government Performance and Results Act of 1993 (P.L. 103-62). There is a persisting concern with reducing the incidence of certain types of "earmarked" research funding that cut through merit-based peer review mechanisms. Indeed, the value of "earmarked" R&D funding is treated by the Whitehouse Office of Management and Budget (OMB) as a metric that reflects potential inefficiencies in resource allocations – although earmarking linked to "pork barrelling" in the federal budget is, at the same time, consistently pursued by both Republican and Democrat administrations. Details of the most recent US Federal R&D budget can be found in Chapter Five of *Analytical Perspectives: Budget of the United States Government Fiscal Year 2007*. The OMB budget web site also provides downloadable spreadsheets of federal R&D funding going back to the 1950s that are far more detailed and analytically useful that the data provided by other OECD governments. The OMB R&D data includes estimates of the value of the federal R&D capital stock as a knowledge-based asset in which applied research and experimental development are depreciated at a rate of ten percent per annum but basic research is not depreciated at all (on the basis that this fundamental knowledge has an infinite shelf life).

The US policy framework is notable in the long-time horizons considered within public sector R&D (notably those in defence R&D).[8] These long-time horizons are defined around preparedness concerns. In effect, the long-term R&D associated with national security (but not restricted to national security) is *centrally planned*. US policy-makers recognise that, with regard to R&D, markets are myopic, and that both the military and industry require long-term centrally planned R&D that addresses a range of preparedness concerns. Spin-off from defense R&D is useful because it *both* stems from the long-term exploratory work that can generate disruptive technologies and involves programmed spending on driving down technical risk that extends beyond the experimental development stage *per se*. This increases the likelihood of commercial adoption in a timely manner.

This combination of preparedness and basic science priorities allows a greater proportion of the US R&D effort to be directed at very long-term exploratory objectives with little or no expectation of tangible short-term benefits aside from the "insurance policy premium" objective of mitigating the impact of identified risks, notably in defence R&D, and in not missing out on major opportunities such as biotechnology. These balanced priorities also encourage the development of fundamental theory and tools that allow a wide range of science and technology applications to be treated as viable options – a valuable investment portfolio in an uncertain world.

The United States' approach socialises the costs and risks of undertaking fundamental, often exploratory, theoretical work whilst also actively promoting the private appropriation of the profits eventually generated. Indeed, the US policy framework is noteworthy in the vigorous encouragement it gives to the private appropriation of the profits generated from long-term exploratory R&D *and* in the limits and penalties it places on anti-competitive bahaviours. Take the Bayh-Dole Act for example. The stricture that federally funded R&D that generates commercialisable findings should result in the legal protection and exploitation of these property rights within a specified time period is linked to the notion that companies may also suppress potentially useful scientific and technological advances if they threaten corporate net worth (i.e. they are what corporate strategists call "disruptive technologies").

According to the accounts of those involved at the time, the Bayh-Dole legislation was originally being drafted with a view to it applying only to small businesses that had received federal R&D funding. The leading research universities became aware of the legislation being drafted and lobbied for federal funding for university research to be coved by the new Act.[9] Their aim was to create a norm for universities to retain ownership of the IP generated by their research, irrespective of the source of funding, in order for them to meet their public interest mission to develop and

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8 For example US Department of Defense R&D projects are currently underway that address preparedness concerns expected to arise in 2040.

9 This point emerged from workshop-related discussions involving US university technology licensing office principals held as part of preparing a UK guide to the strategic management of intellectual property in universities, aspects of which are reported on in: UK Patent Office, Universities UK and AURIL (2002) *Managing Intellectual Property – A Guide to Strategic Decision-making in Universities*. Report prepared by SQW Ltd. It has not been possible to corroborate this anecdotal point using peer-reviewed findings. However, subsequent consultations did confirm that there is additional anecdotal evidence of lobbying by the representatives of some US universities in the late 1970s over the treatment of university ownership of inventions. As is often the case, these behind the scenes influences on policy-making do not necessarily get recorded in the public policy literature.

disseminate useful new knowledge. By retaining ownership of IP it is possible to stipulate "use it or lose it" clauses in commercial licensing contracts that prevent companies suppressing disruptive technologies.

The Bayh-Dole Act exemplifies a "balanced" policy framework: it encourages an active venture capital sector and corporate investment in research commercialization whilst also seeking to limit anti-competitive corporate behaviour that may seek to constrain consumer benefits generated by publicly funded research. Indeed, US universities, and high profile not-for-profit institutions, seek to own the IP generated from their R&D not in order to make money but in order to fulfill their mission to generate and disseminate useful new knowledge (and maintain their tax status as charities).[10]

The process of "learning-by-doing" in US research commercialization, facilitated by the Bayh-Dole and other related technology transfer Acts, has improved the "receptor" capability of the business sector, in so doing contributing to a highly efficient diffusion of, and financial "yield" from, academic R&D in the United States. This process of learning-by-doing involves getting better at managing the risks faced in commercializing academic knowledge and IP leading to a self-sustaining state of affairs in which subsidies may not be required.[11]

The United States also consistently targets basic theoretical understanding as a key policy objective. For example, when biotechnology started to emerge as a new and potential high-growth industry the United States moved to prioritise basic "discovery" oriented research on fundamental theory and research tools in biology (imaging, understanding and simulating basic biological processes as the path to eventually *controlling* these processes). In contrast, other advanced economies reacted to this opportunity by prioritising applied research and neglecting the basic science. This differential response has been repeated in other key areas and has profound implications for long-term industrial competitiveness. More recently, the US Government has moved to "re-invigorate" the physical sciences, arguably a "preparedness" response to the rise of China following a post-Cold war lull.[12]

From an economic and financial perspective, the US policy framework can be characterized as stressing "low discount" rate R&D priorities. Discount rates determine the value placed upon benefits and costs at different points in the future. The higher the discount rate the more myopic the investment decision.[13] Investment

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10 See *Managing Intellectual Property – A Guide to Strategic Decision-making in Universities*. Op cit.

11 Useful discussions of the risk dimension to innovation can be found in: Chesbrough, G. C. and Rosenbloom, R. S. (2001) 'Defining Risks and Rewards: The Dual-Edged Role of the Business Model' in Branscomb, L and Aursweld, P. E. (eds) *'Taking Technical Risks: How Innovators, Executives, and Investors Manage High-Tech Risks*. The MIT Press. Cambridge, Mass. And Hartmann, G., and Myers, M. B. (2001) 'Technical Risk, Product Specifications, and Market Risk' in Branscomb, L and Aursweld, P. E. (eds) *op cit.* The role of learning-by-doing in research commercialisation is highlighted in Matthews, M and Johnston, R (2000) *International Trends in Public Sector Support for Research and Experimental Development: A Preliminary Analysis*. Report for the Australian Government Department of Education, Science and Training: Evaluations and Investigations Program. Report No. 99-8.

12 The latest in the series of US Congress mandated unclassifed assessments of China's military capability is: Office of the Secretary of Defense (2006) *Military Power of the People's Republic of China 2006*. Annual Report to Congress. Washington DC. US Department of Defense. There are a range of science policy-related measures in the US aimed at evaluating comparative international scientific and technological capability and identifying areas of concern, see in particular the US Committee on Science Engineering and Public Policy (COSEPUP) research field assessments. COSEPUP carries out international benchmarking assessments for science from a policy position that stresses that the US "should be among the world leaders in all areas of science" and "should maintain clear leadership in some areas".

13 The choice of discount rate for valuing investments in slow-moving but potentially very damaging processes that may effect several future generations (such as climate change) is critical. The discount rate must be low enough to

planners in the private sector increase the discount rate to reflect uncertainty and risk over the potential yield on an investment (this issue is discussed later on in the paper). The US policy framework recognizes that governments must fund the areas of R&D over which the nature and extent of any financial returns are uncertain and in which they may take place over very long time horizons. The US government does not expect business to be in a position to drive these very long-term priorities, even though this R&D may eventually generate commercially applicable knowledge.

Preparedness and protecting the value of national balance sheets

The most recent United Nations guidelines for preparing National Accounts recommend that national balance sheets be compiled.[14] This is because these estimates of stocks of national net worth provide a measure of economic progress that compensates for weaknesses in the more widely used annual flows of gross domestic product and related measures.[15] There is also now an additional set of joint UN, EU, OECD, IMF and World Bank national accounts guidelines designed to allow environmental impacts to be considered alongside economic performance – promulgating the concept of 'depletion adjusted net domestic product'.[16] This approach allows for the depletion and degradation of natural assets to be factored into estimates of net domestic product (gross domestic product net of capital consumption).[17]

These developments in national accounting are significant to understanding preparedness. Public science examining long-term processes alerts decision-makers to the nature and extent of any risks to asset values caused by such factors as, for example, dry-land salinity, soil acidification or new quarantine risks from trade in goods. Business decision-makers are then able to factor these future risks into the current market prices of assets such as agricultural and urban land – and increasingly now water.[18] This process of adjusting asset values via market prices allows resource allocations made *now* to anticipate and mitigate future risks.

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allow risk-mitigating investment to be made without overly penalising the current generation who must bear the costs generated by previous generations in order to limit the impact on future generations. This important issue in public policy is discussed in Arrow, K (1995) *Intergenerational equity and the rate of discount in long-term social investment*. Paper presented at the International Economic Association (IEA) World Congress. Available as a Working Paper from the Stanford University Economics Department web site.

14 UN System of National Accounts 1993 (known as SNA93).

15 In essence due to the potential for GDP growth to be based upon running down assets on the national balance sheet. See Thompson, S. (2000) *Making Use of National and Sectoral Balance Sheets*. Paper prepared for the 26th General Conference of The International Association for Research in Income and Wealth. Cracow, Poland 27th August to 2nd September.

16 United Nations et al (2003) *Handbook of National Accounting: Integrated Environmental and Economic Accounting*. Joint draft guidelines issues by the United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development and the World Bank.

17 In the new UN standard for integrated environmental and economic accounting the value of the depletion and degradation of natural capital associated with generating flows of economic activity is added to the value of "economic" capital consumption to produce an estimate of the overall value of capital consumption. See Australian Bureau of Statistics (2003b) *Accounting for the Environment in the National Accounts* in *Environment by Numbers: Selected Articles on Australia's Environment*. Australian Bureau of Statistics. Canberra. Catalogue no. 4617.0 2003.

18 Salinity is an issue for some cities not just agricultural land because salinity degrades the concrete foundations of buildings.

Consequently, the preparedness value of the impact of public science lies in markets being 'forewarned" – avoiding the unexpected and more costly shocks caused by *not* being aware that there are risks to asset values. This opens up a means of valuing some types of preparedness R&D on the basis of the extent to which costly impacts have been mitigated by being forewarned.[19] Should a comprehensive analysis of this type of "downside mitigation" impact be carried out it may significantly exceed the economic impact of the narrow linear model "research commercialisation" pathway that is the dominant expected outcome in current science policy. For instance, in FY04-05 the total value of produced assets on Australia's national balance sheet amounted to AU$2,695.9 billion and total non-produced assets were valued at AU$2,280.0 billion.[20] The magnitude of these components of national *net worth* (AU$4,458.9 in FY04-05) is such that small reductions in the risks to these asset values can be very valuable relative to research commercialization outcomes per se – a comparison of outcomes that it would be useful to quantify in future policy research.

Preparedness and corporate decision-making

The importance of adequate business expenditure on R&D (BERD) is best grasped by considering the role of BERD in helping a company to sustain and grow its net worth via maintaining a portfolio of options to address a range of opportunities and threats – in short via adequate *preparedness* in an uncertain world.

From a preparedness perspective, effective innovation is a business strategy matter but adequate spending on R&D maintains a portfolio of possible scientific and technological options the advancement and selection of which constitutes a key determinant of competitive success. In-house R&D capability is critical to making assessments of, and tapping into, the external the knowledge base that generates preparedness. The mistake is to overlook how BERD helps companies manage the risks to their net worth via risk-based portfolio management methods irrespective of whether or not there are tangible measured "research commercialisation" outputs and outcomes linked directly to patents.

For example, investment in determining the economic viability of the geo-sequestration of carbon dioxide helps to mitigate risks to corporate net worth associated with the risk of future carbon emission imposts. The better the

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19 For a discussion of these issues drawing upon Australian official statistics see Matthews, M. (2003) '*Opportunities for assessing the impact of the geosciences on the Australian economy via the system of national accounts'*. Background Paper prepared for the National Committee for the Development of a Strategic Plan for Australian Geoscience. Policy Intelligence. Canberra. See also, Lange, Glenn-Marie (2003) *Policy Applications of Environmental Accounting*. Environmental Economics Series, Paper no. 88. Environment Department, World Bank. Washington DC. Hajkowicz, S. A. and Young, M. D. (eds) (2002*) The Value of Returns to Land and Water and Costs of Degradation.* Final Report to the National Land & Water Resources Audit. Policy and Economic Research Unit, CSIRO Land and Water. Folio Ref: 02/477. Kemp, A. and Connell, P (2001) *Impact of Land Degradation on Australian Agriculture: A Land values Approach.* ABARE. Report to the National Land and Water Resources Audit. National Land and Water Resources Audit (2002*) Australians and Natural Resource Management 2002* . National Land and Water Resources Audit. Canberra. National Land and Water Resources Audit (2002*) Australia's Natural Resources 1997-2002 and Beyond.* National Land and Water Resources Audit. Canberra. Nordhaus W., D., Kokkelenberg, E., C. (eds) (1999) *Nature's Numbers: Expanding the National Economic Accounts to Include the Environment.* National Academy Press. Washington DC. The chapter 'Accounting for Subsoil Mineral Resources' is re-printed in the US Bureau of Economic Analysis (BEA) *Survey of Current Business*, Feb 2000. Ryan, L., Johnson, T., Singh, J (2001*) Adjusting the National Income Accounts for the Depletion of Natural Resources.* Paper given at the 30th Annual Conference of Economists, 23-27 September. Perth. Australia.

20 Table 16 in Australian Bureau of Statistics (2005) Australian System of National Accounts. 5204.0. Canberra: ABS.

understanding of the technical and economic viability of geo-sequestration, the greater the capacity to mitigate potential carbon emission penalty risks to corporate net worth using evidence of the progress being made towards demonstrated "bankable feasibility" of geo-sequestration solutions.

Similarly, there is now anecdotal evidence that some corporations operating in Australia are paying farmers who have obtained permission to clear land of native trees *not* to carry out this clearance.[21] Such payments may be used in the future to attempt to generate carbon credits as part of net worth protecting preparedness strategies. Corporate preparedness to deal with the potential impact of future carbon emission costs illustrates just how important preparedness is to the business sector.[22] Shareholders expect the value of their shares to be protected via adequate levels of preparedness.

From this preparedness perspective, the expected future benefits of an R&D investment portfolio can be used, in effect, to increase the estimated current *net present value* (NPV)[23] of the company (either directly or indirectly by collective market valuations). The NPV of the company considers both the risks faced in the future and the capacity and capability to mitigate these risks.

Stockbroker and investment bank analysts seek, and usually obtain, detailed information from corporate boards on preparedness issues such as preparations for dealing with a possible carbon emission impost. If, in the analysts' judgment, the state of preparedness is insufficient, this factor will inform "buy or sell" tactics and strategies. It is the analysts' job to seek privileged information and insights on prospects for corporate net worth that anticipate and drive market trends. Indeed, these financial institutions trade on competitive advantage over their competitors in relation in preparedness information. This process allows future risks to be factored into the current market value of corporations.

The roll-out of the new "post-Enron" International Financial Reporting Standards (IFRS), which require that large companies estimate the value of their balance sheets on a "fair value" (i.e. risk-aware) basis further strengthens the way in which a corporate R&D portfolio relating to options for future adoption can increase the *current* NPV of the company.[24]

Indeed, the adoption of IFRS opens up a new avenue for approaching the valuation of corporate R&D investments because IFRS compliance costs are so high. The complexity of actually calculating the value of the assets on a balance sheet on a fair value (and if necessary embedded derivative) basis is driving up regulatory

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21 This behaviour has yet to be documented in the peer-reviewed academic literature, consequently it is at present only an anecdotally based point requiring validation.

22 See for example the corporate participation in the Carbon Disclosure Project: Innovest (2006) *Carbon Disclosure Project – 2005*. London: Innovest.

23 The discounted present value of future revenues less costs.

24 International Accounting Standard 39 (IAS 39) requires that contracts that involve risks to future cash flows be placed at 'fair value'. This means factoring these risks into the value of the balance sheet. In some cases contractual arrangements have to be treated as risk-generating 'embedded derivatives' that reduce the value of a balance sheet. These are profound changes in how companies outside of the United States calculate their balance sheets. The United States has not adopted the new IFRS per se, however existing balance sheet valuation regulations are stricter than was previously the case in many other OECD economies that have now adopted IFRS.

compliance costs.[25] As noted earlier, the IFRS process is also taking place in an era in which the business sector is starting to address new risks to sustained profitability such as potential carbon emission and increased water supply costs – increasingly from a global perspective.[26] The combined impact of carbon and water risks to corporate net worth, now formalised by IFRS, may become an important consideration in some sectors (notably some agricultural sectors like cotton, rice and dairy farming and also for coal burning power stations – which use considerable amounts of water for cooling).

This means is that there is a growing convergence between the complex calculation requirements for IFRS compliance (risk-adjusted balance sheet valuations) and the issues addressed by some types of public and private sector preparedness R&D. This common ground is defined by the need to develop formal risk-based models related to business performance. It follows that the potential now exists to use the formal models developed as part of corporate R&D (and via R&D partnerships with the public sector such as in Cooperative Research Centres) to:

- limit IFRS compliance costs;
- inform balance sheet valuations, and;
- brief stock market analysts whose advice influences corporate market valuations.

Given the points made above, it is clear that a preparedness focus highlights the ways in which R&D helps to protect corporate net worth in far more complex *and timely* ways than the traditional linear model perspective. As financial thinking so often highlights, investing in options for the future impacts upon present circumstances and behaviour. This preparedness perspective places an emphasis on the practicality of actually using option-based R&D valuation methods.

Option valuation and corporate R&D

Interest in using the methods of valuing options contracts, based on the work of Black, Scholes and Merton, is a long-standing feature of R&D management.[27] Although the principle that possessing a portfolio of preparedness options can help to sustain the net worth of a corporation is clear, it does not always translate into corporate practice in R&D management. Case studies that consider how companies appraise their R&D projects reveal a range of approaches are used.

Some companies set threshold 'return-on-investment" (ROI) ratios for individual R&D projects that are designed to generate acceptable returns for the overall portfolio of R&D projects (this benchmark "risky" ROI threshold ratio of benefits

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[25] As one investment banker stressed during discussions of the IFRS compliance issue, many large banks are concerned about their own capacity to achieve cost-effective IFRS compliance internally given the technical complexities faced.

[26] Indeed, the ANZ Bank led the field in Australia a few years ago in publicizing an explicit decision to add a greenhouse gas emission risk factor to its business lending rates. For a more recent account of Australian moves in this direction see, *Australasian UNEP Finance Initiative Newsletter*. Issue 9. March 2005. Pages 14-15.

[27] Black, F., Scholes, M (1973) The pricing of options and corporate liabilities. *Journal of Political Economy.* 81, pp637-659.

over costs is often around 12:1).[28] Whilst it is recognized that many of the projects that pass this threshold test will in fact fail, the assumption is that, on balance, enough big gains will be made by a few projects to generate a positive ROI on the complete set of R&D projects. This is the essence of portfolio-based approaches.

Other companies adopt a more permissive approach and distinguish between different types of R&D project in relation to their broader strategic objectives. They set different types of objective for different types of R&D project. This issue is captured in Exhibit 1 using the "Three Horizons" framework proposed by McKinsey & Co in order to summarise observed corporate best practices. This line of thinking is widely used in strategic planning in the corporate sector.[29] Horizon 1 refers to extending and defending current core businesses. Horizon 2 refers to seeking to build emerging businesses and Horizon 3 refers to the creation of viable options for future businesses. Sustained competitive performance over the long-term requires adequate efforts to address Horizon 3 concerns. In one sense, this widely used approach reflects preparedness concerns because companies that neglect Horizon 3 opportunities will tend to put their sustained net worth at risk.

The framework highlights how reliance on numerical performance measures decreases as one considers longer-term strategic concerns whilst reliance on conceptual thinking increases.

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[28] See the reference to comparisons of public and private sector ROI ratios from a portfolio perspective noted in UK National Audit Office (2002) *Invest to Save Budget.* Report by the Comptroller and Auditor General. HC 50 Session. November 2003.

[29] See Source: based on Baghai, M., Coley, S. and White, D. (1999) '*The Alchemy of Growth*'. Orion Business Books, London. For an account of the use of this type of thinking on innovation strategies in some of the larger corporations operating in Australia See Howard, J H (2006) *Changing Paradigms: Rethinking Innovation Policies, Practices and Programs.* A report prepared for the Business Council of Australia. Canberra: Howard Partners.

Exhibit 1: Key features of managing by horizons from a public policy perspective

Horizon	Aim	Management Activity Focus	Performance Measures	Management Approach (Indicative)	
				Reliance on Numerical Measures (%)	Reliance on Conceptual Thinking (%)
Horizon 1	Extend and defend core business	Manage for profitability	Bottom line accounting-based - Profits - Return on Capital - Costs - Productivity and Efficiency	80%	20%
Horizon 2	Build emerging businesses	Replicate proven business models	Top line oriented - Revenue growth - Market share growth - New customer acquisition - Expected Net Present Value	60%	40%
Horizon 3	Create viable options for future businesses	Seed growth options and test different business models	Risk-reward based - Project milestones - Option valuation - Portfolio profile	20%	80%

Source: based on Baghai, M., Coley, S. and White, D. (1999) '*The Alchemy of Growth' op cit.*[30]

As the above framework makes clear, R&D appraisal and evaluation methods based on conventional numerical performance measures will tend to create myopia in resource allocations – forcing decision-makers to focus their attention on Horizons 1 and 2 rather than on Horizon 3. On the other hand, appraisal and evaluation methods based on contributions to long-term corporate net worth will tend to favour Horizon 2 and 3. Clearly, companies face important decisions over how best to evaluate and appraise R&D spending. Those that innovate in how they appraise and evaluate their R&D investments, may improve their performance by avoiding the pitfalls of restricting all R&D funding to ROI or other Horizon 1 oriented criteria.

One of the best sources of information on the evolution of real-world corporate R&D management thinking is the US journal *Research Technology Management*. Contributors to this journal report on industrial practice and experience in technology management – in effect providing insights into how internal corporate management practices and formal tools have been developing. It is noteworthy that there have been a series of papers in this journal, and also in the *Harvard Business Review*, that report on efforts to translate the (complex) mathematical principle of option valuation deployed in investment banks into a more tractable approach that does not require (very costly) cutting-edge expertise in applied mathematics. [31] [32]

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30 The indicative breakdown of emphasis in the last two columns are the author's own and are based upon experience in management consulting over R&D strategies.

31 "Real options" analysis involves very complex applied mathematics via which particular investment conditions are modeled. Software packages have made the process of option valuation more user-friendly in the business sector.

32 As long ago as 1996 an advertisement appeared in the UK *Financial Times* for applied mathematicians able to work on option valuation methods, with a basic salary at the time of 1 million UK pounds.

An early contribution on options approaches, a 1988 paper by Mitchell and Hamilton, lays out a pragmatic industrial R&D management approach that is also helpful in a public policy context.[33] They draw a clear distinction between three phases in industrial R&D: knowledge building; strategic positioning, and business investment. These are summarised in the following table.

Exhibit 2: The distinct phases in industrial R&D and innovation

	Knowledge Building	**Strategic Positioning**	**Business Investment**
Technical Activity	Fundamental basic/exploratory research "awareness"	Focussed applied research and exploratory development	Development and engineering
Financial Approach	Cost allocation "research as a cost of business"	Options valuation	Net Present Value Discounted Cash Flow Return-on-Investment
Responsibility for Evaluation and Resource Allocation	R&D	CEO/R&D business	Business

Source: based on Mitchell and Hamilton (1988).

These distinctions are useful because they emphasise that, from an industrial perspective:

- the exploratory research involved in "knowledge building" is a cost of doing business and cannot be assessed financially;
- strategic positioning ("preparedness") is a matter of owning a range of options in an uncertain world and is driven by strategic parameters;
- moving forward with specific options or bundles of options is the only phase for which conventional investment appraisal methods may be appropriate (Net Present Value-Discounted Cash Flow and Return on Investment).

Since that paper was published, and on the basis of the insights into actual industrial practices contained in such journals as *Research Technology Management*, there has been a growing application of option-valuation methods to industrial R&D management.[34] This has resulted in more tractable ways of valuing R&D options based upon

[33] Mitchell, G R and Hamilton, W F (1988) Managing R&D as a Strategic Option. *Research Technology Management*. May-June.

[34] Indeed, a senior executive from (what is now) BHP-Billiton alerted the author to the existence of this business-practice based literature on applying real options valuation methods to industrial R&D in 2000, by which time the literature base was well established.

decision-tree approaches in which conventional NPV methods can be used.[35] The easily grasped principle is to break down the sequence of decision-making stages and to consider the choices and risks faced at each point and how the increases understanding impact upon the risk-adjusted NPV of the investment options.[36] This line of work has resulted in the development "binomial lattice" methods for R&D project valuation that readily incorporate technical risk factors.[37] The binomial lattice approach has the advantage that it can encompass the familiar NPV metric, but in a preparedness manner. The NPV of the R&D project portfolio rests on the synergies between different options in an uncertain business context in which contingent events are the most important consideration.

Survey and literature review based assessments of the state of diffusion of real options methods in business indicate that adoption of these approaches is patchy and is constrained by the complexity and perceived lack of transparency in the approach. In their recent survey of option valuation methods in the pharmaceutical industry Hartmann and Hassan[38] found that academics and management consultants (who tend to advise companies on such issues) favour the binomial lattice method because the mathematics are far easier to handle and technical risk is readily captured. In contrast, the Black-Scholes approach used in the financial sector to value option contracts is far more complex and does not readily capture technical risk factors pertinent to R&D.

In summary, whilst it is not yet clear whether option valuation techniques will ever start to dominate the appraisal of business sector R&D investments, the conceptual principle that R&D generates option values is coming to be accepted. This, in turn, supports the notion that preparedness R&D is a consideration in the formulation of corporate R&D strategies. Most importantly, the wider corporate interest in seeking to protect company net worth in the face of future risks, coupled with the new IFRS requirement to value a balance sheet in a risk-aware manner, suggests that the preparedness dimension to corporate R&D strategies will get much stronger over future years. Indeed, growing awareness of this issue may lead some Australian corporations to re-think their skepticism of the importance of formal R&D spending to competitiveness (as distinct from "innovation" per se).[39]

The geopolitical dimension

The Working Group on Asia of the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) has recently published a paper examining Australia's

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35 See for example, Faulkner, T (1996) Applying Options Thinking to R&D Valuation. *Research Technology Management*. May-June. Luehrman, T (1998) Investment Opportunities as Real Options. *Harvard Business* Review July-Aug. Luehrman, T (1998) Strategy as a Portfolio of Real Options. *Harvard Business* Review Sept-Oct.

36 This approach is compatible with "Stage-Gate" R&D project selection methods, however use of the latter does not necessarily involve calculations of this type.

37 Cox, J., Ross, S., Rubinstein, M. (1979) Option pricing: a simplified approach. *Journal of Financial Economics*. 7 pp 229-264.

38 Hartmann, M, Hassan, A (2006) Application of real options analysis for pharmaceutics R&D project valuation – empirical results from a survey. *Research Policy*. Vol 35(3), pp343-354.

39 For a discussion of corporate scepticism over the competitive importance of formal R&D in relation to innovation in Australia, see Howard, J H (2006) *Changing Paradigms: Rethinking Innovation Policies, Practices and Programs*. A report prepared for the Business Council of Australia. Canberra: Howard Partners.

position in the new world order.[40] This is a welcome and timely move because geopolitical considerations are integral to science, innovation and preparedness. The aim of this section of the paper is to attempt to illuminate the relationship between geopolitical and economic factors that impact upon science, innovation and preparedness.

Defining the geopolitical domain

"Geopolitics" is a term frequently used in financial and commodity markets. It refers to considerations that impact upon investment decision-making that are attributed to non-market factors in which there is an international political dimension. For example, oil market analysts refer to the "geopolitical premium" component to oil prices. This is shorthand for the ways in which political tensions over oil supply security generates risk-hedging in oil futures markets. The risks of cuts to oil supplies in the future due to military action tend to get factored into oil futures prices and, in turn, drive up the current price of oil.

From an academic perspective, geopolitics is concerned with the complex spatial challenges faced in dealing with national security, territorial disputes, sovereignty and other matters of concern with a geographical dimension. As summarised by Oyvind Osterud:

> *"In the abstract, geopolitics traditionally indicates the links and causal relationships between political power and geographic space; in concrete terms it is often seen as a body of thought assaying specific strategic prescriptions based on the relative importance of land power and sea power in world history. . . . The geopolitical tradition had some consistent concerns, like the geopolitical correlates of power in world politics, the identification of international core areas, and the relationships between naval and terrestrial capabilities".*[41]

Many academics are wary of using the term geopolitics because it has some specific connotations linked to the role of naval power in projecting force (the time and speed of delivering force is affected by specific land-sea configurations).

However, the use of the term in financial markets, particularly those concerned with natural resources indicates that the concept is evolving to refer to the international political consequences of *geology* rather more than geography per se. The powerhouse economies in the global economy require vast natural resource inputs, many of which must be obtained from other nations. This generates latent political and military tensions over security and energy and raw material supplies. The result is a web of "trans-national value chains" than span the world - looping through different national economies and generating strong inter-dependencies in energy, raw material and environmental security.

To give a notable example, the rapid economic development of China involves the evolution of a new web of trans-national value chains in which China is hub, importing energy and raw materials and exporting low-cost manufactured goods to major urban centres worldwide and limiting inflation in most industrial economies. Furthermore, the domestic political legitimacy of the Chinese Communist Party is linked to the sustained growth in real income, which in turn, relies on the trans-

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40 PMSEIC Working Group on Asia (2006) *Strengthening Australia's Position in the New World Order*. Canberra.

41 Oyvind Osterud, The Uses and Abuses of Geopolitics, *Journal of Peace Research*, no. 2, 1988, p. 191.

national value chains continuing to feed rapid economic growth via imports and exports. This system of trans-national value chains is highly complex and not well mapped. As China illustrates, this system is as much political as economic.[42] Investment banks certainly approach the 'rise" of China from a geopolitical and financial perspective.[43]

Geopolitics "matters" in this context because decisions over the "design" of these trans-national value chains in terms of the national economies they loop through are not just economic – they are also political. This is one reason why there is currently growing interest amongst academic researchers in examining the interdependencies between economic and security concerns – particularly in relation to China. In addition, a range of US government departments and agencies now closely monitor the evolution of China's R&D capability, including the use of detailed bibliometric assessments.[44] Indeed, the rise of China's R&D effort has been dramatic and is a concern to the US from a geopolitical perspective not just an economic one.

The latest estimates made by the OECD for 2004 place China's overall level of R&D expenditure at US$102,623 million, which as in previous years puts China as the third largest R&D spender in the world, but now amounting to 33 percent of US R&D spending (US$312,535m) and 91 percent of Japanese spending (US$112,714.7m). Two years previously, China's R&D spending had been estimated by the OECD at 27.3 percent of the US level and 67 percent of the Japanese level. In 2004, 61.6 percent of identified global R&D spending was accounted for by the US, Japan and China[45]. Annex A contains a profile of international imbalances in R&D.

Against the backdrop of these asymmetries in global R&D there are stringent export restrictions that apply to sensitive defence and "dual use" science and technologies.[46] Companies that infringe these restrictions face severe penalties. The US government in particular, has demonstrated the willingness and ability, to take legal action to penalize transgressors, such as when US aerospace companies were prosecuted for helping another nation fix problems in its missile guidance systems. More generally, there are few areas of S&T research that are totally unrelated to military and counter-terrorism concerns – although security restrictions mean that information on this issue is inevitably incomplete. Research into new materials, lasers and optics, medical & health issues (including genetics), psychology, applied mathematics, simulation modeling, and many other areas are covered.

Furthermore, country-specific decisions over the exports of this science and technology are made by major science powers. These decisions weigh-up the opportunities and risks associated with allowing transfers of specific types of

42 Systems of "national" statistics on production and trade tend to focus on bi-lateral relationships rather than indirect global economic inter-relationships through extended supply chains involving many industries.

43 The major global investment banks maintain substantial on-the-ground competitive intelligence gathering capabilities in China. The analyses produced are noteworthy in the strong emphasis placed on the geopolitical dimension as a basis for the analysis of business conditions and their implications. See, for example, a fairly well known paper on China written by a commentator and analyst linked to Goldman Sachs, Ramo, J. C. (2004) *The Beijing Consensus*. Foreign Policy Centre. London.

44 See for example the work produced by the Office of Naval Research, US Navy: Kostoff, R. N et al (2006) *The structure and infrastructure of Chinese Science and Technology*. Office of Naval Research. Discussion Paper.

45 All R&D expenditure figures are on a US$ current price Purchasing Power Parity basis. OECD (2005) *Main Science and Technology Indicators* and OECD (2004) *Main Science and Technology Indicators*.

46 See for example, the web pages of the Directorate of Defense Trade Controls at the US Department of State.

scientific and technological knowledge to specific countries.[47] The parameters considered are (broadly):

- what are the risks that the S&T might be passed on to third parties that are less friendly?;
- how would the transfer help to enhance the military capability of the ally?;
- to what extent might the transfer of S&T generate a competitive commercial threat to the donor economy from the ally?, and therefore;
- on balance, is the international transfer well-advised?

By implication, the rather opaque nature of these decisions means the operation of this process it is not always clear –nor particularly well researched. This is because so much of the information either comes under national security provisions, or commercial-in-confidence provisions covering negotiations involving major corporations and governments. This lack of transparency, in turn, makes it difficult for policy researchers to demonstrate the importance of these deliberately designed *impediments* to closing the S&T gaps between nations relative to the opportunities for closing these gaps.

To an extent therefore, the S&T gaps between nations are "managed" by the major science powers and multi-national corporations on a specific bi-lateral and value chain basis. The problem is that there is little comprehensive information on the strength of this impediment relative to the opportunities for "catch-up". Simply to assume that a failure to catch-up is solely due to domestic impediments to improved S&T capability neglects the fact that these S&T gaps are, to an extent, "managed".

Geopolitical factors are also major drivers of uncertainty and risk in the modern global order. Topical examples are the highly differential capabilities to deal with infectious diseases and the growing international political tensions associated with the proliferation of the science and engineering capabilities required to design and manufacture weapons of mass destruction (in the nuclear, chemical and biological families).[48] This geopolitical dimension to science and innovation policy is a relatively uncontroversial topic within the US policy community - as is the related issue of the critical role of basic research in a modern science power.[49]

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[47] These sorts of "trade-off" issues are explicitly addressed in a range of policy documents, see for example: Committee on Science, Engineering and Public Policy (1987) *Balancing the National Interest: US National Security Export Controls and Global Economic Competition*. Washington DC: National Academies Press.

[48] For instance, when the new powerful Apple Macintosh G3 computer was first launched several years ago the US Government did not allow it to be sold in mainland China for "strategic" reasons but, rather strangely, did allow its sale in Hong Kong. The on-line ordering form included questions asking whether the intended use was to design nuclear, chemical or biological weapons (in which case the implication was that the order would not be accepted). High-end computers have always been subject to export restrictions because they are critical to running the sophisticated calculations required to design nuclear weapons.

[49] Following initial policy-relayed work carried out by the RAND Corporation, relevant US Government departments are now obliged to report to Congress on the nature and extent of their international engagement in science and technology – particularly with regard to the benefits that this generates for the domestic US research community (such as access to research facilities that are unavailable within the US).

Lessons from technology transfers linked to climate change

The managed nature of international S&T gaps has become an issue with regard to addressing climate change concerns (and relates to current consideration of uranium enrichment and nuclear power options). The nations that possess the IP associated with various technologies that could reduce greenhouse gas emissions world-wide naturally seek to extract value from that IP. This involves seeking to licence the use of the IP whilst minimizing the risk of losing the IP via "reverse engineering" and IP-infringement.

Where possible, "turnkey" technology solutions provide this sort of assurance by providing, for example, a complete power station that incorporates advanced technologies and has been designed using advanced science, but which does *not* readily allow full understanding of how the systems work at a detailed level. The major engineering companies who are able to design and build major systems like coal and nuclear power stations (e.g. Siemens in Germany and Edison in the US) naturally seek to minimise IP leakage in the "turnkey" designs that they provide. This impacts, in turn, upon the "systems engineering" design trade-offs (deciding how to bundle different technologies together to maximum effect). A particularly promising and therefore valuable sub-system might not be used if it can be easily "reverse engineered".

Indeed, the potential purchasers of complete power stations (which can cost around $1 billion dollars a unit though with significant cost variations by fuel source) stress that an advanced level of domestic R&D capability is necessary in order to secure a good deal on even a complete "turnkey" power station solution. The issue at stake is the detailed technical specification of what the design must achieve in performance terms – and, equally as important, what this specification will cost to deliver in practice and, therefore, what the profit margins are likely to be for both the provider and the purchaser.[50]

The more opaque the technical details provided by the supplier the greater the risk to the purchaser that the system may not perform as planned under local conditions and/or that too high a price was paid for it (with consequent implications for the return-on-investment actually achieved). This risk factor is not lost to the investment banks who finance such large debt-funded projects. Hence, the greater the transparency of the engineering design the lower the interest rate charged for the investment. The result is that efforts to restrict the leakage of IP held by the major science powers reduces the "bankable feasibility" of "big ticket" low emission technology systems, in so doing restricting their diffusion. This is, clearly, likely to be a major issue as many nations move to a more active consideration of the nuclear power option in the face of energy security and climate change concerns.

Thus, whilst the potential to reduce greenhouse gas emissions world-wide through investment in new plant (of various types) does exist, concerns over the loss of

[50] Industrialists sometimes stress that the capability of the engineering staff required to provide an adequate risk assessment for a major capital *purchase* like a wide-bodied jet or power station must be broadly comparable to the capability to design the system in the first place. Indeed, this is why there is such a strong innovation "pull-through" effect from customers to providers for major capital goods – the purchasers' engineers are particularly well positioned to drive the innovation process based on accumulated operational experience. This information is fed to the providers engineers via the design specification and subsequent partnership working as the project proceeds.

valuable IP in low emission technologies tends to limit the global diffusion of these technologies.

Geopolitical impacts on business commitment to R&D

Geopolitical considerations are also relevant to some specific institutional failures in corporate commitment to R&D investment. The issue here is the extent to which spin-offs from defence R&D have crowded out private sector R&D in particular industries in particular periods (notably the "peace dividend" of more relaxed restrictions on spin-off following the end of the Cold War).

For example, in the oil exploration industry the combined impacts of the post-Cold War peace dividend (de-classified signal processing technologies from submarine warfare applied to analyzing seismic data), advances in low-cost computing and the opening up of significant and easily found and extracted oil deposits in the former Eastern Block have been generating reductions in the cost of finding oil *without* the need for major corporate R&D investment in oil exploration methods. The result has been dramatic reductions in private investment in oil exploration R&D (the methods used to find oil, particularly in old and complex geological systems such as in Australia). The consequence has been that the portfolio of emerging scientific and technological options for finding oil in more difficult circumstances has now been run-down – arguably oil exploration businesses have become too myopic as regards their investment in oil exploration R&D as a result of these wider geopolitical developments. Public R&D can play a key role in mitigating these geopolitically driven market and institutional failures.

A more general point is that academic researchers' interest in whether defence R&D is good or bad for the civilian economy appears to have waned following the end of the Cold-War.[51] It would be useful to policy-makers if this issue were, now, to be re-examined.

Responding to the geopolitical dimension

There are three key points to stress as regards the issue of actively "managed" S&T gaps between nations.

Firstly, policy researchers should not be reticent in examining this issue. It is an important consideration that reflects the reality of the way in which the global economy operates.

Secondly, the geopolitical dimension to science and innovation tends to manifest itself in IP-related issues similar to the more general concerns over IP leakage/infringement that characterize both bi-lateral and multi-lateral agreements over trade. The difference is that the geopolitical dimension applies to licit not just illicit losses of IP.

Thirdly, there is an important role for diplomacy in seeking to overcome specific barriers to international transfers of scientific and technological knowledge.

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[51] Notable work in this area was carried out by Seymour Melman and by Mary Kaldor see: Melman, S. (1985) The Permanent War Economy: American Capitalism in Decline. New York: Simon & Schuster. And, Kaldor, M (1981) *The Baroque Arsenal*. London: Abacus Books

Negotiations in which access to specific areas of scientific and technological knowledge and data is sought by trading access to another negotiation "asset" can have a major impact on S&T catch-up. However, this potential cannot be exploited very effectively if the requisite "scientific and technological diplomacy" capability is lacking.

It is also necessary to have "assets" that can be put on the table in such negotiations. Indeed, major multi-national corporations deliberately maintain blocks of patents and other IP solely in order to provide this sort of negotiation asset. This IP is only valuable to the company because it may be valuable to *another* company or government.

There is anecdotal evidence that Australia possesses these sorts of "negotiable" assets, but the picture we have is patchy. For example, the United States, via the National Science Foundation (NSF) does occasionally approach Australian organizations with a view to sharing insights in cutting-edge research fields like quantum computing and nanotechnology. This indicates that smaller economies can afford to develop leading research capability in niche areas that are of considerable interest to the major science powers. The challenge is to ensure that we develop a range of these assets and the capability to benefit from them via effective scientific and technological diplomacy.

One pragmatic implication for policy-makers is that the value of the IP generated from public sector R&D may well lie in its *indirect* use via diplomatic negotiations. If project appraisal and evaluation methods ignore this important source of the value generated by IP then it is less likely that diplomats will have the requisite range of assets to negotiate with.

As an ally of the United States and some major European countries, Australia is in principle well positioned to engage in scientific and technological diplomacy. The challenge appears to lie in exploiting this comparative advantage in the ability to leverage overseas R&D via diplomatic expertise in science and innovation. For example, this aspect of foreign policy does not feature as a significant theme in the current foreign policy white paper. Furthermore, some members of the scientific community in Australia are understood to have encountered hostility to the notion that our diplomatic and trade negotiations should also encompass scientific and technological issues if their effectiveness is to be maximised.

In summary, the geopolitical dimension to science and innovation matters because the major science powers recognize and use science and innovation in a geopolitical manner not just in an economic and cultural manner. This means that smaller economies need to position themselves as best they can to interface with the major science powers by explicitly recognizing the opportunities and constraints created by the geopolitical dimension and by equipping themselves to act effectively in these circumstances.

Theoretical power

The so-called "linear model" of public R&D originated in the tri-partite distinction between basic research, applied research and experimental development proposed in 1945 by Vannavar Bush in his book "Science the Endless Frontier". Bush had been asked by the US President to prepare a vision for US science policy in the post-war era. When his scientific colleagues suggested that this distinction was unrealistic as a representation of how research and its application actually takes place Bush's response was that he was well aware of the mismatch between this model and reality, but that the point was that the model was easy to grasp, stressed the importance of "basic" research, and would therefore help to secure funding from Congress.[52] This linear model concept and corresponding breakdown of R&D was subsequently adopted in the OECD's influential 'Frascati" manual and went on to define how OECD nations collect data on R&D expenditure.

The strength of this linear model is its simplicity – which has been beneficial in securing sustained support for long-term exploratory "discovery" research by avoiding complexity and debate within the US. In contrast to many other OECD economies, business lobby groups in the US tend to be vocal in criticising federal funding for near-market applied research and experimental development as "corporate welfare" – advocated a stronger emphasis on basic research as the key mission for federal funding. Again, this differs from business lobby positions outside of the US.

Indeed, as note earlier, even the hard-nosed Whitehouse *Office of Management and Budget* (OMB) seeks to stress the importance of basic research by reporting official budget estimates of the value of the net stock of federally funded R&D capital in which the value basic research never depreciates (whereas the values of the stocks of applied research and of experimental development are depreciated at ten percent per annum).[53]

A great deal about what currently goes wrong in science and innovation policy can be understood once we recognise that the concept of R&D was developed in relation to public science and in order to secure support for basic research via the deliberately crafted simple linear model assumption. The concept was then applied to what takes place in the business sector, but has never fitted comfortably either with how business innovation occurs or with how public science actually operates. In particular, the notion that basic research is divorced from practical applications has been promulgated via the Frascati definition of R&D. The consequences for policy have been profound, and as is argued below, highly distorting.

The distortion stems from the failure to recognise that basic research, applied research and experimental development are closely coupled activities via which:

(a) practical concerns influence "open ended" discovery objectives (e.g. we carry out undirected basic research on viruses because we want to understand how to handle these threats in the future);

(b) practical applications reveal anomalies that cannot be explained by current vintages of theory - hence defining the objectives for future theoretical work, and;

(c) technological advances in research instrumentation define the directions taken by, and the rate of progress of, discovery research - which consequently involves the

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52 Stokes, D (1996) *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington DC: Brookings Institution.

53 See OMB *Analytical Perspectives* op cit. The OMB R&D capital stock estimates do not align with those of the Bureau of Economic Analysis (BEA) – which does depreciate basic research on the assumption that the knowledge does become obsolete. Arguably, the most plausible approach would assume that it is only the value of fundamental theoretical breakthroughs that does not depreciate – as argued in this paper, this is a small subset of *all* R&D outcomes because advances in fundamental theory draw upon the testing carried out beyond basic research per se.

"experimental development" of new and improved research instruments as an integral part of the discovery process (in so doing generating important commercial spin-off activity).

Indeed, a substantial proportion of the "experimental development" carried out in universities and public sector research organisations is not the experimental development of new products or processes in the linear model sense, it is the "experimental development" of new and improved research instruments linked to basic and applied research.

For example, radio astronomy is a "classic" blue-sky concern, yet the technologies, skills and expertise developed as the means to this end involved pushing the envelope in microprocessor design and signal processing. This, in turn, involved deliberate strategies for training graduate students in a range of trans-disciplinary areas of science and engineering. The highly skilled scientists and engineers developed via this strategy went on the found many companies in so doing contributing to a substantial amount of wealth and employment creation.[54]

The distinctive feature of this sort of science and engineering-enabled blue sky research is that it advances generic skills in identifying and reacting to patterns in highly complex situations. This requires skills in developing advanced technologies for communication and signal processing plus many other enabling areas, such as materials science and applied mathematics, which are used throughout modern economies. The critical factor in such work is that it involves advances in the fundamental theoretical understanding of complex processes and the skills required to do this.

The resistance expressed by the research community to policy-makers attempting to define research objectives for 'blue sky" research is not based upon a reluctance to allow for practical objectives to be addressed via public science. Rather, it is based upon recognition that "open ended" inquiry may be required in order to explore and learn about complex phenomenon in this "closely coupled" manner, and that peer-review mechanisms provide the best means of allocating resources to such exploratory activities because a tremendous amount of tacit knowledge is required to make robust judgments about scientific merit.

How high-tech companies use fundamental theoretical understanding

The following illustration is taken from engineering design in technologically advanced industries like ICT and aerospace, however the principles are far more generic.

High-tech businesses such as pharmaceutical and aerospace companies fund internal "basic" research in the form of work on fundamental computationally based theoretical understanding (principally in the form of advanced applied mathematics describing natural behaviours). Some of this work is outsourced to universities and government research organisations, but the really critical work is kept in-house. They do this because better computationally based theory is critical competitive asset.

54 See Matthews, M and Frater, R (2003) *Creating and Exploiting Intangible Networks: How Radiata was able to improve its odds of success in the risky process of innovating.* Case Study prepared for the Science and Innovation Mapping System Taskforce.

Possessing better theory than competitors allows new and improved products (such as an aeroengine or new chemical compound) to be developed faster and more cheaply than these competitors. This is largely because fewer design iterations are required to finalise a design, in turn because the better theory allows more accurate simulation models to be developed and used – thereby cutting down the number of "real" prototypes that must be built and tested at great cost and over long periods of time.

In short, the better the theory (and the capability to apply that theory) the greater the confidence that the bulk of design targets can be met on the first attempt – and the lower the cost and shorter the lead time of subsequent attempts to meet these targets. The following diagram illustrates this principle (see Exhibit 3).

This diagram represents different design capabilities in terms of confidence curves: the different probabilities of meeting or exceeding a given percentage of design targets on the first design iteration. These confidence curves apply to any science and engineering based design process. The better the design team the higher the percentage of the design targets that will be met or exceeded on the first iteration. 'Learning-by-doing' has the affect of shifting these confidence curves to the right. Pushing the 'design envelope' moves a team's confidence curve to the left because there is a reduced familiarity with the specific technical challenges and a decreased capacity to rely upon using existing solutions.

Drug design uses sophisticated databases and software models of molecular behaviour push the confidence curve to the right. Similarly, Computer Aided Design (CAD) and other simulation technologies that assist designers also play a major role in allowing this curve to shift to the right – provided the skill exists to use these tools effectively. Given the severe cost and time to market penalties of substantial re-design work a strong confidence curve can be extraordinarily valuable (particularly if being first into the market brings with it a stream of substantial future commercial advantages).

This framework has been used to explain why some companies place a very high value on the teams of scientists and engineers who possess "outlier" skills in achieving ambitious design targets with very few (costly and time to market extending) design iterations.[55] [56] The idea of applying "confidence curves" to the innovation process drew upon the investment appraisal methods commonly used by oil companies to value oil deposits in the face of substantial uncertainties over how much oil is actually there and how economic it will be to extract it.[57]

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[55] See Matthews and Frater (2003) op cit.

[56] Related arguments can be found in Dodgson, M., Gann, D., Salter, A (2005) *Think, Play, Do: Innovation, Technology and Organisation*. Oxford University Press.

[57] Oil companies plot cumulative probability curves "confidence curves" for the estimated NPV of oil deposits in an effort to quantify the uncertainty faced in deciding whether or not to proceed with major investments in oil extraction. These curves, derived from seismic analysis and geological patterns recognition, generate "P90" and "P50" and "P10" NPV estimation points, i.e. a 90 percent probability that the NPV is at least \$x, a 50 percent probability that the NPV is at least \$y and a 10 percent probability that the NPV is as high as \$z.

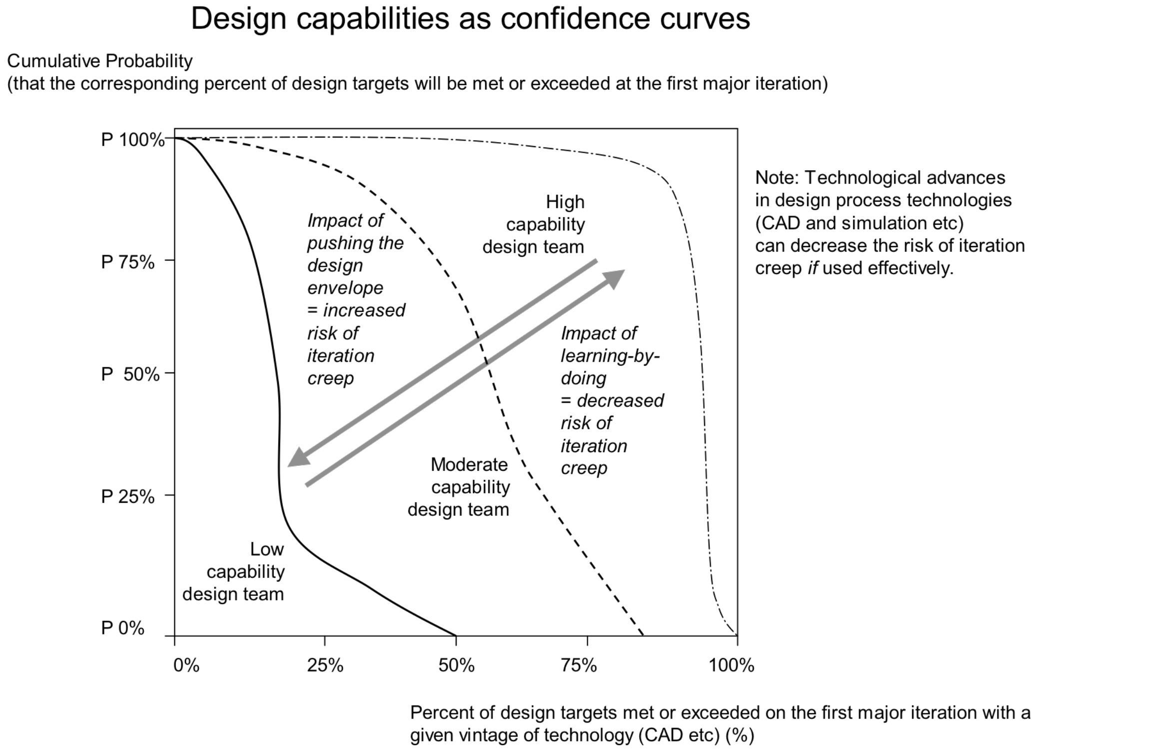

Exhibit 3

Source: Matthews, M and Frater, R (2003) *Creating and Exploiting Intangible Networks: How Radiata was able to improve its odds of success in the risky process of innovating.* Case Study prepared for the Science and Innovation Mapping System Taskforce.

The lesson is that advances in underpinning computationally-based theory have powerful and pervasive economic and commercial impacts simply by virtue of how better computational capability allows for greater confidence that the right design targets have been set and that the scientists and engineers can meet these design targets with a low a number of costly design iterations.

It is important to stress that the term "theory" is used here in the specific sense of formal mathematical and computationally based methods that seek to describe and/or predict real phenomena. Consequently, this is a sub-set of the wider range of theoretical knowledge generated by science.

Problem definition skills and human capital

Exactly the same "confidence curve" principle applies to scientific human capital. The better the theory, the greater the confidence that the hypothesis to be tested is a useful one to test, and the faster and more effective the testing process. This points to the same underlying epistemological principle: *public science and industrial R&D involve logical reasoning in which the aim is to improve theory.*

Outstanding "problem definition" skills in complex situations are a key enabler of this fast-tracking capability. As good Ph.D. supervisors (who want good completion rates) stress, the better the definition of the problem as a viable project the faster the work can be completed and lower the risk of mistakes, blind alleys, re-work or noncompletion. These efficiencies are particularly important with regard to how we think about human capital and in national preparedness for dealing with a range of risks and threats. These theory-based considerations are also central to strategies towards industrial R&D.

The following diagram (Exhibit 4) provides a "public science" version of the preceding representation of the role confidence curves in an industrial innovation environment. This draws-out the way in which scientifically trained "human capital" can be valuable intangible assets by virtue of the ability to define problems in a tractable (solvable) manner. A minimal number of experimental iterations are required to improve both fundamental theoretical understanding and achieve practical outcomes. Minimising the number of experiments holds-down research costs and speeds the time to publication – major benefits in global research competitiveness.

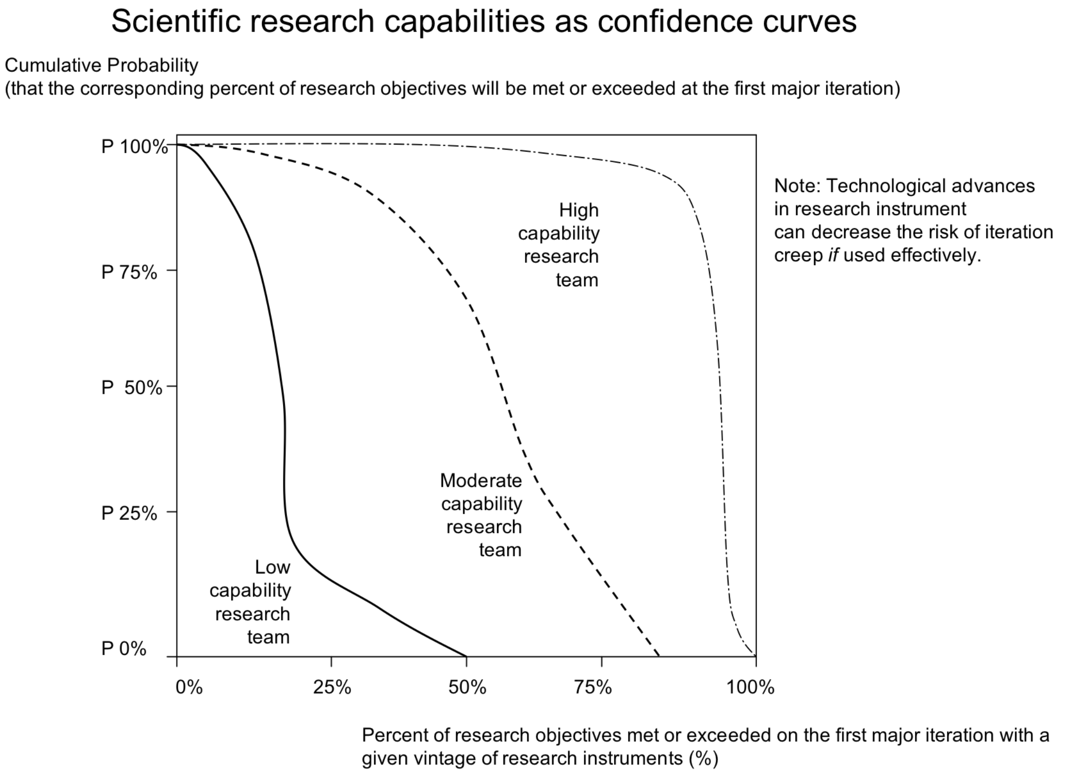

Exhibit 4

This perspective is useful for illuminating why peer review plays such an important role in public science. Peer review is not simply a mechanism for determining research "excellence" and professional reputation (promotion prospects etc). The peer review principle focuses on "contested knowledge" - mechanisms for validating theoretical claims on the basis of factual data and for encouraging explicit recognition of the cumulative nature of the knowledge thus generated via debates over veracity. A theory is never "proved" it just remains, as yet, not disproved.

The contested nature of claims of veracity is important from a highly practical stand-point. Good theory, derived from peer review scrutiny of the match of theory with data, allows researchers to operate in the "high confidence" region of the above diagram. Problems are defined in a tractable manner and, as a result, relatively few experimental iterations are then required to move forward in discrete steps in the discovery process. In effect, the "stock" of peer-review moderated cumulative knowledge reduces the risk of mis-specified research puzzles and experiments.

The draw-back to peer-review is, as many recognise, the problem that new perspectives and avenues of inquiry can be "locked-out" by conservative peer reviewers, in so doing holding back the advances in knowledge.[58] It is therefore essential that peer-review mechanisms allow for sufficient plurality and "redundancy" in investigations in order to avoid the weaknesses associated with peer-review mechanisms blocking "disruptive" science whilst allowing for these benefits of strong theory to be exploited via the peer-review process.

In contrast, weak theoretical capability (either poor theory itself and/or inadequate application of that theory) tends to result in a larger number of experimental iterations and "re-work" loops as mis-specified problems and badly designed experiments waste time and cost. Once again, these are familiar issues in doctoral supervision. This is also a perspective that lends support for strengthening rather than watering down the emphasis placed upon advancing theory and research methodology in doctoral research.

The "long-shelf life" publications that are still being cited several decades after they were first published sometimes owe this to the way in which they defined a new, and more elegant and tractable analytical method that saves time and therefore cost in a research field. In effect, the long-shelf life stems from the way in which the research pushed the collective "confidence curve" to the right – allowing all researchers able to understand and apply the approach to be more efficient and effective in the discovery process – requiring fewer experimental iterations to make progress.

It follows from this argument that contested claims of theoretical veracity also serve as a means of generating valuable human capital skilled in defining and solving complex problems quickly and cost-effectively *throughout* the economy. This is why leading investment banks recruit physics, mathematics and engineering graduates – a rigorous scientific training generates valuable generic skills in problem definition and problem solution in complex situations in which timeliness is critical. Better theory and the skills in applying this theory allows given objectives to be achieved with a fewer number of problem-solving iterations, thereby generating competitive advantages in both cost-effectiveness and lead-times.

Implications for measuring the value of stocks of scientific human capital

From this perspective, the stock of scientifically trained human capital possesses the capability to progress knowledge via decision-making with minimal iterations resulting in lower cost and greater speed of progress. "Re-work" and "scrap rates" are lower because the problem was well defined in the first place. It is not hard to

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58 See Latatos, I (1970) The Methodology of Scientific Research Programmes. In, Lakatos, I and Musgrave (eds) *Criticism and the Growth of Knowledge*. Cambridge: Cambridge University Press.

see that this provides a basis for valuing scientific human capital in a manner that is relevant to all sectors of the economy in which scientific knowledge and data are pertinent to decision-making, i.e. from drug design in a company through to environmental policy advocacy in an NGO.

This approach would be based upon considering how much longer and more costly it would be to use less skilled and experienced human resources in the decision-making process. In short, the value of human capital can be derived from the cost-savings associated with reduced re-work and scrap rates in the process of advancing knowledge and/or arriving at complex decisions. This concept is compatible with economists' approaches to human capital[59] and may be useful in allowing the value of scientific human capital to be estimated.

The epistemological common ground between public science and industrial R&D

The implication is that public science and industrial R&D exploit the same epistemological capabilities. Science seeks to develop ever more parsimonious explanations of complex phenomena (critical to tractable problem definitions) via experimental testing aimed at selecting and evolving theory. If operating effectively (something that cannot be assumed) peer review plays a critical gate keeper role in reducing the incidence of incorrect theoretical propositions that risk wasted time and cost in future research if not spotted by the "epistemological immune system". Similarly, industrial R&D uses experimental development to test theory and simulation models in order to avoid wasted time and cost in both future R&D and market introduction processes. Markets provide an alternative selection mechanism – but one that kicks in at a later stage in the process.

The differences between public science and industrial R&D are not epistemological (at the cutting-edge both share a concern with continuously advancing theoretical power), rather they lie in the subtleties over what the theory seeks to achieve. Thus, experimental development in industrial R&D seeks to use theories and formal models that can handle the added complexities of "scale-up" and related "implementation" issues of less relevance to public science.

Public R&D and rational expectations

Public R&D influences expectations about the future. The principle here is not dissimilar to of the notion of "rational expectations" in economic theory – the proposition that all decision-makers will access and use the best available models and data.[60] For example, as work on climate change modeling advances the potential exists for decision-makers throughout the global economy to access and use these forecasts to inform their own decision-making.

Whether or not the findings from this R&D are actually accessed is of course a critical policy issue, posing the question: are enough companies able to understand

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59 There is a vast body of work in this area, most notable associated with Gary Becker's 1964 contribution entitled *Human Capital*. This tends to focus on the "yield" from the stock of human capital with measures of educational attainment and professional experience used to estimate the quality of the stock (the greater the investment in acquiring knowledge the greater the yield on that investment).

60 The original contribution that generated a large body of economic analyses of this issue was made by: Muth, J. F. (1961) Rational Expectations and the Theory of Price Movements. *Econometrica.* Vol 29 pp 315-335.

and use the methodologies and data?. This is a matter of what economists term "institutional failure" (i.e. limits to management and human resource capability) rather than market failure per se. Institutional failure can be thought of as "friction" in the "rational expectations" model of how public R&D generates pervasive economic outcomes. In an uncertain world access to less imperfect information is valuable and R&D makes the information that we have less imperfect than would otherwise be the case.

This type of R&D impact may well be, by far, the most important means via which public R&D generates economic, social and environmental benefits. It is also a type of impact that the notion of "preparedness" highlights.

Preparedness for potentially disruptive technologies

Theory-related breakthroughs in the form of "disruptive technologies" are also a major concern to the businesses whose market value may be at risk. This is an important, though rarely stressed, reason why major high-technology corporations fund academic research. Their principal aim is that of "insurance" – obtaining early warning of potentially disruptive technologies associated with major research breakthroughs.[61] Funding leading research teams in universities allows these companies to tap into the global academic research effort, not so much in terms of publications and IP but more in terms of rumour, speculation and conjecture about who is looking at what and how much progress they may be making. This sort of linkage amounts to intelligence gathering with a view to maximising preparedness to defend corporate net worth. Particular attention is paid to the potential for new technological paradigms to emerge based on advances in basic science.

Final remarks on the importance of formal theory to business

This section of the paper has highlighted the way in which corporate competitiveness in high-tech sector can be based upon superior theoretical capability. The improvement in this theoretical capability is driven by the close coupling of basic research with applied research, experimental development, post-R&D market introduction processes and also by in-service experience of products and processes. From this perspective, what happens "after" the basic research that deals with advances in fundamental theoretical understanding is the key driver of improvements in this theoretical understanding. The greater this theoretical understanding the lower the investment requirement for applied research, experimental development and market introduction/product development processes. The following section extends this argument on the power of theory into the financial domain. It explains how the effective coupling of theory with practice can generate "bankable feasibility" in investment propositions – increased net present values based upon lower risk-premia attached to the cost of capital. This is a particularly important issue for large debt financed investments like power stations, but the general principles apply far more widely to the innovation process.

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[61] UK Patent Office, Universities UK and AURIL (2002) *Managing Intellectual Property – A Guide to Strategic Decision-making in Universities*. Report by SQW Ltd.

Theoretical power and investment risk

The manner in which a major new investment is to be financed can be critical to whether or not the potential investment is financially viable. For debt financed investments the aim is to demonstrate, in as credible a manner as possible, that the investment risk is lower than a less well informed and in-depth analysis might conclude. For equity financed investments the aim is to demonstrate that risk-taking that exceeds market norms could, potentially, lead to returns-on-investment that exceed market norms.

In both cases the emphasis is upon striving for as accurate a possible an estimate of the risk-reward relationship. This is one reason why major investment banks employ teams of experienced engineers and scientists. Scientific and engineering expertise is critical to judging investment risk. The same principle applies to areas of science in which there is significant commercialisation activity – such as in the bio-medical area.

It is for this reason that some industrialists are starting to stress a type of R&D outcome that is far less familiar to the majority of academic researchers (especially those without commercialisation experience) – namely lower investment risk relative to market norms - a factor known as "*beta*". On a number of occasions, discussions with industrialists over what they are looking for in "third stream" research partnerships with universities and public sector organizations results in the phrase "we are looking for a lower *beta*".

This type of R&D outcome is explained in Exhibit 5 in the form of the Capital Asset Pricing Model (CAPM). The CAPM[62] is widely used in large corporations, including banks as a convenient means of assessing the rate of return on a prospective investment that reflects the level of risk faced (to be specific the level of risk that cannot be offset by other mechanisms such as financial hedging).[63]

The principle of viewing research outcomes as reductions in *beta* is straight-forward. Consider a new coal fired power-station design that could reduce greenhouse gas emissions. This design may involve bundling together different leading-edge technologies, many of which can be acquired from specialist providers. The result is that the design is a 'systems integration" challenge – working out how best to get all these systems to work together. Until a real-world power station with the new bundle of technologies is built the risks must be estimated via simulation modeling but they cannot be demonstrated conclusively.[64] For a major debt financed investment this risk dimension is a critical factor. Delays in the power station going on line and/or cost-over runs will also reduce the estimated net present value (NPV) of the investment proposition.

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62 Whilst strong criticisms have been levelled against the CAPM by academic financial economists it is still used because it is tractable – "generally true even if it is precisely wrong".

63 Future and derivatives contracts are an important mechanism for hedging against uncertainty. For example, electricity generators in de-regulated electricity markets used derivative contracts to hedge against unpredictability in weather that can drive spikes in the price of electricity and black-outs when demand exceeds supply.

64 Significantly, the brown coal burning power station that has the highest thermal efficiency and the lowest carbon dioxide emissions in the world was built by a publicly owned state utility in Germany. This was possible because it did not need to borrow the funding from the private sector and could therefore tolerate a greater level of technical and business risk (i.e. *beta*) that a privately financed solution. Once built, this "first of a kind" (FOAK) power station has the affect of reducing beta for subsequent privately financed designs of this type – allowing these to achieve a level of "bankable feasibility" that may not otherwise have existed.

Irrespective of the precise method used by the merchant banks or major corporations who will provide the finance, the general principle will follow the CAPM principle: the higher the estimate of *beta* the greater the required rate of return to offset the risk and/or the higher the discount rate applied in the NPV calculations. Whatever the approach, higher technical risk associated with "pushing the envelope" in innovation terms translates into a lower NPV via *beta*-related investment risk assessments.

This is why some industrialists are becoming very interested in using R&D outcomes to demonstrate what they term "bankable feasibility" by collating robust evidence that *beta* is in fact lower than their bankers and investors assume. This can involve a dialogue not dissimilar to that which takes place over the regulatory approval for a new drug, in which data that helps to set *beta* in scrutinised, challenged, and a particular *beta* value eventually agreed upon. On the basis of the available published evidence, drawing such a close connection between R&D and bankable feasibility via *beta* is currently an intention for many companies and a reality for a few rather than a well-developed and widely adopted methodology. Policy-making would benefit from paying attention to this dimension of the innovation process – particularly in relation to third stream activities.

This type of "technological due diligence" tends nowadays to revolve around correlations between the results of simulation modeling and data from large-scale experiments and prototypes, or even real systems being operated elsewhere. The better the correlation between theory and data the stronger the case for setting *beta* at a level that generates "bankable feasibility".

Exhibit 5: Reduced "beta" as the research outcome: understanding the value of research outcomes using the Capital Asset Pricing Model

The Capital Asset Pricing Model (CAPM) is a frequently used, and relatively simply formal method for calculating the required rate of return on an investment on the basis of prevailing investment conditions. The standard equation used is as follows.

$$K_d = R_f + \beta[R_m - R_f]$$

Where:

K_d is the required rate of return from the investment (the cost of debt)

R_f is the risk free rate of return (usually taken as the 10 year govt bond rate)

β is the measure the specific project risks relative to general market risks

R_m is the expected rate of return in the market as a whole

The greater the estimated value of β the higher the required rate of return to compensate investors for the additional risk that they face and the lower the net present value (NPV) of an associated investment opportunity.

Estimates of β are widely used in the finance sector to inform decision-making. For example, in December 2001 BHP Billiton had a beta of 1.51, the National Australia Bank (NAB) had a beta of 1.49 whilst the oil company Santos had a beta of 0.84. This tells us that Santos was assumed to be a low risk candidate relative to the market as a whole but that investments in BHP Billiton and the NAB faced risks that were greater than those prevailing in the market as a whole.

It is not hard to see that any R&D outcome that helps to demonstrate that β is lower than would otherwise be assumed to be the case can generate "bankable feasibility" for an investment opportunity. Commercial-in-confidence studies do exist that examine how R&D generates bankable feasibility via *beta* - however none have been found in the public domain to date (precisely because they are so commercially important).

Given the importance of *learning curves* (cumulative experience in building a particular design leads to lower unit costs, shorter lead times and reduced technical risk) simulation modeling that closely matches experimental data has the effect of allowing a number of "virtual" systems to be built prior to the first real-world system. Considerable attention is paid to the "first of a kind" (FOAK) design configuration in major engineering design projects as these provide a starting-point for both reaping learning-driven gains and demonstrating *beta* for subsequent projects.

Significantly, scale-up issues are often central to the FOAK risk-assessment milestone. This is why so much attention is paid to developing simulation models that can accurately predict real, full-scale behaviours.[65]

The outcomes generated by "third stream" partnerships in which universities link with companies to work on specific major design projects can be framed in terms of "virtual" progress along learning curves. In effect, the all-important FOAK may be the 3rd or the 4th "unit" built in learning curve terms because the R&D has allowed a significant amount of design "de-bugging" prior to the first build.

This perspective opens up a new regime for defining the outcomes from 'third stream" activities based on combining investment risk factors (*beta*) with established

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65 Venture capitalists pay particular attention to scale-up risks because what works at the R&D scale can be a poor predictor of what works at a full operational scale.

learning curve methods. R&D partnerships can generate substantial benefits by securing "bankable feasibility" for designs that push the performance envelope – in so doing facilitating the diffusion of more advanced technologies that address global concerns such as climate change. Hence, the industrialists that look for the outcomes from R&D partnerships in terms of reductions in *beta* have identified a critical outcome from public sector R&D. This is not, unfortunately, an outcome that the Cooperative Research Centre programme accepts as valid. The potential exists to develop research impact metrics for the new Research Quality Framework based on "virtual" progress along learning curves prior to the FOAK. This approach would be particularly useful in capturing the outcomes from engineering R&D – in which "designs" can be important outputs.

How applicable theory assists with achieving "bankable feasibility"

An applicable theory can be thought of as a formal mathematical approach that can be related statistically to data from real-world experiences. As the correlation between the theory and real world experience increases (by virtue of using data from experimental development to drive improvements in the underpinning theory) so the value of that theory increases. Being able to formally demonstrate a strong statistical correlation between theory and data can be critical to achieving bankable feasibility.

As noted earlier, the main difference between cutting-edge public science and cutting-edge industrial R&D does not appear to lie in how theory for competitive advantage is used so much as in the issues addressed by theory. In an industrial R&D context the challenge is to develop and use theoretical models to handle highly complex real-world issues such as scale-up – in which the number of variables required tends to increase dramatically in comparison to laboratory-scale models and analysis. This is why it is US government policy to encourage the weapons laboratories to "commercialise" older vintages of the highly sophisticated numerical methods used to simulate nuclear explosions as a substitute for real nuclear tests.[66] Disseminating advanced "non-linear" mathematical methods helps industry to reduce the time, cost and risk in scale-up efforts.

This is most clearly demonstrated in relation to the product families formed by successive design improvements. As any design is tweaked and improved there are likely to be major costs and long lead times associated with obtaining regulatory approval. The ability to "frame" the case for regulatory approval against statistically robust correlations between theory and practice is of great assistance in lowering the costs and lead times of the approval process. This is also an area where competitors can act to try to block "fast tracking" to regulatory approval.

For example, several years ago one aero-engine manufacturer was seeking to obtain regulatory approval for an engine design derivative on the basis of mathematical modelling of that design, based in turn upon statistically robust data that demonstrated how effective the model was of actual engine behaviour for that design family. Because the design was a derivative of an already certified design, the US Federal Aviation Administration (FAA) was willing to certify the new design simply

[66] "Statements if intent and other information on this matter can be found on the official web sites of the weapons laboratories, such as Los Alamos.

on the basis of the mathematical model of demonstrated explanatory power. Whilst for the industry as a whole this was the "holy grail" of applicable theory in R&D and market introduction processes it became prudent for competitors to take legal action to block this precedent in order to seek to limit short-term competitive disadvantage. This regulatory compliance "innovation" and the litigation response highlighted the tremendous value of applicable theory backed by robust data.

Similar considerations apply with regard to the source code for advanced weapon systems. For example, it has been reported that the lead-up to the French underground testing of nuclear weapons in the South Pacific mid-1990s involved attempts to obtain nuclear explosion simulation software for that class of warhead from the United States. When the US refused to provide the source code the French were forced to proceed with their own real test in order to assess the extent to which their own mathematically based simulation models were accurate. This software *code validation* is an important issue for nuclear powers because they need to be able to assess the extent to which their stockpile of warheads is degrading over time.

The US has a long-established tradition of not releasing source code relating to a wide range of weapons systems – further emphasising the importance of applicable theory as a strategic asset – *software is applicable theory*.[67]

It is also important to bear in mind the fact that there are major differences between research areas with regard to the scope for this type of theory-enhancing feedback within R&D. It is only possible for experimental development to drive theoretical advances in a major sense if the formal theory and the implementation of that theory in simulation models are able begin to match the complexity of the real processes being studied.

For example, until the mathematics of "computational fluid dynamics" (CFD) were developed and implemented in software simulations wind tunnels were the most effective means of optimising the aerodynamics of aircraft, motor vehicles and large structure designs (such as suspension bridges and skyscrapers). The data generated from these wind tunnel tests provided the raw material that defined the challenges for CFD theory and modeling. However the ability to use the statistical correlations between formal theory and the experimental wind tunnel tests to identify anomalies between theoretical prediction and actual behaviour required that the theory was able to make predictions that were "in the same ballpark" as regards the nature and extent of the complex behaviour mapped by the experimental results.[68]

Similarly, the mathematical modeling and software simulations of complex bio-chemical processes is playing the same sort of role as CFD in reducing reliance on costly and time-consuming experimental development and compound screening in areas like drug design and genomics. The difference is that the greater levels of complexity and uncertainty over how biological systems behave may mean that formal theory faces more severe limits in efficacy than in the case of CFD. Consequently, the long-term scope for the fast-tracked progress associated with "closely coupled" advances in theory and experimentation differs markedly between research areas as a function of the sheer complexity of the processes involved.

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[67] A useful discussion of defence issues see: Brabin-Smith, R (2006) Priorities for Defence Innovation in Australia. In *Growth 57: the Business of Defence - Sustaining Capability*. Committee for the Economic Development of Australia.

[68] An excellent discussion of the epistemological dimension to engineering can be found in Vincenti, W. (1990). *What Engineers Know and How They Know It*. Baltimore: Johns Hopkins Press.

The limits to the R&D concept in a business context

The caveat to the importance of formal R&D is that in a number of high-technology industries, such as aerospace, "R&D" is viewed as an accounting and tax treatment matter. In such industries, innovation strategies focus on broader concerns with capability acquisition and systems integration in extended technology supply chains. Formal R&D plays a role in facilitating capability acquisition and systems integration, but not the dominant role some commentators unfamiliar with actual corporate innovation strategies and practices assume. Consequently, emphasising the distinction between business innovation and technological innovation would help to clarify debate over the impact of business R&D spending on industrial competitiveness. However, scope would still remain for improving the accuracy of the assumptions about the role of formal R&D in those industries in which technological innovation is a key component of competitiveness. For analysts working in Australia this would require greater exposure to how things work in major high-technology engineering corporations outside of the minerals, resources and agricultural/wine sectors (in which Australia *is* a key actor in the global competitive process).

Moving toward a more balanced policy framework

A key aim of this part of the paper is to highlight some of the opportunities for enhancing the effectiveness of our policy framework. Some of the opportunities considered relate to the role of investment risk factors and international engagement in influencing how effectively spending on science and R&D are translated into enhanced national income, wealth and preparedness. The perspective is familiar to scientists and officials working in the defence sector because "capability" concepts linked to addressing risks of various types feature strongly in that area of strategy and policy. The objective is to disseminate this capability and risk-based perspective more widely and to consider its more general implications for science and innovation policy.

International engagement and bankable feasibility

The way in which R&D helps to generate the "bankable feasibility" that facilitates the innovation process creates particular challenges for smaller economies. The large-scale technology demonstrators that are linked to R&D (those that provide "proof of concept" etc) trend to be very expensive. This means that smaller economies face a severe budget constraint that limits the ability to demonstrate bankable feasibility for complex large-scale systems.

Effective international engagement provides a means of gaining access to the knowledge and data that expensive demonstrator projects provide. In order to do this it is essential that negotiating assets are held that we can afford to generate that are of interest to the larger economies, and that the capability exists to conduct negotiations of this type.

This would involve strategic investments in generating "negotiable" S&T knowledge and data assets (such as quantum computing) to be used to gain access to the "bankable feasibility" data than Australia cannot afford to generate due to domestic budget constraints. It would involve a capability to link and coordinate investments and international negotiations that greatly exceeds current experience.

Prosecuting this sort of "scientific and technological diplomacy" strategy would be a radical departure from current arrangements. It would require a far more comprehensive "whole-of-government" approach than exists at present, particularly with regard to the "interoperability" of the Department of Foreign Affairs and Trade (including AusTrade), the Department of Education, Science and Training, and the Department of Industry, Science and Resources. Whilst greater "interoperability" would be welcomed by many scientists and engineers experience to date suggests that such a move may be resisted by some of these departments.

Mismatches between public and private intellectual property management strategies

In many industries a major component of the value of a patent portfolio lies in "blocking" competitor's R&D and product development strategies. This involves anticipating a competitor's long-term technology strategy, and then pre-emptively taking out patents that deny IP territory to the competitor(s). In so doing, it is possible to drive-up competitors' R&D costs, and to increase their time to market, by forcing them to "invent around" this IP territory. In some industries the competitive value of the patent blocking component of the patent portfolio equals or exceeds the competitive value of the patents that secure IP over the technologies used in current and future products and processes.[69]

Consequently, there is a marked divergence between IP management strategies in the public sector and the private sector. The public sector approaches the value of patents *intrinsically* – it focuses on the potential value of patents as options that could generate substantial economic benefits if impediments to executing these options are removed. The existence of major imbalances in the intrinsic value of patents (a very small number of patents account for the bulk of the economic value created) becomes a matter for policy concern.

In contrast, the private sector views patents as assets in a far more complex competitive game in which the value tends to be *extrinsic* – it lies in second-guessing others' competitive strategies and denying access to areas of technology. These values are harder to judge because they are ambiguous and contingency-based.

This mismatch between public and private sector approaches exemplifies the problems generating for policy-making if the preparedness dimension is down-played. The private sector is playing a (complex) preparedness game via patent portfolios not looking for direct causal relationships between investments in securing and maintaining patents and tangible commercial returns.

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[69] In the aerospace industry the value of a patent portfolio lies mainly in the following three areas: (a) the patents that secure the companies product and process trajectories; (b) the patents that block competitors' product and process trajectories; (c) the patent clusters that can be used as tradeable assets in other business negotiations (their value lies in disposing them not retaining them). Consequently, the contemporary emphasis on "culling" extensive patent portfolios is risky if this multi-dimensional aspect of the value of patent portfolios is overlooked. From a preparedness perspective it may be premature to overly cull a patent portfolio.

Conclusions

The major global investment banks and national security communities have well-developed capacities for exploiting on-the-ground intelligence in order to inform their risk management strategies. This financially and geopolitically aware approach to understanding the role of uncertainty and risk in science, innovation and preparedness in the modern global order provides a far more relevant and effective basis for policy than current thinking.

Public policy should therefore be learning from the private sector in the significantly different area of strategic approaches to managing uncertainty and risk via *portfolio methods* and including the key role of geopolitical factors.

Such a policy framework would involve placing a greater emphasis on the role of governments in funding the very long-term and high-risk R&D critical to reducing uncertainty in both preparedness and innovation. This type of R&D cannot be driven by market signals but is driven, notably in the United States, by well-developed central planning mechanisms linked to geopolitical and other preparedness concerns and that extend way beyond national security issues per se.

This policy framework would replace current implementations of output-outcome approaches with more explicitly "risk-aware" investment portfolio management and engineering design methods.

- Relevant areas of public R&D would be bundled together to facilitate risk-taking not to limit it.
- The returns to spending would be judged on this portfolio basis not on individual project "ROIs".
- Where appropriate, R&D outcomes would be measured as reductions in "*beta*" (relative investment risk that cannot be offset by other means) and related to progress toward "bankable feasibility".
- Some R&D impacts could also be measured as "virtual" progress along learning curves prior to building the "first of a kind" (FOAK).

In addition, mechanisms would be created to allow projects rejected as too risky by some government funding programs to attract special "risk finance". It is significant that the United States' *Defense Advanced Research Projects Agency* (DARPA) has a special budget for funding projects deemed to be too risky for other channels of research funding.[70]

Preparedness-focused measures of the outcomes generated by public and private R&D, particularly with regard to the interactions between the two, could be based upon the impacts on national and corporate *net worth*. The "invisible hand" in market processes operates by collapsing a multitude of subjective risk assessments into clearly grasped prices – thereby providing transparent signals for decision-making over resource allocations. It is perfectly logical, therefore, to look for R&D outcomes in different levels of net worth than would otherwise be the case, i.e. in the

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70 As noted in British Government (2005) *Science and innovation investment framework 2004-2014: next steps*. London: HM Treasury.

ways in which different types of preparedness R&D have impacted upon subjective risk assessments, and hence the current prices of the assets whose future yields are influenced by various risks and uncertainties. This risk-aware focus on net worth encompasses expected future streams of profitable activity associated with more conventional productivity growth measures but in the forward-looking option-based view adopted by financial markets. This perspective is emphasised in the "Austrian" economic tradition – which is concerned with the economic implications of the existence of *time and ignorance* as starting assumptions.[71]

It is logical, therefore, to look for R&D outcomes in how they impact upon time and ignorance: *risk, uncertainty and preparedness* in a risky and uncertain world. Universities generate their most substantial benefits by generating better knowledge and data on the complexities of both natural and "invented" phenomena and by training people to make better decisions in a complex and uncertain world *throughout* the economy. When the new knowledge/data is used by scientifically trained people better judged "rational" decisions tend to result. In a world of inherently imperfect information these pervasive impacts of combining research-trained human capital - "decision-making capability"- with the publicly disseminated data used to make these decisions results in *less imperfect* information than would otherwise be the case. In effect, the much maligned "neo-classical" economic model of perfect information becomes a little less inaccurate.

This tendency is counter-balanced by the ways in which scientific research generates new uncertainties and perceptions of risks – many of which we would not be aware of without scientific research (e.g. climate change or epidemiology). The result is a "tug of war" over risk-drivers as the "inventory" of known risks that we face is depleted by progress in science (e.g. vaccines) and at the same time augmented by new risks identified via scientific research (or indeed, created by science and technology). If we neglect the ways in which science has contributed to more rational decision-making throughout the economy in the face of uncertainties and risks then we rule-out efforts to capture the main benefits of public support for science, innovation and preparedness.

The preparedness outcomes generated by public research rest on the ways in which public support is able to address *low discount rate* concerns: identifying and preparing for potential challenges that are too slow moving, ambiguous and/or risky for market-based resource allocations to cope with. Business decision-makers cannot be effective without the skills, knowledge and data generated by this type of public research because these "low discount rate" concerns impact upon "high discount rate" business decisions. Consequently, resource allocation mechanisms for public research that encourage high discount rate behaviour by setting short-term financial incentives will tend to limit the effectiveness of public research in assisting both *business* and government decision-making. It is precisely because markets require businesses to use relatively high discount rates that these same businesses require access to the fruits of public research based on low discount rate objectives.

From this discount rate based perspective, the move to develop a *Research Quality Framework* (RQF) in Australia risks establishing a high discount rate incentive system that will tend to limit this type of pervasive low discount rate driven research impact.

[71] See O' Driscoll, G., P. and Rizzo, M. J. (1985) *The Economics of Time and Ignorance*. London: Basil Blackwell.

Unless explicit consideration is given to the implied discount rate generated by particular RQF designs it is possible that the RQF will generate an incentive system that results in a similar discount rate to that used in markets.

It would therefore be useful if the Productivity Commission modeled the implied discount rate (i.e. social rate of time preference) generated by different prospective RQF designs. This would test whether or not the implied discount rate is a matter of concern from a policy perspective. Bibliometric analyses of the time taken for citation impacts to peak and then drop-off indicate that it can take several years for citations to peak in some fields and that this time path differs across fields.[72] It is the outlier "long shelf life" academic publications that are still generating citations that buck the trend in the "ageing" of the literature in the relevant field(s) that should be rewarded – and certainly not penalized.

For low "discount rate" preparedness research, quality is measured via long-lead times to research impacts not the more myopic time frame associated with market-related discount rates. Indeed, the real value of preparedness research lies in those fields in which citations and impacts are all but non-existent for long periods of time but which unexpectedly become critically important. For instance, the work on retroviruses that was a backwater until HIV-AIDs emerged – at which point possessing that preparedness capability became highly valuable. If public policy neglects preparedness as a broad scope outcome class for public science then it will be the general community, the business sector and government that must bear the costs of being *unprepared*.

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72 See Glanzel, W., Schoepflin, U. (1994) A stochastic model for the ageing of scientific literature. *Scientometrics*. Vol 30(1) pp 49-64. Glanzel, W., Moed, H. F. (2002) Journal impact measures in bibliometric research. *Scientometrics*. Vol 53(2) pp 171-193.

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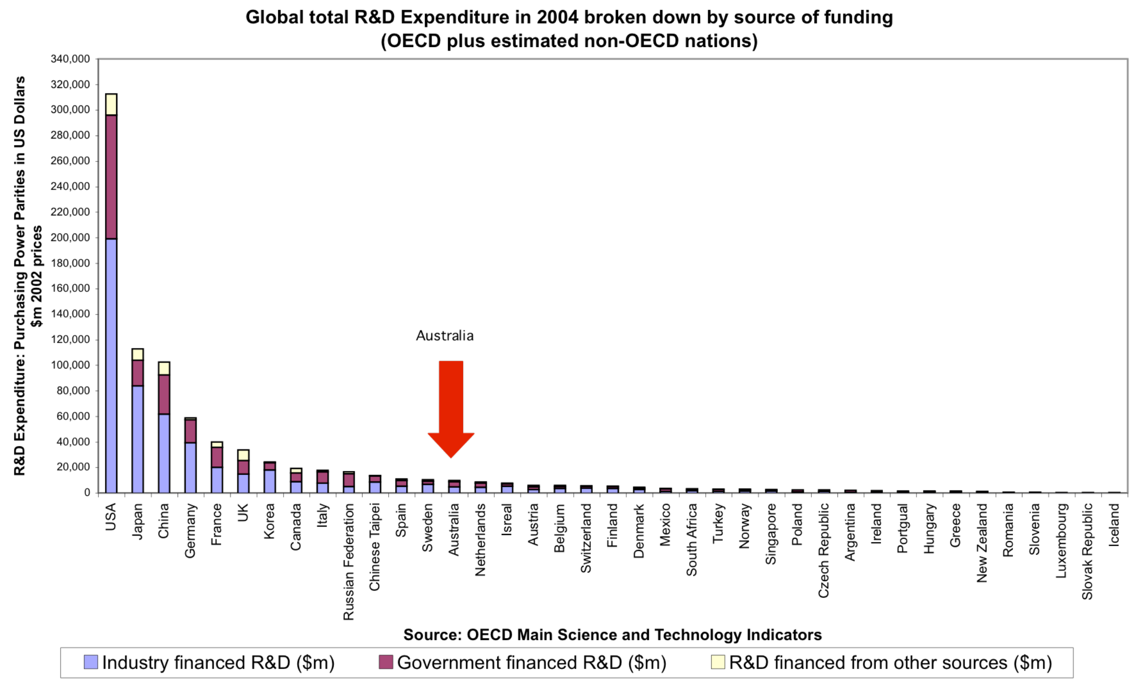
Annex A: Data on the global imbalances in R&D expenditure

Figure 1 and **Figure 2** summarise what is known about the distribution of global R&D expenditure by country. The data are the latest made available by the OECD and, significantly, include the OECD's estimates for non-OECD economies (and notably China).[73]

The first graph provides a source of funding view and the second graph a sector of performance view. Table 1 provides the data for identified global R&D by source of funding.

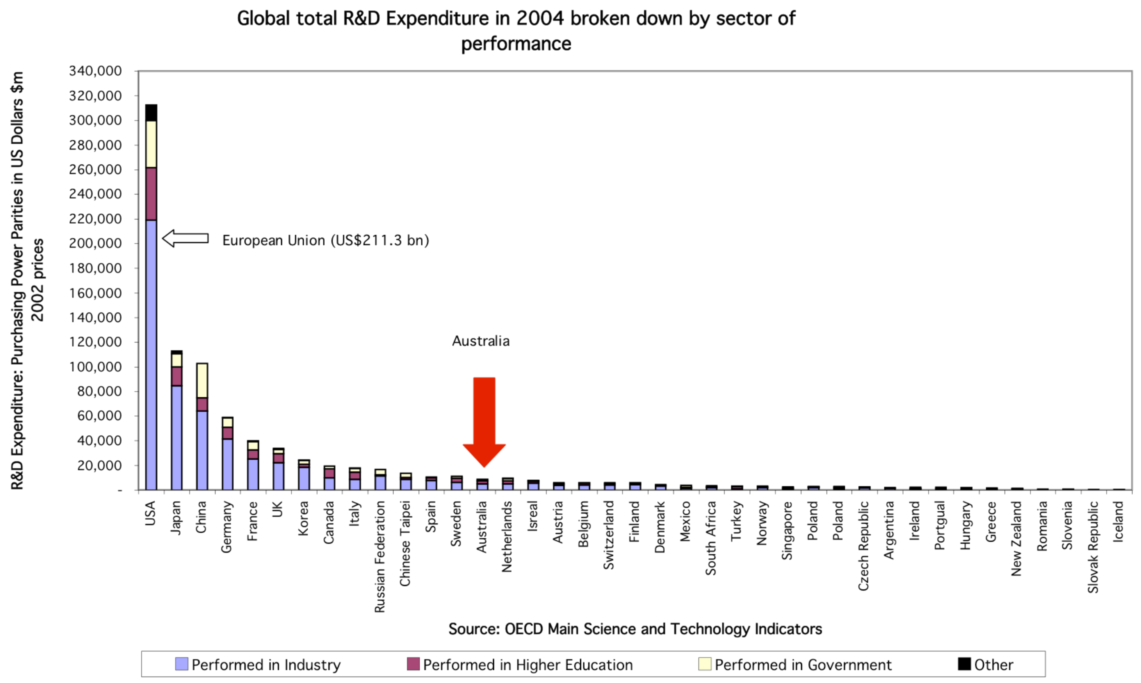
Figure 1: Identified global R&D by source of funding



Source: Calculated by the author from data contained in OECD (2006) *Main Science and Technology Indicators*. OECD: Paris.

[73] These data were obtained by calculating the monetary values of each countries' R&D expenditure by sector of performance and source of funding using the appropriate percentage breakdowns provided by the OECD in their "Key Figures" summary table (p14 of Main Science and Technology Indicators).

Figure 2: Identified global R&D by sector of performance



Source: Calculated by the author from data contained in OECD (2006) *Main Science and Technology Indicators*. OECD: Paris.

Table 1: Identified global R&D ranked by country and source of funding, 2004.

2004 US$ Purchasing Power Parities and prices	Industry financed R&D ($m)	Government financed R&D ($m)	R&D financed from other sources ($m)	Total R&D ($m)	Percent of global R&D (%)
USA	199.085.0	96.886.0	16.564.4	312.535.4	36.45%
Japan	83,972.5	19,950.5	8,791.7	112,714.7	13.14%
China	61,676.4	30,684.2	10,262.3	102,622.9	11.97%
Germany	39,379.4	17,841.0	1,467.2	58,687.6	6.84%
France	20,188.1	15,498.7	4,053.5	39,740.3	4.63%
UK	14,796.8	10,549.9	8,359.0	33,705.7	3.93%
Korea	17,962.5	5,801.4	509.7	24,273.7	2.83%
Canada	8,928.8	6,841.6	3,556.1	19,326.5	2.25%
Italy	7,610.4	8,990.9	1,097.3	17,698.6	2.06%
Russian Federation	5,167.7	9,973.4	1,316.6	16,457.8	1.92%
Chinese Taipei	8,487.5	4,790.2	215.9	13,493.6	1.57%
Spain	5,358.8	4,439.8	1,273.3	11,071.8	1.29%
Sweden	6,721.0	2,429.9	1,189.1	10,340.0	1.21%
Australia	**4,689.0**	**4,074.0**	**845.6**	**9,608.6**	**1.12%**
Netherlands	4,353.7	3,230.4	1,123.3	8,707.4	1.02%
Israel	5,326.0	1,853.8	417.9	7,597.7	0.89%
Austria	2,556.0	2,108.4	1,225.0	5,889.5	0.69%
Belgium	3,679.0	1,276.6	847.2	5,802.9	0.68%
Switzerland	3,888.3	1,305.5	433.3	5,627.1	0.66%
Finland	3,643.5	1,337.7	223.8	5,205.0	0.61%
Denmark	2,681.3	1,159.1	533.6	4,374.0	0.51%
Mexico	1,080.2	2,142.3	402.4	3,624.8	0.42%
South Africa	1,732.6	1,144.2	373.8	3,250.6	0.05%
Turkey	1,245.0	1,525.3	244.2	3,014.5	0.35%
Norway	1,456.9	1,240.7	263.5	2,961.1	0.35%
Singapore	1,441.6	973.5	244.7	2,659.7	0.31%
Poland	748.9	1,549.7	173.0	2,471.6	0.29%
Czech Republic	1,270.2	1,007.9	127.5	2,405.6	0.28%
Argentina	653.8	1,373.7	102.2	2,129.7	0.25%
Ireland	1,009.5	563.7	188.5	1,761.7	0.21%
Portugal	485.9	921.3	125.7	1,532.9	0.18%
Hungary	534.2	730.7	159.5	1,424.4	0.17%
Greece	427.4	659.9	304.9	1,392.2	0.16%
New Zealand	417.6	489.2	177.9	1,084.7	0.13%
Romania	294.6	308.9	45.4	648.9	0.08%
Slovenia	354.1	210.1	26.0	590.1	0.07%
Luxembourg	347.4	48.4	36.3	432.1	0.05%
Slovak Republic	155.0	231.1	18.6	404.7	0.07%
Iceland	110.9	101.3	40.4	252.6	0.03%
Total	**523,917.3**	**266,245.1**	**67,360.3**	**857,522.7**	**100.00%**

Source: Calculated by the author from data contained in OECD (2006) *Main Science and Technology Indicators*. OECD: Paris.

The increased prominence of global civil society as a source of R&D funding

Warren Buffet's recent announcement that he will be providing a substantial contribution to the already well endowed Bill and Melinda Gates Foundation highlights the growing importance of the civil society sector as a source of global R&D funding. Currently, the Bill and Melinda Gates Foundation has an endowment valued at US$29.2 billion and dispersed US$1.36 billion in 2005. 70 percent of funding (both R&D and non-R&D) went on global issues covering 100 countries. Research features strongly in the funding profile (such as US$258 million for the developing country orientated Maleria Vaccine Initiative).[74] This means that, as the size of the endowment increases significantly of the next decade, this Foundation alone stands to outspend a number of the smaller OECD economies on R&D.

In total, as Table 1 demonstrates, 7.8 percent of identified global R&D is financed from sources other than business and government. "Other" R&D funding in the US alone, at US$16.6 billion is broadly equivalent to the Russian Federation's total R&D spending (the 10th ranked economy by R&D spending in 2004). The US accounts for 1.9 percent of total 'other" R&D funding in the global economy and 24.6 percent of all global funding in this category.

The implication of these numbers is that civil society, with a strong emphasis on the US-based charities that fund R&D, is a significant player in global R&D. This is changing the "balance of power" in the global R&D system because the trans-national R&D funding provided by these philanthropic sources is becoming an important source of R&D funding in key areas like health and the environment. This also implies that a few individuals now have the scope to allocate a significant proportion of global R&D funding on the basis of their personal preferences – adding a C19 dimension to the modern global R&D effort.

This adds further weight to the notion that it is preferable to approach global science, innovation and preparedness not as a collection of "national innovation systems" but, rather, as a global system in which each nation must articulate how it plans to relate to the global system as a primary policy objective.

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74 Bill and Melinda Gates Foundation *Fact Sheet* and *Annual Report* for 2005.