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Innovation and Productivity: Using Bright Ideas to Work Smarter

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Summary

Innovation is one of five 'drivers' of productivity identified in recent Treasury work to develop a framework intended to help New Zealanders meet the challenge of lifting productivity levels and raising future living standards in a sustainable manner.

Innovation is a key element in economic growth

The case for innovation as one of the drivers rests on solid ground. Most of the huge rise in living standards in the developed world over the last two centuries (the era of modern economic growth) has come about through technological breakthroughs based on increased knowledge. Mostly this knowledge has been scientific but it has also been practical knowledge about production processes, and organisational, social, legal and marketing knowledge. The explosion in knowledge has gone hand in hand with tremendous advances in the education and skills of the broad population.

In the end, economic growth is about knowledge and ideas coming to fruition: inventing a new product, developing a new service, establishing a better way to manage a business and so on. Instead of rising living standards being limited by diminishing returns, increases in knowledge and innovation by entrepreneurs have allowed real incomes per head to rise by an average of around two per cent a year for at least the last century in the leading economies.

Adding to the case for a focus on innovation is the strong argument that new products and processes are an increasingly essential way for a developed country like New Zealand to prosper in a globalising world. Innovation is the means to compete with countries with low-cost labour that produce a wider and wider range of existing goods and services at very competitive prices.

Knowledge has special economic characteristics

In order to design good policies it is necessary to understand that knowledge and innovation have a number of special characteristics that differ from standard economic commodities. Most importantly, knowledge is *non-rival*, meaning that once an idea has been developed, others can use the idea at no additional cost. In addition, knowledge is characterised to varying degrees by the inability to exclude others from using a particular

idea, by uncertainty in the results of research, and by lags between when ideas are first formed and when they can be used commercially. Knowledge is also cumulative in nature: it builds on past knowledge.

These characteristics create the potential for markets on their own to fail to deliver the best outcome. First, knowledge can 'spill over' to those who did not create it, resulting in a social return to knowledge creation that is greater than the private return. Secondly, the non-rival nature of knowledge suggests it ought to be made widely available once it has been created.

Government involvement is likely to be required for optimal investment in knowledge

Given these features, there is likely to be less investment in new knowledge and less spreading of it compared to what would be best for society as a whole. This is why there is an important and potentially quite active role for government to create the best conditions for innovation, ranging from subsidising public- and private-sector R&D, ensuring that institutions for intellectual property rights and higher learning work well, and encouraging strong links between private-sector firms that apply knowledge and public research organisations that create it.

The empirical literature on returns to R&D provides support for the existence of knowledge spillovers, as observed in a large and consistent gap between the private and social rates of return to R&D investment. New Zealand-specific evidence is limited, but also finds some evidence of spillovers.

A useful concept that helps identify strengths and weaknesses across a range of aspects of innovation is that of a 'national innovation system'. Studying New Zealand's national system of innovation can help uncover opportunities for beneficial changes in the roles and interactions of the government, research organisations, entrepreneurs and firms, and in the supply of skills.

The relative weakness in New Zealand's innovation system is in the 'D' part of R&D, i.e. in the successful commercial application of new knowledge. Innovation requires firms to have a range of internal capabilities to be able to accumulate and apply knowledge, where that knowledge is either generated internally or absorbed from external sources. It also requires entrepreneurs to face positive incentives to innovate arising from product market competition, regulation and access to skills and finance. These are covered in more depth in other papers in the series.

While New Zealand's innovation performance is improving it still has a significant way to go

Overall, New Zealand's performance as an innovative economy presents a mixed picture. While it is improving, there is still a significant way to go before New Zealand's innovation system is firing on all cylinders. On the positive side, New Zealand's science base delivers research outputs at a relatively high rate compared with the OECD average. We have a relatively large number of researchers, and our R&D has been growing at a fast rate relative to most other OECD countries. On average, New Zealand firms have comparable innovation rates to EU firms across a range of measures.

On the other hand New Zealand is generally behind the global technology frontier – as indicated by the country's low overall level of productivity and its low productivity level in a majority of industries compared to the UK – a medium productivity performer. Innovating firms are the key institution for translating knowledge into national economic success and lack of such firms (in both number and size) is a significant weakness.

The level of R&D, as a percentage of GDP, is very low in New Zealand compared to the OECD, particularly business R&D. This last feature means that public research organisations, principally Crown Research Institutes and universities, perform a high proportion of total R&D, and this increases the need to get high economic returns from them through excellent links with industries and individual firms. The level of patenting in New Zealand is also low.

A range of policies are needed to make the innovation system work well and help raise productivity

The government has recently undertaken a number of positive initiatives to enhance the innovation system such as the introduction of R&D tax credits for private firms and the appointment of what is effectively a 'Minister of Innovation'. Given these, and New Zealand's current situation, the key areas for policy to focus on to achieve a high-performing innovation system (that will help raise productivity) are:

- Ensuring as much as possible that incentives (both market ones and government-influenced ones) encourage entrepreneurship, and knowledge creation and dissemination. Examples of these are the tax credits for R&D, the terms the government sets when it funds research, and flexible product-market and other forms of regulation.

- Keeping in mind that innovation occurs within a wider context, and some factors could still present barriers, for example:

    - uncertainty about returns to innovation – for example through regulations or exchange-rate volatility;

    - innovators require a large market to gain good returns from the high fixed costs of innovation and this necessitates exporting (given New Zealand's small size); but distance makes exporting so early in a firm's life-cycle a big challenge;

    - strong competitive pressure that drives firms to innovate to survive may be lacking owing to New Zealand's small market size and isolation;

    - capital-market under-development is likely to make it difficult for young, innovative firms to access funding, specialist networks and advisory services; and

    - low broadband provision may affect some firms and limit opportunities for innovation.

- Improving links in the innovation system between firms, public research organisations, and training organisations to promote knowledge exchange, and the development of skills that help firms take up new technologies.

- Strengthening mechanisms to help firms to become smart technological followers absorbing and applying relevant pieces of knowledge from both domestic and international sources.

- Identifying areas of actual and potential strength in the economy so that investment in R&D, education and skills and support for firms to innovate and internationalise is concentrated in these areas. The idea here is that these different investments will complement and reinforce each other in a virtuous circle of further investment, higher productivity, and higher returns.

In the end, in order to raise productivity by a significant margin, New Zealand needs a large number of firms to raise their performance through smart new product offerings, better technology, the use of more skilled workers and improved organisational and human-resource practices.

Innovation and productivity: using bright ideas to work smarter

Introduction

New Zealand faces a big challenge to overcome its long-standing productivity shortfall

One of the biggest challenges facing New Zealand is its productivity shortfall relative to other OECD countries: New Zealand is currently ranked 22nd out of the 30 OECD countries in the productivity league table and an hour worked in New Zealand typically generates 30 per cent less output than an hour worked in Australia. Low productivity is not a new phenomenon; productivity has been an issue in New Zealand since at least the 1970s.

A focus on productivity is desirable not only so that New Zealand becomes more internationally competitive, but also because, in the long run, growth in incomes is fundamentally linked to output per worker. Growth in GDP per person rests on either encouraging a greater proportion of the population into work, or by improving the productivity with which each worker produces output. New Zealand has performed well in encouraging increased numbers of people into the labour market, but there is a limit to how much increased participation in the workforce can drive further growth. Productivity improvements must be at the heart of New Zealand's future economic growth.

This is one of a series of Treasury papers on productivity performance……

This paper is part of the *Productivity Performance and Policy* series of papers that discuss New Zealand's long-term productivity performance and the factors that may be inhibiting New Zealand from reaching its potential[1]. *Putting Productivity First* is the overview paper which sets out the productivity challenge facing New Zealand and highlights key issues across five drivers of productivity: enterprise, skills, innovation, investment, and natural resources. The next two papers, *New Zealand's Productivity Performance* and *Does Quality Matter in Labour Input? The Changing Pattern of Labour Composition in New Zealand*, discuss past and more recent productivity performance and the impact that improving labour quality has had on labour productivity respectively. The final four papers

[1] The papers in the series can be found at http://www.treasury.govt.nz/publications/research-policy/tprp

address the enterprise, innovation, investment and skills drivers in turn, building on the analysis in the preceding papers by reviewing and interpreting available evidence to draw conclusions for the underlying factors affecting productivity.

A number of factors are important for lifting productivity and there are no quick fixes. For some measures the impact may not be seen for decades.

….. and is about innovation as a key driver of productivity and, ultimately, of living standards

Innovation and the policies that underpin it are one important element in lifting productivity performance. Most of the huge rise in living standards in the developed world over the last two centuries (the era of modern economic growth) has come about through technological breakthroughs based on increased knowledge. Mostly this knowledge has been scientific but it has also been practical knowledge about production processes, and organisational, social, legal and marketing knowledge. The explosion in knowledge has gone hand in hand with tremendous advances in the education and skills of the broad population.

Adding to the case for a focus on innovation is the strong argument that new products and processes are an increasingly vital way for a developed country like New Zealand to prosper in a globalising world. Innovation is the means to compete with countries with low-cost labour that produce a wider and wider range of existing goods and services at very competitive prices.

This paper will look briefly at the evidence for the importance of innovation as a driver of productivity and rising living standards. It will then examine the special characteristics of knowledge that cause it to differ from standard economic commodities. This is important since these characteristics create the potential for markets on their own to fail to deliver the best outcomes for society. As a result there is an important and potentially quite active role for government to create the best conditions for innovation, ranging from subsidising R&D, ensuring that institutions for intellectual property rights and higher learning work well, and encouraging strong links between private-sector firms that apply knowledge and public research organisations that create it.

The paper then looks at the key role of firms in translating knowledge into higher productivity performance. It describes the concept of a 'national innovation system'. If this system works well, new ideas and best practice spread to multiple firms and this boosts economy-wide productivity.

The paper next takes a look at the performance of New Zealand's innovation system in recent years. We find that it presents a mixed picture.

Finally, the paper brings together the concept of a good innovation system with New Zealand's current performance and recent policy initiatives. We draw conclusions on the most important areas for future policy attention. These are the ones that will, in our view, have the greatest impact on lifting the innovation and productivity performance of a large number of New Zealand firms.

Knowledge and innovation are important drivers of productivity

Increases in knowledge and innovation by entrepreneurs have allowed living standards to rise on average by around two per cent a year for a long time

In the end, growth is about knowledge and ideas coming to fruition: inventing a new product, developing a new service, establishing a better way to manage a business and so on. Instead of rising living standards being limited by diminishing returns, increases in knowledge and innovation by entrepreneurs have allowed real incomes per head to rise by an average of around two per cent a year for at least the last century in the leading economies. The next section tells the amazing tale of advances in lighting technology over the last two centuries and we then look at the broader evidence on the key role of innovation in raising living standards.

An 'illuminating' tale

A modern day family consumes more than a hundred times as much artificial illumination as its predecessor of two centuries ago but at a fraction of the price

In a fascinating study, the American economist William Nordhaus (1997) analysed the real price of light and showed how it has fallen by over a thousandfold over the last two centuries. Whereas a typical American household in 1800 spent around four per cent of its income on illumination - candles, oil, lamps and matches – a modern-day family spends around one per cent on average. Yet, the quantity of artificial illumination that the modern family consumes is more than a hundred times as much as its predecessor of two centuries ago.

The huge advances in artificial illumination technologies have been an enormous boon and source of value – Nordhaus estimated that it has contributed seven percent to the growth of real wages over the nineteenth and twentieth centuries. Yet the impact of this revolution is comparatively minor compared with the development of general purpose technologies such as steam, electricity, the internal combustion engine, plastics and ICT.

All these breakthroughs were technological in nature. It is worth noting however that other innovations – social, economic, legal and institutional – were needed alongside to fully translate them into rising living standards. Examples of these are the system of mass production, the development of the joint-stock company, the large industrial enterprise and the social-insurance state.

The crux of the story of light and the many other stories of dramatic changes in technology and knowledge is that at least in rich countries these developments appear to have made a huge difference to living standards. The next section briefly examines whether rigorous scholarly studies confirm this insight.

There is a large base of evidence about innovation and productivity

Growth accounting is a method of decomposing the growth in real GDP per head into the proximate factors of labour utilisation (number of hours of paid labour per head of population) and labour productivity (output per hour worked). Labour productivity in turn is driven by capital intensity (the amount of capital per worker) and multi-factor productivity or MFP (a measure of how much output is produced for given inputs of labour and capital). MFP is influenced by a variety of things but the level of knowledge and technology is the most important. Thus growth accounting studies that break down historical growth in GDP per head into these factors can indicate the relative importance of advances in knowledge to lifting living standards.

There is good evidence that over half of differences in output per worker come from multifactor productivity – a proxy for knowledge and technology

Klenow and Rodriguez-Clare (1997) is a good example of a growth accounting study that examines the proximate causes of growth in labour productivity. They find that over half of 1985 differences across countries in levels of output per worker are accounted for by differences in MFP rather than in physical and human capital. The same goes for growth rates: differences in MFP growth from 1960 to 1985 between countries explained the overwhelming majority of the differences in growth rates in GDP per worker.

Recognising the central role of knowledge and innovation in economic growth, economists have come up with a whole generation of growth theories that model the mechanisms whereby this happens. While the evidence is not conclusive on which particular one of these "endogenous growth models" is most credible, increasing returns from knowledge[2] play a critical role in most of them. This is not only a key ingredient to explain the on-going rise in living standards over several centuries, but also has important implications for policies designed to foster growth.

Countries divide crudely into technological leaders and followers

Countries divide crudely into technological leaders and followers. On the one hand, a group of leading countries invest heavily in science and research (within the OECD over 80 per cent of R&D is performed in just 6 countries[3]) and push out the global technological frontier. These are generally also the richest countries in terms of real GDP per head. On the other hand, remaining countries, including New Zealand, are largely technological followers. This gives them the opportunity of becoming "fast followers" by importing knowledge from the leaders – either embodied in equipment and services such as computers and engineering expertise, or in the form of the knowledge itself which they can absorb, adapt and apply within their own economies. Some of the most successful fast followers

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2 Economists refer to returns to scale being either decreasing, constant or increasing depending on whether output increases proportionately less than, the same as or more than increases in inputs.

3 The countries (in order of R&D expenditure) are US, Japan, Germany, France, UK and Korea; see OECD (2008) Main Science and Technology Indicators dataset

have been the small Asian 'tiger' economies of Singapore, Hong Kong, South Korea and Taiwan. More recently, and very significantly, the huge economies of China and India have joined them.

New Zealand can surely learn valuable lessons from the economic history of the Asian tigers and before them, Japan. They have all been successful in taking existing knowledge, understanding it, adapting it, applying it, and spreading it. However, it is other small, open, developed economies with strong natural-resource bases that are probably even more relevant as models for New Zealand. Examples of this group are the Netherlands, Canada, Australia, Finland, Sweden, Norway and Denmark.

New Zealand can likely learn valuable lessons from other small open economies with strong natural resource bases such as the Netherlands and Finland

Keith Smith is a leading scholar on the role of innovation in these economies that he labels of the "New Zealand type". He found (see Smith, 2006) that their successes have come from (i) building innovation gradually and pervasively on their traditional low and medium-tech resource base; and (ii) developing high-value-added niche industries arising from upstream and downstream activities linked to the traditional base, for example in electronics, chemicals, machine tools, paper machinery, navigation systems and telecommunications. While the niches under (ii) are important, Smith notes that they are relatively modest in size, and "prosperity continues to depend on continuously upgraded traditional industries".

One further set of findings is important to note: even within quite narrowly defined industries, there are typically large differences in productivity levels across firms and these persist over time (Law, Buckle and Hyslop, 2006; Dunne et al, 2002). This evidence and other studies that have built on it indicate that high-value-added firms tend to use combinations of skills, modern technology and good organisational practice and they co-exist over long periods with firms that adopt none of these. This suggests that these features (i.e. skills, technology etc) strongly complement each other and that a low-productivity firm somehow needs to engineer simultaneous progress on all of them in order to transform itself to a high-productivity firm. This is likely to be hard and means that the upgrading process is complex and not automatic.

Both the findings reported by Smith, and the findings on persistent firm productivity differences, point to the phenomenon of *path dependence* - not only for economies as a whole but also for individual firms[4]. In terms of policy, path dependence sometimes means it is better to work with the grain of what is already there, but in other cases it means finding interventions that are effective in helping to escape from an undesirable path.

4 Path dependence means broadly that the future development path of a firm or economy is strongly influenced by the characteristics of its path (product mix, skills, technology etc) up to the current time.

In summary then, there is strong evidence that knowledge and innovation are key drivers of productivity and living standards over the medium to long run. New Zealand is more of a technological follower than a leader and can likely learn valuable lessons about successful development from other small, open, resource-based economies. The process whereby firms upgrade the skills of their workforce, their technology and organisational practices to achieve high productivity is complex and not automatic.

Knowledge is an unusual economic good and this has important implications for institutions and policy[5]

Knowledge in an economic context can be thought of as a type of instruction or recipe that sets out how a good or service can be produced. Innovation, on the other hand, is “the successful development and application of new knowledge” (OECD, 2005).

Using the definition of knowledge as an instruction or recipe, we can turn to look at some of the key characteristics of knowledge, and the implications of these characteristics.

Non-rivalry

The most important characteristic of knowledge is non-rivalry, which means that one person’s use of an idea does not preclude another person using it at the same time

From an economic perspective, the most important characteristic of knowledge is non-rivalry, since it is this characteristic that implies increasing returns to scale in production and the potential for knowledge spillovers.

Non-rivalry simply means that one person’s use of the good does not diminish another’s use. As Jones (2004) puts it: “Once the design of the latest computer chip has been invented, it can be applied in one factory or two factories or ten factories. The design does not have to be reinvented every time a new computer chip gets produced.”

Jones (2004) (referencing Romer, 1990) provides a simple illustration of how non-rivalry leads to increasing returns to scale. As a simplified representation, we can think of a firm as something that produces output from a number of inputs – knowledge, capital, labour, and so on. The key point is that we need only double the standard inputs (capital, labour, etc) to double the amount of output. We do not need to double the stock of knowledge because knowledge is non-rival: the existing chip design can be

5 This section draws extensively on Blakeley, Lewis and Mills (2005) to which the reader is referred for more detailed discussion of the characteristics of knowledge as an economic good.

used in the new factory by the new workers. However if we do double the existing stock of knowledge (in addition to doubling the standard inputs), the output will more than double, ie we get increasing returns to scale.[6]

Increasing returns to scale can create problems for competitive markets to reach the best outcome for society. When competitive markets work well, they do so by decentralising millions of input-output decisions to individual workers and firms. But if there are increasing returns to scale then competitive markets could result in harmful monopoly, suboptimal provision, or coordination problems that prevent a new industry emerging.[7]

Fixed and marginal costs

Coming up with a good new idea typically costs resources (often significant resources) but subsequent uses of the idea are possible at zero marginal cost, since it can be simultaneously used by many people or firms. We can say that the new piece of knowledge has an initial high fixed cost but low constant marginal costs with respect to repeated uses of the idea. This is another way of describing increasing returns to scale.

It is important to note that while the marginal cost of production (or use) of an existing idea is zero, this does not necessarily imply that *transmission* of the idea is costless. For example, think of a design for a computer chip, which is transmitted via a blueprint. Additional copies of the blueprint might be required, and these have a cost and are rivalrous – so would be included as standard inputs in the simplified representation of a firm above.

Non-excludability

Another important characteristic of knowledge is the inability to exclude others from using it, though the degree of excludability will vary according to a number of factors

Another characteristic often attributed to knowledge is non-excludability. Non-excludability means that once a good has been created, it is impossible to prevent other people from gaining access to it (or more realistically, is extremely costly to do so).

While non-rivalry is an inherent feature of knowledge, it makes sense to think of non-excludability as more of a continuum, with the degree of excludability varying depending on a range of factors. These include:

- the observability of the knowledge (for example, the process for manufacturing a product may be more excludable than the design);

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6 It may not be intuitively obvious what "doubling the stock of knowledge" means in practice. Clearly it is not identical to doubling standard inputs like labour – rather we can think of it as doubling the number of useful ideas or simply developing new and better ideas. It is common practice in empirical studies to estimate a "stock" of knowledge based on the flow of new knowledge through research and an estimate of depreciation on existing knowledge.

7 More technically, increasing returns to scale can also give rise to problems because of the possibility of non-existence of a competitive equilibrium – or the existence of multiple equilibria, some of which will be inferior (in terms of efficiency) to others.

- the legal and regulatory environment;
- the state of technology; and
- the characteristics of both imitators and knowledge creators.

If knowledge is not perfectly excludable, others can benefit from the knowledge other than the creator. The knowledge "spills over" to others – a positive externality. This outcome is good from a social point of view, because the benefit to society as a whole outweighs the loss of potential economic rents the creator could have made from keeping the knowledge to herself (because knowledge is non-rival). However, the creator's ex post inability to capture enough of those rents will diminish the incentive to invest in developing knowledge in the first place.

Neither perfect excludability nor perfect non-excludability is likely to result in the socially optimal outcome

An important insight then is that while excludability solves one of the problems of knowledge (giving creators of new ideas an incentive) it generates another one by restricting the dissemination of knowledge. Consequently, neither perfect excludability nor perfect non-excludability is likely to result in the socially optimal outcome. Thus there is a fundamental tension between incentives to create knowledge and incentives to disseminate it.

In the New Zealand context, this discussion should also consider that the majority of world knowledge is created abroad. For example, strengthening excludability in New Zealand (eg, through IP rights) could increase incentives for New Zealand firms to innovate, but could also make it more difficult for New Zealand firms to make use of innovations developed overseas.

Other characteristics

Knowledge is also characterised by a dependence on past knowledge, by uncertainty, and by long lags before practical application

A number of other characteristics of knowledge have been discussed in the literature, including the cumulative nature of knowledge, uncertainty, and lags.

Non-rivalry and non-excludability are sufficient to create the possibility of economic problems around knowledge. However, other characteristics of knowledge may add to the risk of suboptimal investment in knowledge production and dissemination. Below we briefly summarise the issues raised.

The Cumulative Nature of Knowledge

An important feature of knowledge is that it is an input not only into the production of *final* goods like pharmaceuticals and software, but also into the production of further knowledge. As Sir Isaac Newton famously said, "If I have seen far, it is by standing on the shoulders of giants".

The cumulative nature of knowledge adds further to the (increasing) returns to investment in knowledge. It is another channel whereby new knowledge can benefit society and the overall benefits may be large, long-lived and widely dispersed across the economy (Nelson, 1959). In turn this increases the risk of under-investment in knowledge creation given the difficulty of identifying (and recouping costs from) the beneficiaries. It also implies that benefits are likely to be difficult to predict in advance, which adds to *uncertainty* around knowledge production.

Uncertainty and Lags

Both the production and distribution of knowledge are subject to considerable uncertainty and long time lags. By definition, firms involved in knowledge creation do not know exactly what they are attempting to produce, how best to achieve it, or even whether or not they will succeed. Similarly on the demand side, consumers of knowledge may not understand exactly what they are buying until after it is purchased. For these reasons, investment in knowledge creation is a highly risky undertaking and this may make it difficult to attract private funders, particularly when the project is closer to basic rather than highly applied research.

The presence of uncertainty does not of itself imply market failure, since markets have developed sophisticated contract mechanisms for dealing with risk allocation. However, these mechanisms are imperfect, work less well over very long time periods, and tend to be subject to moral hazard problems (for example, insurance against the risk of a research project not succeeding will adversely affect the researchers' incentives to succeed). Uncertainty may be more problematic in the case of knowledge production than for other types of goods, due to the difficulties of assessing risk, measuring outcomes, and asymmetric information (Tisdell 1995). It is also likely to be particularly acute for basic research that is primarily an input into further knowledge.

Evidence on knowledge spillovers

The empirical evidence is quite consistent in showing that social rates of return to R&D are large and typically significantly higher than private rates of return

The most widely studied aspect of market failures around knowledge is knowledge spillovers from R&D, as measured by the social versus private returns to R&D activity. The private returns accrue to the specific firm that undertook the R&D, whereas the social returns additionally include returns to other firms throughout the economy. These studies are quite consistent in finding that:

- the private rates of return to R&D are high; and
- the social returns to R&D are higher than the private returns.

Good reviews of the empirical evidence can be found in Weiser (2005), Cameron (1998) and Griliches (1992). Estimates of private rates of return to R&D generally fall in the 20% to 30% range. Studies of the spillover benefits from R&D on average yield estimates of spillovers that are around two times higher than private rates of return – thus giving total social rates of return (private returns plus spillovers) in the order of 90% to 100% (Weiser, 2005; Cameron, 1998; Griffith, 2000)[8].

The important point from a policy perspective is not the size of the private or social returns in isolation, but rather the difference between them

The most important point from a policy perspective is not the size of the private or social returns in isolation, but rather the difference between them. The source of any difference is attributable to spillovers - one of the main potential sources of market failure identified earlier. These spillovers and their large size suggest that the marginal social benefit to more R&D is higher than the marginal social cost.

While some investigators have questioned these results and cited contradictory findings, on balance the majority of the literature points in the direction of significant spillovers from R&D. After surveying measurement difficulties associated with observing R&D and its impact, Hall (1996) nonetheless states in her conclusion that there is "overwhelming evidence that some positive externalities exist for some types of R&D".

Institutional and policy responses to the challenges of knowledge creation versus dissemination

Societies have developed a range of policies and institutions that at least partly overcome the tension between knowledge creation versus dissemination

The characteristics of knowledge outlined above – non-rivalry, together with a varying degree of non-excludability and other features such as uncertainty – suggest the possibility of market failures around knowledge, including spillovers and tensions between ex-ante incentives for creation and ex-post incentives for diffusion. Moreover, the empirical evidence of large spillovers from R&D indicates that these failures and consequent underinvestment in knowledge could be quite severe.

Given the importance for economic progress and human wellbeing of knowledge and innovation, it is not surprising that societies have developed policies and institutions that at least partly overcome the potential market failures associated with them. These include:

Intellectual property rights (IPRs) – while these incentivise knowledge creation they do so at the cost of giving monopoly power over the use of something that actually costs nothing (because knowledge is non-rival) for another firm or consumer to use. To limit this cost, IPRs are typically circumscribed. For example patents are time limited (perhaps 10-20 years), require the holder to publicly disclose the nature of the invention, and do not permit excluding others from using the knowledge to conduct further research.

[8] An interesting side point is that most studies suggest that spillovers *between* industries are important as well as those *within* industries.

Subsidising open science – the incentive to create knowledge under open science is the recognition and status of being the first person to make a discovery. This recognition requires laying out research results in a very public way (i.e. publication). Status also accrues to scholars in relation to the number of citations to their published work. This provides an incentive for making discoveries that others will find interesting and useful for further research. The downside of open science is the cost of funding it (usually by the taxpayer) and the risk of weak incentives on researchers to ensure their work is sufficiently relevant to yield high social returns.

Public subsidies for private R&D – these usually come in the form of tax concessions or grants to firms that undertake R&D. The primary motivation for these subsidies is that they compensate firms undertaking R&D for the spillover benefits that accrue to other firms.

Direct government purchase of research – the government purchases research directly either by choosing among offers from potential research providers or through direct funding of research organisations. Sometimes the government uses this research to help it provide goods and services such as military and civil defence, environmental protection and public health services. In other cases - mainly basic research - the new knowledge is published according to the norms of open science. In still other cases, the rights to the intellectual property created are assigned to the research provider to exploit commercially.

Prizes for inventors – Governments or private benefactors have sometimes offered large prizes to the first person to come up with a solution to a particular problem or challenge. The discoverer receives the prize in exchange for the solution being made widely available. A famous example of this was the British Admiralty's offer in 1714 of a large prize to the first solution to the problem of determining longitude - critical for accurate marine navigation. The prize stimulated much ingenious research and building of devices and was eventually awarded to John Harrison. He worked along quite different lines to the scientific orthodoxy of the day by inventing an extremely accurate ship's clock or chronometer.

The concept of a national innovation system

The concept of a 'national system of innovation' is useful for identifying strengths and weaknesses in how knowledge is created, disseminated and commercialised in an economy

Much current public policy analysis of innovation is informed by a body of work that uses the concept of the 'national system of innovation' of a country. This concept is a useful complement to market-failure analysis. The emphasis is on the non-linear character of innovation, and how it happens within a system of interconnected organisations, firms and people - both public and private - in which feedback loops, complementarities and cumulative causation are features.

Studying New Zealand's national system of innovation can help to identify strengths and weaknesses across a range of aspects. It can indicate how the institutional infrastructure that forms the national innovation system influences the production, accumulation and diffusion of knowledge. It can uncover opportunities for beneficial changes in the roles and interactions of the government, research organisations, entrepreneurs and firms. The concept is useful in bringing out the key role of firms in the successful commercialisation of knowledge.

Smith (2006) notes the typical characteristics of innovation processes as:

- *non-linear*, in that research-business links are most effective when they exhibit strong feedback loops;

- *pervasive*, since innovation typically occurs right across the economy, in low-tech as well as high-tech areas, and so policies should support both developments;

- *involves specialisation,* as firms invest in capabilities and intangible assets that support innovation. The resource commitments involved are risky and exhibit path dependence;

- *cumulative,* with learning over time and the accumulation of knowledge and skills by firms leading to patterns of industrial specialisation, but also with resources being locked into particular technologies and associated infrastructures; and

- *collaborative,* in that, for innovating effectively, firms require interactions with the science system and within industry clusters over long periods.

Smith then defines the main functional processes of an innovation system. He argues that successful innovation systems are characterized by institutional arrangements (which may differ significantly across countries) that take care of five broad problems:

- **identification of innovation opportunities** – innovation opportunities are rarely obvious and often represent a complex interplay between government, businesses, financial systems and research infrastructures. Exploiting opportunities is not usually an automatic market process but something an innovation system may handle well or badly;

- **the creation and distribution of knowledge capabilities** – this is much broader than R&D, it includes non-R&D inputs to innovation and the distribution of knowledge via relationships, intermediaries, people mobility, and education and skills;

- **business finance and development** – commercial success depends on far more than a good idea. Ability to develop and finance a business rests on complementary assets such as management capability, a conducive financial system, logistical and marketing capabilities, including the ability to operate internationally;

- **risk and uncertainty management** – risk and uncertainty are inherent in innovation. A basic problem is the mismatch between the shorter time horizon of profit-seeking firms and their investors, and the longer time horizon of most research endeavours. The system needs mechanisms to bridge this important gap; and

- **infrastructure provision** – much innovation is infrastructure dependent, either physical infrastructure (e.g. a broadband network) or knowledge infrastructure (e.g. a university system). Infrastructures are typically expensive both to create and operate and they pose problems whether these are undertaken by the private or the public sector. Knowledge infrastructures perform increasingly important functions with respect to innovation – they create knowledge, they store and maintain knowledge, they help create new enterprises, and they support innovation-related problem solving.

Using this framework, Smith concludes that:

- Given the systemic nature of innovation, coordination failures and means of overcoming them are important. System failures might occur in the joint use of infrastructure, the transmission of knowledge, or in the disruption caused by new technologies. Coordination can occur by institutionalising a market to perform the needed function, or the use of an administrative process.

- New Zealand is not unlike other small, open, economies (eg, Finland, Norway, Denmark, and Canada) that have based their development paths on "the sustained development of both upstream and downstream linkages" from their low or medium tech resource-based industries. The implication is that New Zealand should leverage off its equivalent industries and support the process of technological upgrading. He notes that in Scandinavian economies the emergence of linkages and "development blocks" did not just happen, but was organised.

Innovation and the firm

Firms must be centre-stage in order to meet the challenge of using innovation to significantly lift New Zealand's productivity

The challenge for the New Zealand economy is to improve its productivity performance. This can really only happen if New Zealand firms produce more higher-value, higher-skill-intensive, more-knowledge-intensive goods and services. Innovation is a major part of this process. It is about firms introducing new technologies, processes, and goods and services. It goes beyond the R&D undertaken within the firm or in public research institutions, and requires the successful commercial application of new knowledge. Arguably the relative weakness in New Zealand's innovation system is in the last of these components. To deal with it requires a "change of gear" from investigator-led R&D to market-led innovation. This is no simple task, and requires firms to have a range of internal capabilities.

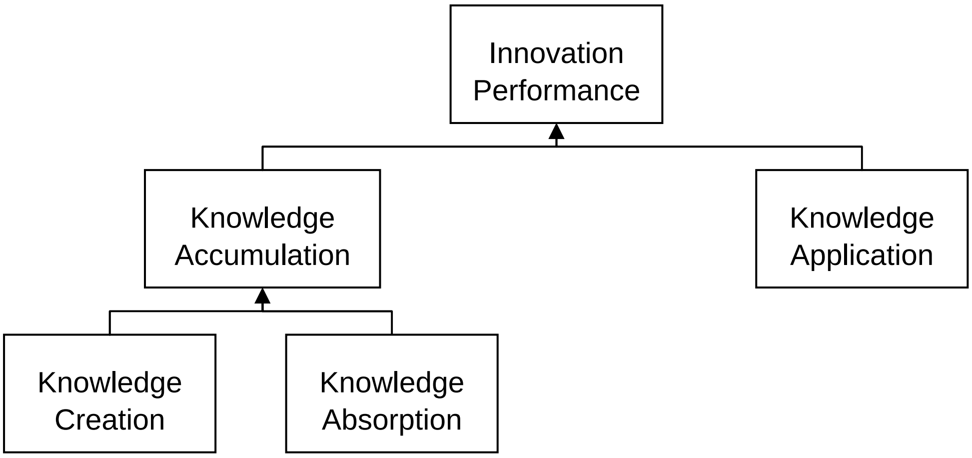
Fabling and Grimes (2006) investigated data from the New Zealand Business Practices Survey 2000, and found that innovation-related activities are central to improved firm performance, particularly through capital investments in up-to-date technologies, R&D practices, practices that reward employee performance and market research.

A useful way of thinking about the role knowledge plays in innovation is to consider what processes drive a firm's innovation performance (and ultimately productivity), and the factors that influence each of these processes. This discussion is not intended to be exhaustive, and does not cover in any depth the incentives that entrepreneurs face to innovate arising from product market competition, regulation and access to skills and finance. These are covered in greater depth in other papers in the series.

Innovation at the firm level depends on creating, absorbing, and applying knowledge

Figure 1 below sets out the drivers of a firm's innovation performance: the ability to accumulate knowledge and the ability to apply that knowledge, where knowledge can be accumulated by either creating new knowledge or absorbing existing knowledge. These different processes are discussed in turn below.

Figure 1 – Firm-level processes that drive innovation



Knowledge creation

Knowledge creation is the firm itself coming up with new ideas. The most obvious method of knowledge creation is formal R&D, defined by the OECD's Frascati Manual as follows: "Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications." (OECD 2002). However, firms can also create knowledge informally, such as through on-the-job idea generation. Factors influencing knowledge creation within the firm will include the amount of R&D it performs, the effectiveness/efficiency of that R&D, the firm's internal capabilities, and incentives for informal innovative activity.

Higher productivity firms tend to have strong internal capabilities. These include having a skilled workforce, and being good at adopting newer technologies, applying improved organisational and management practices, and generating and managing knowledge. Greater investment in these complementary inputs puts firms in a better place to produce innovative goods and services and increase productivity. However, these internal capabilities are difficult to acquire and take time to develop. As a consequence, a firm's whole history of choices about technology, skill and internal organisation have an enduring influence on its ability to upgrade. Despite new firm entry and exit of old firms, this constrains dynamic change. In addition, wide productivity differentials between firms in an industry will slow the rate of diffusion of innovations across firms in the industry.

Knowledge absorption

Most knowledge is created outside any particular firms so the internal capabilities of firms to absorb this knowledge are critical

Absorption is important because the vast majority of new knowledge is created outside any particular firm. Firms may be able to apply some external knowledge immediately, but in most cases they will require internal capabilities to (a) find knowledge that has been created elsewhere, (b) make sense of it, and its applicability to the firm, and (c) adapt it to the New Zealand context in a commercially viable form. Sources of knowledge outside the firm include universities, Crown Research Institutes, other domestic firms, and overseas sources.

New Zealand's 2003 innovation survey found that the three most important sources of ideas for firms' innovation were businesses within the same industry, customers and suppliers

The Statistics New Zealand Innovation Survey 2003 found that the three most important sources of information and ideas for firms' innovation were businesses within the same industry, customers and suppliers - perhaps because these groups are the most likely sources of information about recent innovations, consumer preferences and demand, and information about new inputs. In contrast, the survey found that universities and other research institutions were much less important sources.

New Zealand's productivity growth will be improved by accelerating the rate at which our firms catch up to the global technology frontier

For a small country like New Zealand, the majority of world knowledge is created outside of the country – for example, less than 0.2 percent of OECD R&D expenditure occurs within New Zealand. Our productivity growth will be improved by accelerating the rate at which New Zealand firms catch up to the global technology frontier. New knowledge (in the form of innovative products, technologies, and business practices) can flow from overseas to New Zealand firms through a range of channels such as trade, investment and people flows, and as "embodied" knowledge, such as through imported capital equipment (DeLong & Summers, 1991). However, this knowledge transfer does not happen quickly or completely, and is impeded by our distance from overseas sources. Taking steps to help firms locate, adapt and absorb knowledge from abroad therefore offers opportunities for improving technology catch-up.

Knowledge application

Finally, knowledge application is the process of using accumulated knowledge to create value for the firm, through commercialisation of a new good or service, or implementation of a new production technique for example. This process is by no means trivial, and is likely to require different capabilities to those involved in knowledge creation or absorption such as entrepreneurship, good business management, marketing skills, and so on.

Studies of individual firms provide valuable insights into how firms innovate successfully, and why some do and others stick to their old ways

Mason (2005) is a study of firms and their search for high value-added production. It takes an in-depth look at the factors influencing innovation by firms in four UK industries. The main factors motivating firms to move to high-value-added production were the higher profit margins available, and the opportunity to avoid the intensity of competition associated with lower-value-added products. However, firms faced barriers in moving up-market through capital constraints, market uncertainty and skill deficiencies, with the relative importance of these varying sharply between industries. Mason found that movement towards higher value-added products was incremental. Firm responses reflected a strong degree of path dependence, flowing from past choices about physical, human and organisational capital in the firm.

Other studies add further flesh to this picture of how innovation actually takes place at firm level. A European project explored in some depth how innovation occurs in low- to medium-tech (LMT) industries[9]. The case studies in this project highlight a number of characteristics of innovation in such industries. Innovation in production or distribution activities is usually incremental. Improvements are often driven by technology developments by upstream suppliers, or by downstream adjustments needed to meet customer requirements, or by the needs of distribution systems. External knowledge held by upstream or downstream organisations plays an important role in triggering product or process innovations. This requires relatively close coordination, networking and communication amongst firms.

LMT firms are also typically characterised by limited or no independent R&D capacity. The processes of innovation are therefore significantly influenced by the practical knowledge and experience of firms, the processes of learning by doing and using, and the capacity to recognise and utilise external knowledge. Even for successful LMT firms, it is a process of continuous development and customisation. But others, lacking capability or will or both, tend to stick to their previous low-productivity paths.

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9 The project findings are described in Hirsch-Kreinsen (2005)

Recent innovation performance presents a mixed picture

Many New Zealand firms and industries lag their counterparts in other countries in productivity

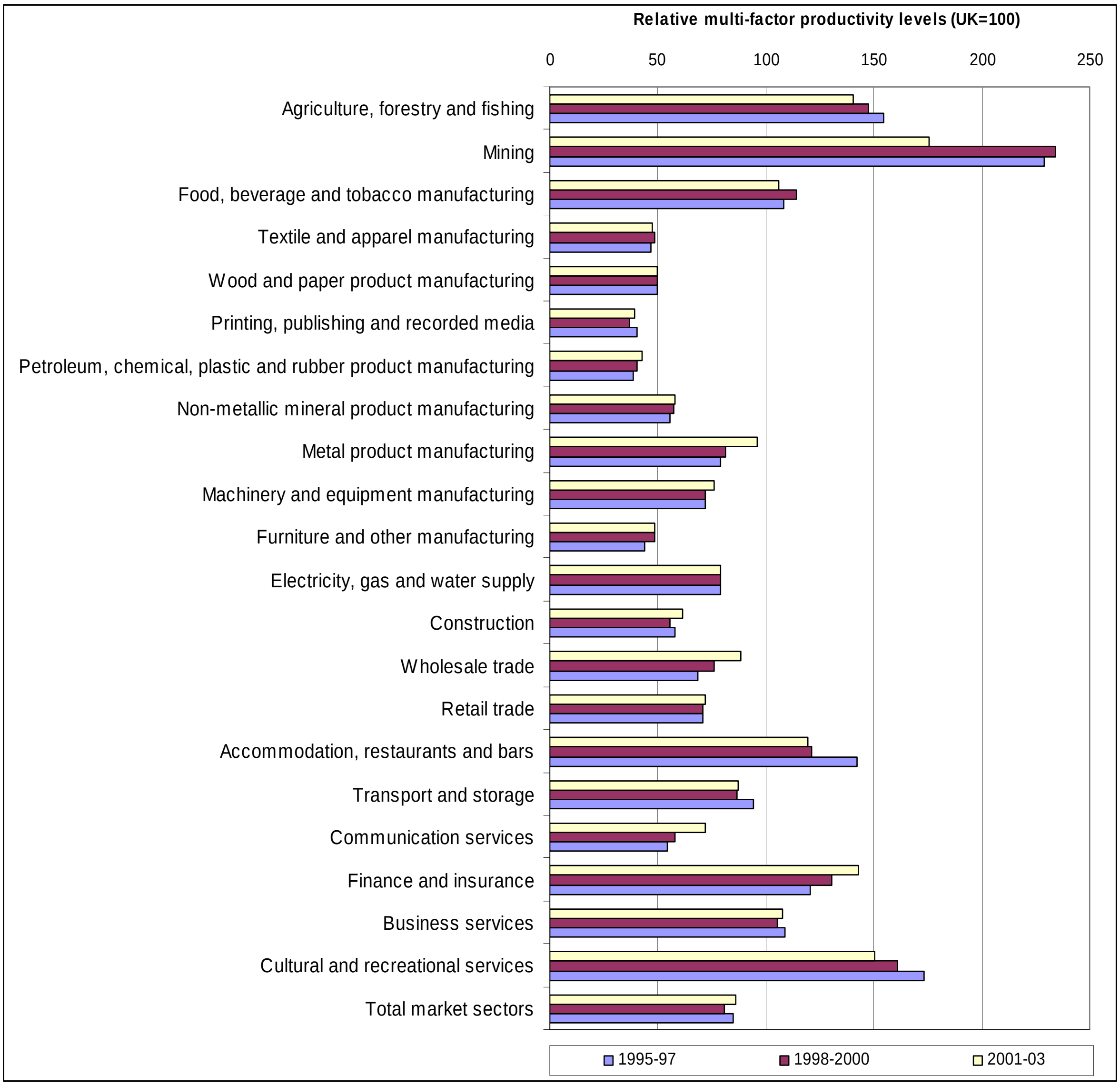
In a study for the New Zealand Treasury, Mason and Osborne (2007), gathered information on productivity levels and growth rates in 21 specific industry sectors and compared them with corresponding sectors in the UK. In turn it is possible to make comparisons with a wider set of countries by drawing on a separate study comparing similar sectors in the UK, France, Germany and the United States (Mason et al, 2006).

From an innovation perspective, we are interested in multi-factor productivity (MFP) not only because it is a rough proxy for innovation but also because our analysis leads us to the view that levels of MFP are critical to the level of investment in capital equipment. And we know not only that low capital intensity is a secondary cause of lower output per worker but also that New Zealand firms are comparatively capital shallow.

While there are some measurement concerns in the study (particularly for the agriculture, forestry and fishing sector), there is a reasonably clear general picture: New Zealand is ahead of the UK in MFP levels in 7 sectors but behind in 14, sometimes substantially so (e.g. by more than 50% in a number of manufacturing sectors). Figure 2 shows the ahead and behind sectors over several recent time periods. It should be noted that the UK is itself a middling productivity performer within the OECD.

This mixed picture of sectors fits with the overall statistic of New Zealand's low aggregate MFP compared with most OECD countries. Moreover, Osborne and Mason estimate that only a quarter of the overall difference in aggregate labour productivity compared to the UK arises from New Zealand's employment composition being weighted towards sectors with comparatively low value-added per employee such as agriculture. The other three-quarters of the gap is accounted for by lower within-sector productivity differences mostly driven by lower MFP within these sectors.

Figure 2 – Relative multi-factor productivity (MFP) levels in market sectors, New Zealand/UK, 1995-97, 1998-2000, 2002-04 (Index numbers: UK=100, Three-year averages)



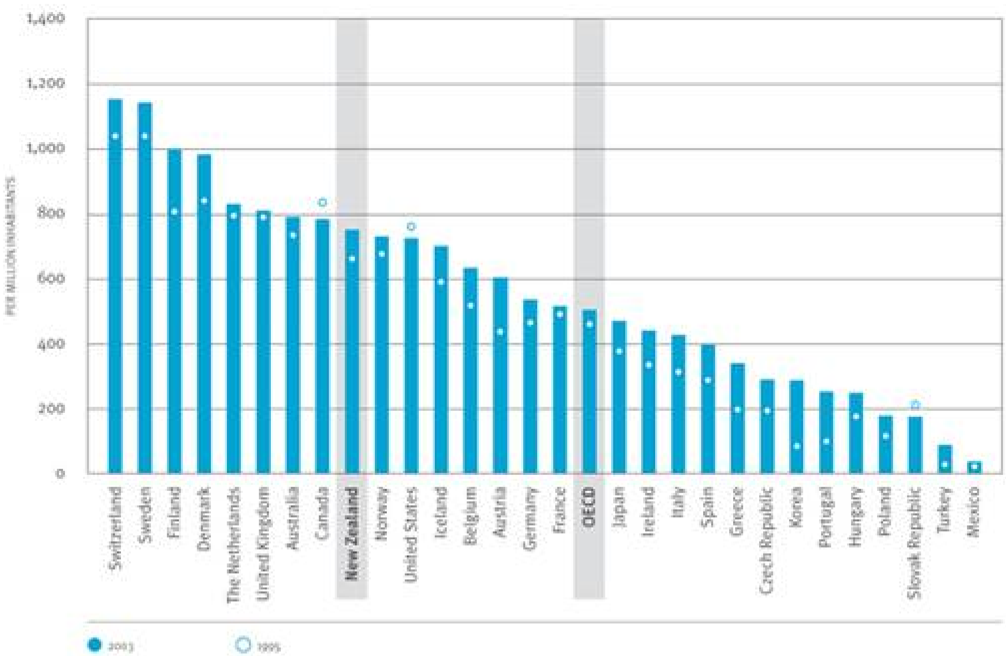
Notes: Estimates are shown as three-year averages on a calendar year basis.

While New Zealand has a good science and research base its record on business R&D and successful commercialisation is much weaker

When it comes to statistics focused more specifically on knowledge and innovation, the mixed picture continues - with a bias towards plenty of room for improvement particularly in the successful commercialisation of good ideas.

New Zealand's wider innovation framework is considered sound, such as policies around competition and firm dynamics, and the infrastructure for public research investment[10]. New Zealand has a strong research base: it is ranked 9th out of 23 OECD countries for the number of science and engineering articles per million inhabitants (figure 3) and is ranked 7th in the number of researchers per 1000 people employed. Business R&D has been increasing rapidly; it grew at an annual rate of 7% from 1995 to 2004, much faster than Australia, the UK, the US and the OECD average (figure 4), and 52 per cent of firms report some form of innovation, comparable to other OECD countries.

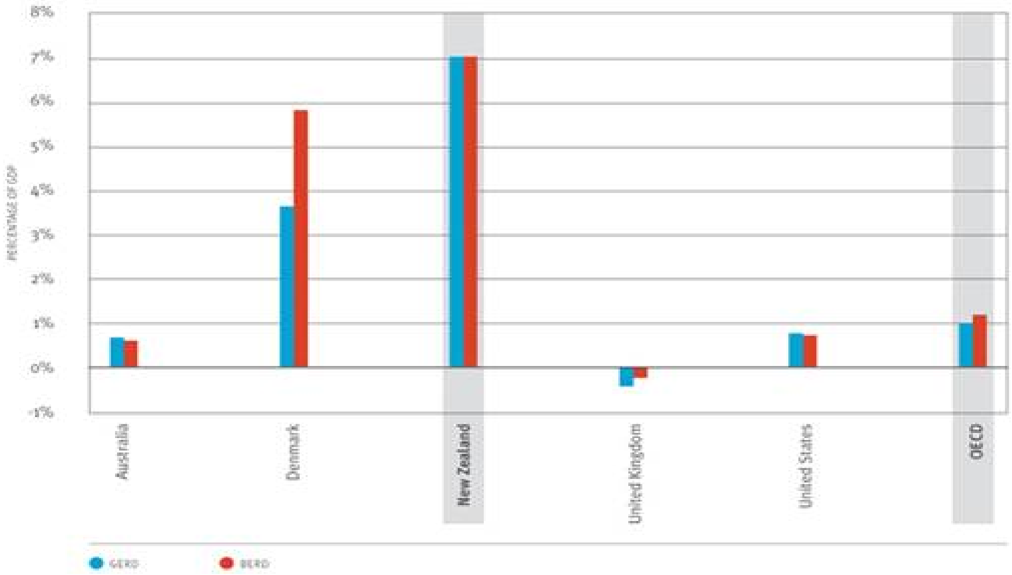
Figure 3 – Science and engineering articles per million inhabitants, 2003



Source: OECD Science, Technology and Industry Outlook 2006, Table 38

10 OECD Reviews of Innovation Policy: New Zealand, 2007.

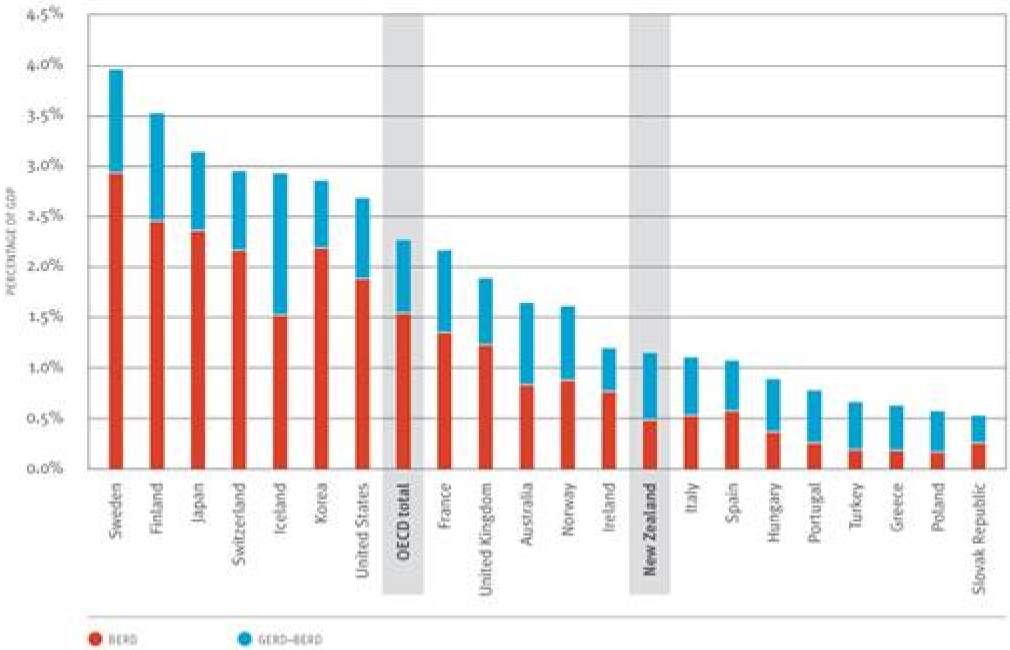
__Figure 4 – Average annual growth of GERD and BERD (selected OECD countries 1995-2004, or latest year available)__



Source: OECD Science, Technology and Industry Outlook 2006, Table 38; NZ data from Ministry of Research, Science and Technology, A Decade in Review

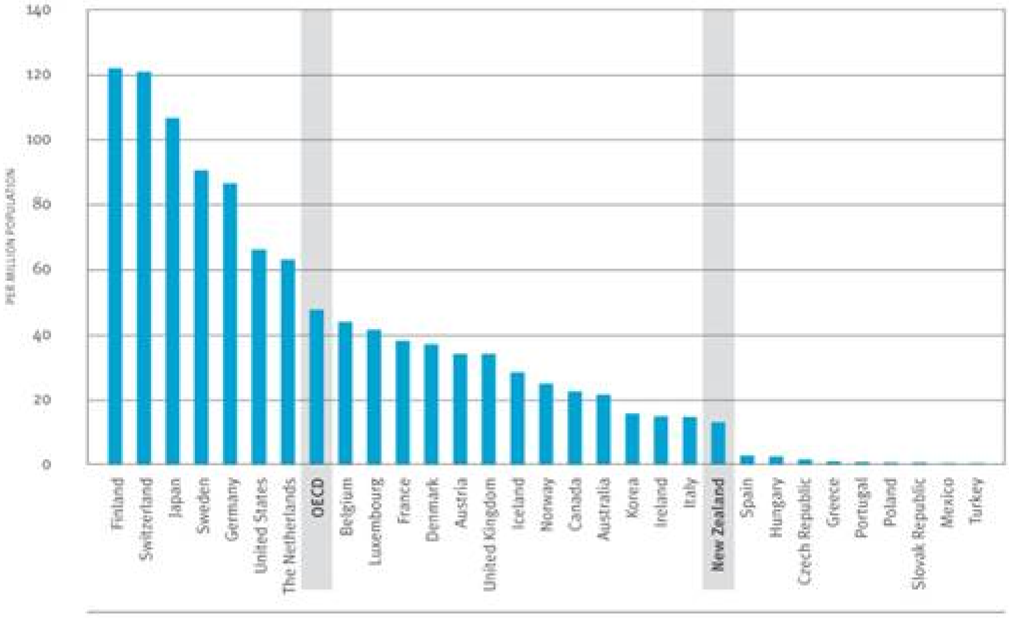
However, despite recent growth, business R&D is still very low by international standards at 0.49 per cent of GDP compared to the OECD average of 1.49 per cent (see BERD in figure 5) and the number of patents per million inhabitants is low (figure 6), suggesting that commercialisation of the research base is a challenge.

__Figure 5 – Research & Development as a percentage of GDP, 2004__



Source: OECD in Figures 2006–07, page 40

Figure 6 – Patents per million population, 2003



Source OECD Science, Technology and Industry Outlook 2006, Table 30; NZ Treasury database; MED calculation

A corollary of low business investment in R&D is that New Zealand's public R&D expenditure is a high proportion of total R&D spending. It is therefore important to get good returns from that investment. This will depend on the effectiveness of public research institutions and knowledge exchange with the private sector. It also requires the alignment and prioritisation of investments made in research by government agencies and consistency in business assistance to firms.

Networking and collaboration play an important part in innovation. Commercially valuable innovations often do not arise in isolation, but develop out of collaborations between firms, customers, suppliers, employees, universities, government research institutes and other players. The quantity and quality of such linkages are vitally important to the effective functioning of the innovation system as a whole.

Linkages within the innovation system are hard to measure but are vital to its effective functioning

Linkages within the innovation system are difficult to measure accurately. One measure is the level of R&D financed across sectors and borders. On this measure, the private sector funded 17.5 per cent of CRI's research in 2005 – this is a high figure by OECD standards but does not tell us how well the bulk of CRI research is meeting industry needs. The level of R&D financed from overseas is low compared with the OECD average, and businesses finance only a low percentage of R&D carried out by universities.

Policy implications for innovation and productivity

To improve productivity performance, New Zealand – the government, entrepreneurs, firms and research organisations – needs to work to achieve a high-performing innovation system and 'national system of learning'. The focus of the innovation system is to create and disseminate knowledge that is taken up by firms and turned into new profitable, higher value-added goods and services. This can be either *product* innovation or *process* innovation – both of which can raise productivity. The role of a national system of learning is to assist New Zealand firms become smart technological followers absorbing and applying relevant knowledge from wherever it is most productive to do so – domestically or internationally.

There have been a number of reviews in recent years of innovation in New Zealand and there is a large degree of overlap in their conclusions

In the past few years in New Zealand, a lot of policy thinking on innovation and some significant policy changes have taken place. In 2006 Treasury conducted an 'In Depth Review' of innovation policy and practice and the Ministry of Economic Development undertook a 'National Innovation System' project. Ministry of Research, Science and Technology policy work focused on a number of topics including 'more stable funding', 'road maps' to set clearer directions for public research, science and technology (RS&T), and human resources for RS&T. In 2007, an OECD review of innovation in New Zealand was released. While there was not complete unanimity in the conclusions from these reviews, there was a large degree of overlap. The directions for change recommended below are a Treasury view, but they also reflect this quite broad consensus that has emerged.

Recent changes such as the R&D tax credit and the appointment of a 'Minister of Innovation' are likely to have a significant positive impact over time

Some significant changes have already been implemented or are underway. Taken as a whole these are likely to have a significant positive impact over time on New Zealand's innovation and productivity performance. These changes include:

- introduction of a broadly available R&D tax credit for private firms from 1 April 2008;
- introduction of 'research application' performance indicators for CRIs that increase their incentives to choose research projects and transfer the findings to users in ways that achieve strong economic impact;
- switching a portion of FRST-funded research from a contestable bidding process to a more negotiated approach (a positive impact will depend on the new system generating strong applied research programmes, productive collaborations across research groups and close links to users);
- appointment of a single Minister in November 2007 to the portfolios of Economic Development, RS&T and Tertiary Education creating in effect New Zealand's first 'Minister of Innovation'. Under this arrangement, the three policy and three delivery agencies within these portfolios are now

working in a more cohesive and coordinated way to define and achieve a common set of priorities for the innovation system; and

- a move to better align government investment across education and training; research, science and technology; and business and market development towards six 'areas of focus' in the economy (the proposed areas are pastoral systems, environmental solutions, advanced foods and derivatives, health solutions, smart materials, and digital content and tools).

Key areas for future policy to focus on include incentives, a supportive wider environment, further enriching links in the innovation system and improving its governance, supporting firms to locate, adapt and absorb knowledge from abroad, and coordinating public investments to support 'areas of focus' in the economy

Given New Zealand's current performance and these changes on the way, the key areas on which future policy should focus in order to achieve high-performing systems of innovation and learning (that will help raise productivity) are in our view:

- Ensure as much as possible that incentives (both market ones and government-influenced ones, and both carrots and sticks) encourage entrepreneurship, and knowledge creation and dissemination. Examples of these are the terms the government sets when it funds research, effective evaluation and reviews of research programmes, and product-market and other forms of regulation that facilitate a dynamic economy.

- Keep in mind that innovation occurs within a wider context, and that some factors could still present barriers, for example:

  - uncertainty about returns to innovation – for example through regulations or exchange-rate volatility;

  - innovators require a large market to gain good returns from the high fixed costs of innovation and this necessitates exporting (given New Zealand's small size); but distance makes exporting so early in a firm's life-cycle a big challenge;

  - strong competitive pressure that drives firms to innovate to survive may be lacking owing to small market size and New Zealand's isolation;

  - capital-market underdevelopment is likely to make it difficult for young, innovative firms to access both funding and advisory services; and

  - inadequate broadband infrastructure may affect some firms and limit opportunities for innovation.

- Further improve links in the innovation system to promote knowledge exchange between firms and public research organisations. Stronger links can be expected to improve research relevance, and the dissemination and take-up of research results. Mechanisms that help to achieve better links include funding mechanisms, research partnerships, co-funding arrangements, people mobility and effective intermediaries (for example industry associations and training organisations)

- Develop ways to help firms to locate, identify, adapt and apply knowledge from overseas that will lift their productivity. While many international knowledge flows take place as a natural consequence of trade, investment and people mobility, evidence shows that they attenuate with distance i.e. New Zealand's isolation puts it at a disadvantage. There is case for government to take a more active role. A current proposal is to use the international networks of NZTE and FRST, and their expertise in business support and technology transfer to develop a trial scheme. This should also draw on the experience of other countries that have deliberately pursued international knowledge transfer such as Finland and Chile.

- Build on the recent move to appoint a single 'Minister of Innovation' by continuing to improve the joint governance of the central-government innovation agencies. Key areas for improvement include:

  - Joint priority setting;

  - More effective collaboration and joint working towards these priorities;

  - Reduced fragmentation in the system e.g. in the number of programmes (the 'product clutter' problem). The large number of small agencies, centres and establishments may also be a matter of concern in causing complexity, and lack of coordination and critical mass;

  - More effective use of programme appraisal and evaluation; and

  - Development of an 'Innovation Policy Statement' that would provide a clear over-arching description of the innovation system, clarify the roles of the various players, describe the various policies and programmes, and set out key priorities and targets for improvement over a medium-term horizon.

- Continue to support recent efforts to identify areas of actual and potential strength in the economy so that public investments in R&D, education/skills and support for firms to innovate and internationalise is concentrated in these areas. The idea here is that these different investments will complement and reinforce each other in a virtuous circle of higher private investment, higher productivity, and higher returns.

- Support firms to upgrade their capabilities to absorb and exploit knowledge, use more advanced skills and, where appropriate, to internationalise. This area includes helping lower-productivity firms lift their game by adopting best-practice (effective operating and dynamic routines within firms, using external sources of knowledge, adjusting production systems, improving supply chains and marketing, using more skilled workers to take up new technologies, and upskilling the existing workforce). In the end, in order to raise productivity by a significant margin, New Zealand needs a large number of firms to raise their performance through smart new product offerings, better technology, more skilled workers and improved organisational, knowledge-management, marketing and human-resource practices.

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