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The Economics of Knowledge: What Makes Ideas Special for Economic Growth?

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Summary

Knowledge is a key driver of long-run economic growth...

Innovation is a key driver of long-run economic growth and depends on the accumulation and application of knowledge. Knowledge can be thought of as a type of instruction or recipe that sets out how a good or service can be produced. Unlike standard economic commodities, knowledge has a number of special characteristics. 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 an 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.

...but markets alone may fail to deliver the best outcome for society...

These characteristics together create the potential for markets on their own to fail in delivering the best outcome for society. Specifically:

- 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; and
- there is a tension between providing incentives to create knowledge, and encouraging knowledge to be made widely available after it has been created.

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. Overseas studies suggest that New Zealand's small size may reduce the returns to R&D investment, while distance from the technology frontier may increase them.

...suggesting a role for government in specific interventions.

A variety of institutions and policies have evolved to address potential problems around knowledge creation and diffusion, including intellectual property rights, open science, subsidies for private R&D, and subsidising the supply of human capital. All of these interventions have costs and risks as well as potential benefits: the key questions thus become (1) what are the estimated costs of different policy options, relative to their benefits, and (2) how does the current situation sit relative to the socially optimal levels of knowledge creation and diffusion?. This paper is intended to provide a basis for further and more detailed analysis of specific policy proposals, with a view to improving New Zealand's innovation performance and raising its rate of sustainable economic growth.

Contents

Introduction

Innovation and technological progress are widely recognised in the economics literature as key drivers of long-run economic growth. 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.

The special characteristics of knowledge raise a number of issues and challenges for government policy.

Policymakers therefore need a rigorous understanding of the everyday concept of 'knowledge'. But as we shall see, ideas are different from other types of goods. The special characteristics of knowledge raise a number of issues and challenges for policy. In particular, the benefits of a new idea are often experienced much more widely than simply by the person who came up with the idea. How does this affect the incentives for someone to spend time and energy creating an idea in the first place?

The current paper is the outcome of an internal Treasury project, the motivation for which was twofold. First, the importance of knowledge and innovation for long-run growth suggest the need for a thorough understanding of the underlying economics of knowledge. And second, New Zealand does not perform particularly well on some key indicators of innovation in the economy; in fact, innovation is one of the few underlying areas where we look weak (Economic Indicators Report, 2005). It was hoped that a better understanding of the theoretical and empirical literature around knowledge would provide a sound basis for further policy work on innovation, both within Treasury and across the wider public sector.

The paper begins by proposing a working definition of knowledge. We then discuss the main economic characteristics that this definition of knowledge entails and the possible problems (ie, market failures) that may arise as a consequence. Following this, the paper goes on to explore the linkages between knowledge, innovation and R&D, and looks in some detail at the empirical evidence on private vs social returns to R&D and what this evidence suggests about knowledge spillovers. Finally, we conclude with a discussion of broad policy implications.

It should be noted that the approach taken in this paper is to focus on knowledge from a firm's perspective – ie, to look at how knowledge is created and used by firms as an input to production. This reflects the intent to consider the importance of knowledge through an economic-growth lens.

Definition of knowledge

Knowledge can be thought of as a type of instruction or recipe that sets out how a good or service can be produced. It is an input to a firm's production function.

A complex concept like "knowledge" is difficult to define precisely. However, based on our reading of the literature, the most useful working definition for the purposes of this paper is that *knowledge is a type of instruction or recipe* that sets out how a good or service can be produced (see, eg, Jones 2004). Such an "instruction" should be interpreted broadly – it could be a blueprint for a particular good, a method of providing a particular service, a generic production process or organisational structure, and so on.

According to this definition, knowledge is effectively another resource that a business can use in production, alongside physical capital, labour/human capital, and other inputs. Knowledge can then be interpreted as contributing to how productive the other inputs are.

Note that a physical good such as a computer is not knowledge under this definition, even though everyday usage might refer to it as 'technology'. However, it certainly depends on knowledge, in the sense that it was constructed according to a particular set of instructions or recipes (for example, the design of the computer chip, the chemical formula for the plastic etc).

While this definition of knowledge does not capture every characteristic of knowledge that we may think is important, it does capture many of the features that are important from an economic perspective, and that make knowledge different from other types of goods[1]. These characteristics are discussed in the next section.

Before proceeding, it is worth clarifying the distinction between knowledge and innovation. The easiest way to separate them is that innovation is a process whereas knowledge (as defined here) is a "thing" – an idea, instruction or recipe. Put another way, innovation is "the successful development and application of new knowledge" (OECD, 2005), which covers both the creation of knowledge/ideas, and the application of these ideas to develop and implement new products and processes. The relationship between knowledge and innovation is discussed in more detail later in the paper.

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1 Another economically important form of knowledge that we ignore in this paper is "knowledge" that is not an input to production but something that people consume directly. The cleanest examples are pieces of music, film, games software or text in digital form. Such examples share similar characteristics to sets of instructions or recipes and differ similarly from ordinary consumer goods such as wine and clothing. With the rise of digital technology such goods are becoming increasingly common and important in the economy.

Characteristics of knowledge

Using the definition of knowledge as an instruction or recipe, we can now turn to look at some of the key characteristics of knowledge, and the possible 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 (described below) and the potential for knowledge spillovers (or externalities). In turn, these suggest that markets on their own may be insufficient to achieve the optimal outcome for society in terms of resources devoted to knowledge production and dissemination.

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 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.[2]

Increasing returns to scale can create problems for a competitive market to reach the best outcome for society. In a competitive market, the price of a computer chip would reflect the prices of all the standard inputs, leaving nothing left over to compensate the idea.[3] In this case, few ideas would be produced because their creators would not be rewarded.[4]

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2 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.

3 In economic terms, competitive equilibrium requires that factors are paid their marginal products – but if we pay all the standard rival factors their marginal products, this exhausts the sales revenue from a unit of output, so that nothing is left over to compensate the idea (non-rival) inputs (Jones, 2004). An alternative is monopoly pricing but this also leads to lower overall welfare, relative to the social optimum.

4 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.

Fixed and marginal costs

Another way to understand how non-rivalry leads to increasing returns to scale is to tackle things from the cost side. First we need to keep in mind that increasing returns and average costs that decrease with the scale of output are two sides of the same coin. Then we note that a non-rival idea costs resources (often significant resources) to create for its first use but subsequent uses are possible at zero marginal cost, since it can be simultaneously used by many people or firms. An initial high fixed cost and low constant marginal costs generate decreasing average costs or 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. Similarly, if human capital is needed as an input (eg, only trained scientists can understand and implement the design from the blueprint), this also has a cost and is rivalrous. In order to double production, we would need to double the amount of capital, unskilled labour and the number of trained scientists. But we still don't need to double the actual knowledge (ie the design), which is non-rival[5].

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. In its purest form, 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);
- the legal and regulatory environment;
- the state of technology; and
- the characteristics of both imitators and knowledge creators.

5 Note that just like knowledge, a rivalrous good (for example, a machine) will also require resources to "transmit" (eg, to transport and install), and may require complementary inputs like human capital to make use of it (eg, in the form of trained operators). The key difference is that there is a marginal cost for the use of a machine (ie the opportunity cost of denying its use elsewhere), whereas there is no such cost for the use of an existing bit of knowledge.

It is important to note that theorists in the economics of knowledge do not assume that all knowledge is non-excludable, and this assumption is not necessary for knowledge to create problems for a free-market outcome. For example, Jones (2002, adapting Romer, 1993), gives some examples of non-rivalrous knowledge goods that are at the "non-excludable" end of the spectrum – eg, basic R&D, calculus – and those that are at the "excludable" end – eg, encoded satellite TV transmission. Similarly, Romer's model actually assumes that ideas are fully excludable in the "application of ideas or blueprints to the production of goods" – but not excludable in the research process. For example, a researcher can acquire patent protection for the design of a new drug, but cannot protect against other researchers using the ideas to develop a new and improved drug design (see Dowrick 2002, p9).

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 the full benefits of new knowledge will diminish the incentive to invest in developing knowledge in the first place.

The right to exclude would give owners of the intellectual property (IP) the ability to charge prices to cover and probably exceed their average costs. But economic efficiency demands prices equal marginal costs. Since the marginal cost of using a piece of knowledge more than once is zero, such prices would then not cover average costs. Thus there is a fundamental tension between incentives to create knowledge and incentives to disseminate it. It is similar to the problem of using competitive market prices to incentivise the efficient production and consumption of public goods and of any "natural monopoly" good whose production is characterised by decreasing average costs. In each case there is no practical ideal way to incentivise both production and consumption at the same time.

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

An important upshot of the above discussion 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.

In the New Zealand context, this policy 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 (also referred to as recombinance), uncertainty, and lags.

In our view, non-rivalry and non-excludability are sufficient to create the possibility of economic problems around knowledge. However, the other characteristics of knowledge listed above 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 establishes 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 underinvestment 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

Both the production and distribution of knowledge are subject to considerable uncertainty. 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, knowledge consumers may not understand exactly what they are buying until after it is purchased (Arrow 1962). For these reasons, investment in knowledge creation is a highly risky undertaking.

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 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). This 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.

Lags

The long lags that are often involved in knowledge production and use may further exacerbate the problems discussed above. For example, the length of time between commencement of a research project and production of usable knowledge may increase the risk and uncertainty associated with investment in knowledge creation. Also, the fact that there may be a long lag – perhaps decades – between the development of a body of knowledge and a particular application adds to the difficulty of identifying and recouping costs from the beneficiaries.

Knowledge vs human capital

A distinction that may be worth clarifying is that between "embodied human capital" – ie, the skills and abilities possessed by people – and "knowledge" – the accumulated stock of ideas themselves, which may be embodied in people, physical capital, blueprints, scientific texts etc. Both are important for growth, but knowledge is arguably more important for driving long-run growth, and is the main focus of this paper[6].

Although knowledge and human capital can be distinguished conceptually, clearly there are important links and complementarities between them. For one, human capital is an important input into the creation, acquisition and application of knowledge – a more educated workforce is more likely to identify, understand, develop and implement useful new ideas (see Dowrick, 2002). Secondly, possession and understanding of knowledge is one of the defining features of human capital – although not the only feature.

Tacit vs codified knowledge

Another distinction that is often made with regard to knowledge is that of "tacit" versus "codified" knowledge. Like excludability, this distinction may be more of a continuum – Cowan, David and Foray (2000) argue that the set of knowledge that can really not be codified is small. Rather, the decision whether or not to codify knowledge depends on the economic costs and benefits of doing so. A decision to codify is usually made to facilitate transfer of knowledge, and so will depend on the value of being able to undertake this transfer.

Summary

To summarise, the characteristics of non-rivalry and varying degrees of non-excludability that are typical of knowledge create problems for a competitive market system to achieve efficient production and use of knowledge. Non-rivalry leads to increasing returns to scale and a tension (even assuming it is possible to create IP and effectively exclude others

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6 Reasons for supposing that knowledge is more important for driving long run growth are that: (1) the accumulation of human capital has finite boundaries for each individual, due to the limitations of human capacity; and (2) human capital, unlike knowledge, is rivalrous in the sense that each person's time is limited. For both these reasons, human capital is likely to be subject to diminishing returns and is therefore unlikely to sustain productivity growth indefinitely over time (see Dowrick, 2002). However there are clearly important complementarities between the accumulation of human capital and the creation and use of knowledge.

from accessing it illegally) between optimal incentives to create knowledge and to disseminate it. Prices need to be at or above average cost for the former, but must be equal to marginal cost for the latter. Where it is not possible to exclude others from accessing knowledge, spillovers will mean social rates of return exceed private rates with consequent underproduction and inefficiency. As we will see later, any solution that is used in practice is a compromise in the face of the fundamental tension described above.

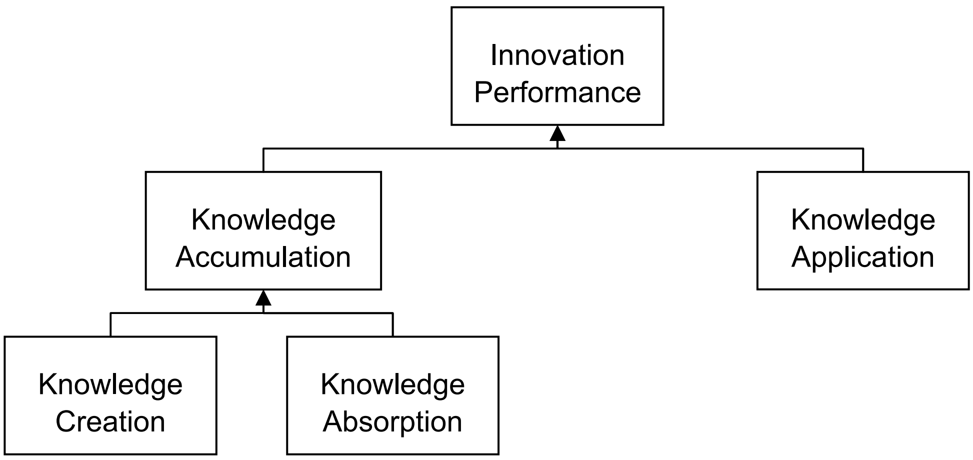
Knowledge, R&D, and innovation

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 what factors influence each of these processes. This discussion is not intended to be exhaustive, but to identify the key features of innovation by firms.

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

The diagram below sets out the drivers of a firm's innovation performance: ability to accumulate knowledge and 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 process of 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 knowledge can also be created informally, such as through on-the-job idea generation.

Factors influencing knowledge creation within the firm will include the amount of R&D being performed, the effectiveness/efficiency of that R&D, the level of human capital, and the firm's organisational structure and incentives for informal innovative activity.

Knowledge absorption

Knowledge absorption is the process of acquiring knowledge from outside the firm, such as from universities, public research organisations, other domestic firms, or from overseas. Absorption is important because the vast majority of new knowledge is created outside any particular firm. In fact, 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.

Firms can apply some external knowledge immediately, but in most cases they will require some internal capability to (a) be aware that it has been created elsewhere, (b) make sense of it, (c) realise its applicability to the firm, and (d) adapt it to the New Zealand context.

Factors influencing knowledge absorption include human capital, R&D capability, linkages with external sources of knowledge (eg, universities, public research organisations, or other firms), and access to "embodied" knowledge, such as through imported capital equipment (DeLong & Summers, 1991). The excludability of existing knowledge – for example, in terms of legal intellectual property protection – will also have an important influence on knowledge absorption.

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 production process for example. This process is by no means trivial, and is likely to require different capabilities to those involved in knowledge creation or absorption – for example, good business management, marketing skills, and so on.

How important is R&D for successful innovation?

Clearly, R&D is not the only driver of innovation performance, nor is it the only mechanism available for creating new knowledge. The importance of R&D relative to other drivers of innovation is an empirical question, albeit a difficult one to answer.

On balance, the evidence suggests that R&D is an important input into innovation, via both knowledge creation and knowledge absorption.

The evidence does suggest, however, that there is a strong link between business R&D and the level of patenting activity[7], which is one widely-used measure of innovation performance and may give some indication of the potential value of new knowledge – if we assume that knowledge with commercial value is more likely to be patented. There is also evidence that business R&D in particular is positively linked with economic growth (eg, OECD Growth Study 2001).

On the other hand, there does not seem to be as strong an association between business R&D and the level of reported innovation in firms – based on survey measures of the proportion of firms that have introduced a new product or process[8]. It is difficult to know how best to interpret this finding however, since the survey measures do not give a very clear idea of the value of the innovations that have been introduced.

As well as being an important driver of knowledge creation, the evidence suggests that R&D helps to facilitate knowledge absorption (see Griffith, 2000). This is presumably because carrying out R&D within a firm (or within a country) leads to greater awareness and understanding of external knowledge, and also increases the capability (eg, through higher human capital) to apply this knowledge.

On balance, we think the evidence suggests that R&D is an important input into innovation, via both knowledge creation and knowledge absorption, but other factors are also likely to be important. R&D also has at least two other features that make it of interest from a policy perspective. First, there are relatively well-established systems for measuring it (unlike more “informal” mechanisms for knowledge creation, which are difficult to measure and compare across countries) and therefore it is likely to be a useful indicator for policy purposes. And second, there is good empirical evidence of spillovers from at least some types of R&D. This evidence is discussed in the next section.

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7 The recent OECD draft WP1 innovation paper reports a cross-country rank correlation of 0.81 between BERD and triadic patents.

8 The recent draft OECD WP1 innovation paper reports that, in general, higher aggregate business expenditure on R&D (BERD) and a greater proportion of firms engaging in R&D are both associated with a greater proportion of firms introducing a new product or process. Note that this refers to products or processes that are new to the firm, which can include both “true” innovations and imitations.

Empirical evidence on knowledge spillovers from R&D

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 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. However, the extent of these market failures is an empirical question.

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 Grilliches (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)[9].

Although the private returns to R&D appear very high, Dowrick (2003) notes that a study by Bernstein and Nadiri (1991) found that private returns to R&D of 20-30% across a number of industries were broadly similar to the private returns to investment in physical capital. This suggests that there may not be a substantial risk premium on R&D investment relative to investment in plant and equipment, and consequently that investment in R&D may be privately optimal at the firm level[10].

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.

In any case, 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. Indeed, Jones & Williams (1998) conclude that even in an R&D-intensive country like the USA, the socially optimal amount to invest in R&D could be two to four times the actual amount invested[11].

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

10 Some studies have found a larger gap between returns to investment in physical capital vs R&D. To the extent that such a gap exists, there are several possible explanations, including systematic risk associated with R&D and finance constraints.

11 This is not to say that the presence of spillovers necessarily implies government intervention is warranted, as there will be costs and benefits associated with any potential policy that need to be considered. These are discussed further in the concluding section of the paper.

There are studies that have questioned the evidence of large R&D spillovers. For example, a recent paper by Diego Comin (2004) argues that econometric R&D spillover studies potentially suffer from omitted variable bias[12]; that is, there are additional explanations for spillovers that are not covered by the studies, making the effect of R&D appear stronger that it really is. Comin presents an alternative approach that suggests investment in R&D in the USA is close to the social optimum.

There are also a number of difficult measurement problems in assessing the private and social returns to R&D. These are well-summarised in Hall (1996), and include: (1) the effect of price index measurement on the measurement of productivity growth; (2) the low variability of R&D spending in individual firms and the difficulties that this creates for identifying the intertemporal aspects of knowledge production; and (3) the importance of R&D depreciation estimates for measuring rates of return.

However, despite the existence of some contradictory findings, on balance the majority of the literature points in the direction of significant spillovers from R&D. There is also no reason to think that the measurement problems associated with studying returns to R&D are necessarily any worse than for econometric studies of other topics. After surveying the measurement difficulties, Hall (1996) nonetheless states in her conclusion that there is "overwhelming evidence that some positive externalities exist for some types of R&D". For these reasons, we think that the most parsimonious explanation for the divergence between private and social returns to R&D found in the literature is that significant spillovers are occurring – although the size of spillovers is likely to vary depending on a number of factors such as the type of R&D, the industry, the degree of excludability (eg, via intellectual property rights), and country-specific factors like size and distance from the technology frontier (country-specific factors are discussed further below).

What are the studies measuring?

It is important to have a clear understanding of what the R&D return studies are measuring. This section provides a descriptive summary, while a more mathematical treatment can be found in the annex. The two key parameters measured are (a) the rate of return to R&D, and (b) the elasticity of output/value-added with respect to the knowledge R&D stock.[13] Empirical studies broadly estimate one of these two parameters, defined mathematically as:

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12 A potential for omitted variable bias could occur if another activity is omitted from the study but is both causally related to productivity increases and correlated with R&D. One example could be human capital: a firm with greater capability to perform R&D is likely to actually perform more R&D. To the extent that studies attempt to control for such effects (as at least some do), the findings will be more reliable.

13 The knowledge R&D stock refers to the cumulative effect of all past R&D less depreciation.

Empirical studies attempt to measure the relationship between R&D expenditure and value-added, measured as either a rate of return or an elasticity.

$$[\text{rate of return}] = \frac{[\text{change in value - added}]}{[\text{R \& D}]}$$

$$[\text{elasticity}] = \frac{[\text{\% change in value - added}]}{[\text{\% change in knowledge R \& D stock}]}$$

The rate of return is the ratio of the change in value-added ("what you get out") to the flow of R&D ("what you put in"). This parameter can therefore be thought of intuitively as a rate of return. The elasticity of output with respect to the knowledge R&D stock gives a measure of the responsiveness of value-added to increases in the stock.

For those studies estimating the rate of return, the "social rate of return" is generally the measured "total" return of increases in productivity at an industry/national/international level for a given increase in aggregate R&D. The "private rate of return" is based on measured increases in productivity at the firm level for a given increase in firm R&D. As alluded to earlier, the important point from a policy perspective is the difference between estimates of the private and social returns. While this gap of itself does not tell us how much R&D should be performed, the fact that the gap as measured in many empirical studies is relatively large suggests that we may be some way below the social optimum.

The majority of studies estimating elasticity show a strong link between the knowledge R&D stock and output, with elasticities of around 0.05–0.10. Given the knowledge R&D stock to output ratio, these elasticities can be converted to a rate of return. Whether it is a social or private rate of return depends on whether output and knowledge stock has been measured at the firm level or the economy-wide level.

Relevance of the empirical literature to New Zealand

An obvious question is to what extent the literature on returns to R&D is relevant to New Zealand. There have been very few studies on the returns to R&D in New Zealand, and the majority of the available studies have been carried out in the USA and some European countries, which are very different economies to New Zealand in some respects. The available New Zealand studies include Johnson, Razzak, and Stillman (2005), who found some evidence of positive spillovers to the rest of the economy from industry R&D, and Scobie & Eveleens (1987), who found high returns to R&D (around 30%) in the agricultural sector[14]. Work is currently underway within Treasury that should provide some more up-to-date findings for the agricultural sector.

Relevant evidence available from cross-country studies gives mixed guidance on whether returns to R&D are likely to be higher or lower in New Zealand. On one hand, Englander and Gurney (1994), in an OECD study

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14 This study looked at returns to agricultural R&D in aggregate without differentiating between private vs public R&D. However around 80% of agricultural R&D over the period covered in this study was public R&D.

of productivity determinants, conclude that the correlation between R&D and productivity growth is weaker in small countries. They interpret this as consistent with the view that large countries benefit from their own R&D, while small countries benefit largely from R&D done elsewhere. This could be because small countries lack the wider capacity to capitalise on domestic R&D – either production capacity, or size of market, or access to other markets.

On the other hand, Griffith, Redding and Van Reenen (2004) conclude that returns to R&D are likely to be larger in countries that are further away from the technology frontier.[15] The intuition is that in non-frontier countries, there is the potential for innovation to generate productivity growth from both "genuine" innovation (ie, knowledge creation) and knowledge transfer (absorption), whereas countries at the frontier can only raise productivity through knowledge creation. New Zealand's productivity is at the lower end of the OECD range, suggesting that this result is likely to be relevant for New Zealand. However, relative productivity may vary between sectors, and some New Zealand sectors (eg, agriculture) are likely to be at or close to the frontier. In addition, New Zealand's low productivity could be partly due to other factors (eg, a lack of economies of scale) rather than a lower level of technology.

Taken together, these findings suggest that New Zealand's small size may act to reduce returns to R&D, while our distance from the technology frontier may increase them. The combined impact of these two factors on returns to R&D is unclear, as is the effect on the gap between private and social rates of return[16].

Policy responses

The potential for market failures in knowledge is reflected in the range of specific institutions and policies that exist.

Most OECD countries (including New Zealand) have adopted a range of institutions and policy options to address potential market failures around knowledge creation and diffusion. As discussed above, the key market failures are spillovers and the competing incentives for creation and diffusion of knowledge. Market failures in turn may, but do not necessarily, justify policy interventions that try to improve on laissez-faire market outcomes.

This paper does not discuss policy options in detail or offer policy recommendations. Rather, it describes some of the main policies that have been adopted by governments and explains the rationale for them within the framework developed in the paper. The institutions and policies discussed use a variety of mechanisms to internalise spillovers and partly overcome the tension between knowledge creation on the one hand and knowledge diffusion and use on the other. None of them is a perfect solution; typically countries adopt a mixture of these approaches and the

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15 The technology frontier is defined as the level of multifactor productivity.

16 The studies discussed here give an indication of how New Zealand-specific factors may impact on overall returns to R&D. It is not clear whether these factors have an effect on the size of spillovers, or whether they impact on private and social returns equally.

policy question becomes one of choosing the best level of each and balance between them.

Intellectual Property Rights

Intellectual property rights (IPRs) include patents, copyright and trademarks. In one sense they simply establish property rights for intellectual goods in the same way as rights exist for ordinary goods and services. By giving the owner (the knowledge creator) the right to exclude others from using the knowledge unless they pay an agreed sum, IPRs generate incentives to create and sell knowledge that will be useful directly or indirectly to consumers.

A problem with IPRs is that they give monopoly power over the use of something that actually costs nothing (because knowledge is non-rival) for another firm or consumer to use. If this power were unlimited, the owner could also inhibit other researchers from using this piece of knowledge as a building block to further discoveries. Given the cumulative nature of knowledge, monopoly power would have very high social costs. For both reasons, IPRs are generally limited in various ways. For example, patents are time limited, they require the applicant to publicly disclose the nature of the invention, and they do not permit excluding others from using the knowledge to conduct further research. By creating a right but limiting it in these ways, patents strike a compromise between knowledge creation and knowledge diffusion and use.

Subsidising open science

The institution of open science involves communities of scholars with a commitment to high standards of research as judged largely by peer review. In turn peer review requires laying out research results in a very open way. The incentive on individual scientists comes mostly in the form of recognition for being the first person to make a discovery, rather than monetary reward. The culture of the community entails great respect for originality and disapproval of any form of plagiarism or lack of acknowledgement of the intellectual precedents of people's own research.

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.

Clearly the features of open science comprise a package of incentives that encourage the creation, use and dissemination of knowledge. On the downside, open science is generally expensive on the public purse or it requires a high level of private philanthropy. Also, because science is often isolated from market signals, there may be limited incentives on researchers to ensure their work is relevant to the needs of society as a whole.

Public subsidies for private R&D

Public subsidies for private R&D come in the form of either tax concessions or grants to firms that undertake spending on research and development. The primary motivation for such a subsidy is that it compensates firms undertaking R&D for the spillover benefits that accrue to other firms. As described earlier in the paper, the evidence is that these spillovers are on average substantial. In the absence of a subsidy firms will tend to under spend on R&D from the point of view of the economy as a whole.

Direct government purchase of research

In many countries, including New Zealand, 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 the knowledge resulting from this research to help it provide goods and services such as military and civil defense, environmental protection and public health services. In other cases, the new knowledge is the fruit of basic research and it 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.

Government purchase aims to encourage the creation of more knowledge than would otherwise occur, and in some cases the funding also encourages dissemination and wider use.

Facilitating links to internalise spillovers

Policy analysts interested in innovation commonly talk about a "national innovation system". This concept emphasises formal and informal networks and other links between the various players involved in knowledge creation, dissemination and use. Where these links exist and are active, spillovers occur and knowledge is more effectively disseminated and applied where it is valuable. The innovation system works better where flows are two-way with feedback loops from users to researchers and vice versa.

Government can undertake various measures to encourage networks and links. For example, it can:

- pass legislation to enable members of an industry to levy themselves for the purpose of funding joint research (the New Zealand legislation is called the Commodities Levy Act);

- fund scholarships and fellowships to facilitate the movement of researchers and research users between firms, universities and public labs and between countries; and

- encourage research consortia by part funding research programmes agreed among a number of partners including research organisations and end-users.

Subsidising the supply of "knowledge workers"

Subsidising R&D at the point of R&D expenditure is subject to two potential problems. First, there is the risk that the government will try and fail to "pick winners". Secondly, attempts to lift levels of R&D too quickly by boosting demand for R&D may simply raise the incomes of the current fixed supply of workers with specialist R&D skills, with little rise in the actual quantity of R&D performed.

Romer (2000) argues that a good way for governments to encourage the creation and use of knowledge but avoid these two problems is to subsidise the key input to these activities namely knowledge workers. This would involve subsidies for the education and training of scientists, engineers, and mathematicians. Romer argues that it is not necessary to require the scientists or engineers to work in research. Economic gains accrue simply by having more people trained in science and the problem-solving scientific method to boost the creation, dissemination and use of knowledge.

Further options

The above options are the most common. But others are possible and have been used – some famously so. For example, the French government effectively combined the patent system with public purchase when it bought the patent rights for photography from inventor Louis Daguerre in 1839 and made them freely available. As a consequence photography spread rapidly.

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. 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. (See Dava Sobel's popular science book "Longitude".)

Foundation policies

In addition to specific institutions and policies around knowledge, a country's broader "foundation" policy settings will have a very strong influence on all innovation processes: knowledge creation, absorption and application. Macroeconomic stability, financial market development, pro-competitive product and labour market regulation, international openness (particularly to FDI), and the level/volatility of the exchange rate all have an important influence on a firm's incentives and ability to innovate. OECD research suggests that these framework conditions are at least as important for innovation as specialised institutions and policies.

Conclusions

Knowledge is a fundamental input to innovation and hence to economic growth. The characteristics of knowledge discussed in this paper – non-rivalry, incomplete excludability, the cumulative nature of knowledge, uncertainty, and lags – suggest the possibility of market failures around knowledge. The key market failures are:

- *Spillovers*. A firm's inability to fully capture the benefits of knowledge creation and absorption is likely to lead to under-investment. Spillovers are likely to be greater where knowledge has broad application and is less excludable.
- *Competing incentives for creation/diffusion*. The often high fixed cost of creating knowledge and the zero marginal cost of use of existing knowledge create a tension between incentives for knowledge creation and diffusion.

The empirical literature provides some support for the existence of market failures, at least in the case of R&D, where quite consistent evidence of spillovers is observed in terms of a large gap between the private and social rates of return. New Zealand-specific evidence is limited, but also finds some evidence of spillovers. Overseas studies suggest that New Zealand's small size may reduce the returns to R&D investment, while distance from the technology frontier may increase them.

The important questions to answer are the costs of different policy options, relative to their benefits, and where New Zealand sits relative to the socially optimal levels of knowledge creation/diffusion.

A range of policy and institutional responses have arisen to address market failures around knowledge, and the main options have been outlined in this paper. It is important to keep in mind however that different types of knowledge will possess the characteristics outlined in this paper to varying degrees (particularly for non-excludability), resulting in a continuum of potential for market failure. The extent to which the characteristics of knowledge lead to market failure also depends on the voluntary actions taken by agents in the innovation system.[17] Finally, government interventions to address problems around knowledge also have costs and risks. The key questions thus become (1) what are the estimated costs of different policy options, relative to their benefits[18], and (2) how does the current situation sit relative to the socially optimal levels of knowledge creation and diffusion?

Overall, the theoretical and empirical evidence outlined in this paper provides a rationale for focusing policy attention on issues related to knowledge and innovation. It also outlines a high-level policy framework for evaluating relevant policy and institutional responses. The paper is intended to provide a basis for further and more detailed analysis of specific policy proposals, with a view to improving New Zealand's innovation performance and raising its rate of sustainable economic growth.

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17 For example, co-operative arrangements between firms to capture spillovers

18 Lattimore's (1997) analysis of the Australian R&D tax credit provides a good example of cost-benefit analysis of an intervention to address market failures around knowledge.

References

Arrow. Kenneth (1962), “Economic welfare and the allocation of resources for invention.” In Richard Nelson ed *The Rate and Direction of Inventive Activity* (Princeton University Press: Princeton).

Bernstein, Jeffrey I. and M. Ishaq Nadiri(1991) “Product demand, cost of production, spillovers, and the social rate of return to R&D.” National Bureau of Economic Research, Working Paper No 3625. <http://papers.nber.org/papers/w3625.pdf>

Cameron, Gavin (1998) “Innovation and growth: A survey of the empirical evidence.” <http://hicks.nuff.ox.ac.uk/users/cameron/papers/empiric.pdf>

Comin, Diego (2004) “R&D: A small contribution to productivity growth.” National Bureau of Economic Research, Working Paper No 3625. <http://www.nber.org/papers/W10625.pdf>

Cowan, Robin, Paul A. David and Dominique Foray (2000) "The explicit economics of knowledge: Codification and tacitness." *Industrial and Corporate Change* 9(2): 211-253.

DeLong, J. Bradford and Lawrence Summers (1991) “Equipment investment and economic growth.” *Quarterly Journal of Economics* 106(2): 445-502.

Dowrick, Steve (2002) “Investing in the knowledge economy: Implications for Australian economic growth.” <http://ecocomm.anu.edu.au/people/info/dowrick/Humcapigrow.pdf>

Dowrick, Steve (2003) “A review of the evidence on science, R&D and productivity.” <http://www.dest.gov.au/sectors/science_innovation/publications_resources/profiles/review_evidence_science_productivity.htm>

Englander, Steven and Andrew Gurney (1994) “Medium-term determinants of OECD productivity.” *OECD Economic Studies,* 22, Spring 1994. <http://www.oecd.org/dataoecd/48/58/33937115.pdf>

Griffith, Rachel (2000) “How important is business R&D for economic growth and should the government subsidise it?” London, Institute for Fiscal Studies, Briefing Note No 12. <http://www.ifs.org.uk/innovation/randdcredit.pdf>

Griffith, Rachel, Stephen Redding and John Van Reenen (2004) “Mapping the two faces of R&D: Productivity growth in a panel of OECD industries.” *Review of Economics & Statistics*, 84(4): 883-895.

Griliches, Zvi (1992) “The search for R&D spillovers.” *The Scandinavian Journal of Economics*, 94 (Supplement): 29-47.

Hall, Bronwyn (1996) "The private and social returns to research and development: What have we learned?" In Bruce L. R. Smith and Claude E. Barfield eds *Technology, R&D, and the economy* (Washington, DC: The Brookings Institution and the American Enterprise Institute).

Johnson, Robin, Weshah A. Razzak and Steven Stillman (2005) “Has New Zealand benefited from its investments in research & development?” Working paper, Department of Labour.

Jones, Charles I. and John C. Williams (1998) “Measuring the social return to R&D.” *Quarterly Journal of Economics* 113(4): 1119-1135.

Jones, Charles I. (2004) “Growth and ideas.” National Bureau of Economic Research, Working Paper No W10767. <http://dsl.nber.org/papers/w10767.pdf>

Jones, Charles I. (2002) *Introduction to Economic Growth* (New York: Norton & Co).

Lattimore, R. (1997) “Research and development fiscal incentives in Australia: Impacts and policy lessons.” Productivity Commission paper presented to the OECD Conference on Policy Evaluation in Innovation, Paris, 26 -27 June 1997. <http://www1.oecd.org/dsti/sti/stat-ana/prod/lattimore.pdf>

Ministry of Economic Development and The Treasury (2005) *Growth through Innovation: Economic Development Indicators 2005.* <http://gif.med.govt.nz/aboutgif/indicators-2005/report/index.asp>

Nelson, Richard R (1959) “The simple economics of basic scientific research.” *Journal of Political Economy*, 67(3): 297-306.

OECD (2001) *The new economy: Beyond the hype: The OECD growth project* (Paris: OECD).

OECD (2002) *Frascati manual: Proposed standard practice for surveys on research and experimental development* (Paris: OECD).

OECD (2005) “Innovation in the business sector.” Draft OECD WP1 Committee paper.

Romer, P. (1990) "Endogenous technical change." *Journal of Political Economy* 98: S71-S102.

Romer, P. (2000) “Should the government subsidize supply or demand in the market for scientists and engineers?” National Bureau of Economic Research, Working Paper No 7723.

Scobie, Grant M. and W. M. Eveleens (1987) “The return to investment in agricultural research in New Zealand: 1926-27 to 1983-84.” Ministry of Agriculture Economics Research Section, Research Report 1/87.

Tisdell, Clem (1995) "Transaction costs and markets for science, technology and know-how." *Australian Economic Papers* 34(64): 136-151.

Weiser, R. (2005) “Research and development, productivity and spillovers: Empirical evidence at the firm level.” *Journal of Economic Surveys* 19(4): 587- 621.

Annex: What are the empirical studies of R&D measuring?

This annex provides a more mathematical description of what the empirical studies analysing R&D actually measure. The rate of return to R&D (ρ), and the elasticity of output with respect to the knowledge R&D stock (β) are defined mathematically as:[19]

$$\rho = \frac{\partial Y_t}{\partial D_t} \qquad \beta = \frac{\partial Y_t}{\partial D_t}\frac{D_t}{Y_t} = \rho\frac{D_t}{Y_t}$$

where Y_t is output (value-added), D_t is the knowledge R&D stock, and t is a time index. The change in the knowledge R&D stock, ∂D_t, is simply the flow of R&D in a given period.

Note that the rate of return is closely related to the "internal rate of return" often used for financial calculations,[20] and the elasticity is a standard measure.[21] Also note that there is a one-to-one relationship between β and ρ, for a given knowledge R&D stock to output ratio.

Studies that estimate the rate of return (ρ) generally use an equation that takes the form[22]

$$d\log MFP = \rho\frac{R_t}{Y_t} + \mu \ ,$$

where $R_t = \partial D_t$, and μ is a time trend. That is, the studies regress the change in MFP against the flow of R&D (as a proportion of value-added).

Studies that estimate the elasticity of output with respect to the knowledge R&D stock (β) generally use an equation that takes the form[23]

$$\log MFP_t = \log A + \beta \log D_t + \mu t \ ,$$

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19 Start with a Cobb-Douglas production function of the form $Y = AD^{\beta}K^{\alpha_1}L^{\alpha_2}e^{\mu t}$, where Y is output (value-added), A is a constant, D is the knowledge stock, K is capital, L is labour, and μ is a time trend. Take the partial derivative of Y with respect to D and solve for β.

20 The internal rate of return calculation solves the following equation for i,

$$0 = -\partial D_t + \partial Y_t + \frac{\partial Y_t}{1+i} + \frac{\partial Y_t}{(1+i)^2} + \frac{\partial Y_t}{(1+i)^3} + \cdots, \text{ giving } i = \frac{\rho}{1-\rho}.$$

21 This interpretation is seen more easily by rewriting the equation as $\frac{\partial Y_t}{Y_t} = \beta\frac{\partial D_t}{D_t}$.

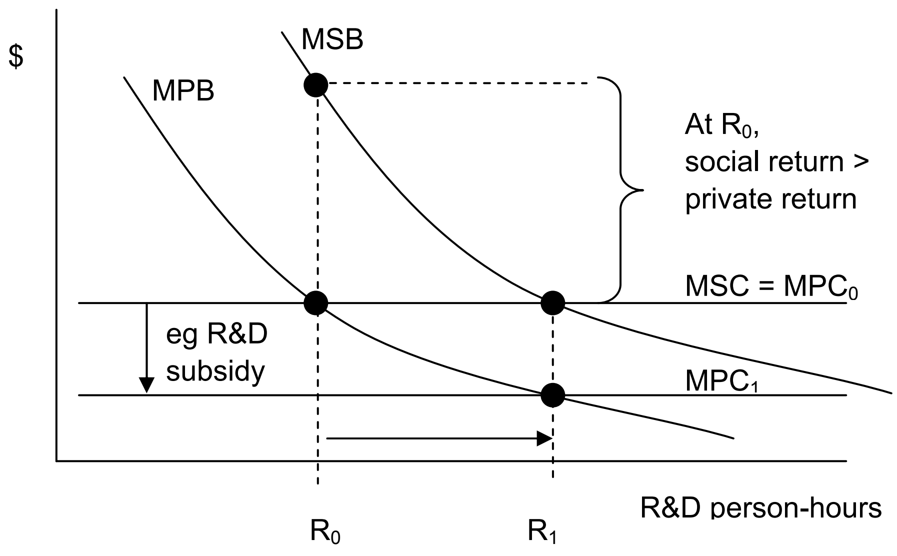
22 Start with the expression for MFP implied by the production function in footnote 19: $MFP_t = AD_t^{\beta}e^{\mu t}$. Take logs and derivatives and substitute the expression for β.

23 Start with the expression for MFP described in footnote 22. Take logs.

where A is a constant. That is, the studies regress the level of MFP against the knowledge R&D stock. Note that in this form, the parameter β can be interpreted as the elasticity of MFP with respect to the knowledge R&D stock.

Studies of the returns to R&D can be illustrated graphically as shown below. The horizontal axis measures R&D activity and the vertical axis measures costs and benefits. The flat lines indicate the marginal social costs (MSC) and marginal private costs (MPC), assuming that both are constant and identical before any subsidy. The curves show the marginal social benefits (MSB) and marginal private benefits (MPB), assuming diminishing marginal benefits and social benefits that exceed private benefits. R_0 is the level of R&D chosen in the absence of a subsidy. The level of subsidy shown in the figure induces firms to increase their R&D hours from R_0 to the socially optimal level R_1 where MSB = MSC.

Figure 2 – Private and social marginal costs and benefits to R&D



Note that empirical studies that estimate the private and social rates of return effectively give the bracketed vertical distance on the diagram above (i.e. the gap between MPB and MSB at R_0). The studies do not show the horizontal distance between R_0 and R_1 – to know this we need an estimate of the shape of the functions. However, the fact that the vertical gap as measured in many empirical studies is relatively large suggests that we may be some way from the social optimum of R&D performed.