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Role of Government and Researchers' Incentives:

Primary Industries Research, Development and Extension

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The Place To Be

Role of Government and Researchers' Incentives: Primary Industries Research, Development and Extension

July 2006

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Foreword

This is the first in a series of technical papers prepared by the Economics & Policy Research Branch that deal with the organization and management of science in the public sector. Dr. Catherine Hollywell, Executive Director of Agriculture Development Division has requested the Branch to undertake research in this area. We acknowledge her on-going support and encouragement for our work.

The aim of technical papers is to assist staff when considering steps to improve the design of departmental systems and to improve the productivity of science in DPI. To improve productivity we need to understand a number of related issues that influence success and the benefits from science.

This first paper by Arthur Ha explains two important concepts relevant to public sector research organisations. The first concept is market failure and it is applicable to broad areas of science activity. This is a valuable filter when considering the role for public involvement. The second concept is of researchers' incentives, the author explains how organizational design features affect the productivity of researchers. This is important because the production of science has important distinguishing features from other forms of economic activity.

This paper, and subsequent papers, represent an important step in applying relevant economic concepts to the production of science by public sector research organizations. Until recently, analysts have not distinguished between private and public sector research or even between routine production activities and creative, innovative economic activities such as scientific research and extension. Understanding the differences and how public sector research contributes to long-term economic growth can help maximize the benefit to society of publicly-funded research. The technical papers will help policy-makers understand the issues associated with maximizing the value of public sector research.

Loris Strappazzon

Lead Economist

Executive Summary

Introduction	This technical paper is designed to explain the economics of research, development and extension (RD&E) of public research institutions. The main motivation is to improve the productivity of public investment in agricultural and natural resource scientific research through improved allocation and appropriate incentives for researchers. RD&E investors and research managers can use this paper to identify problems and possible solutions within their activities.
1. Role of government in research, development and extension (RD&E) (page 2)	The role of government refers to where government intervention can generate the most benefits rather than an ideological principle — it is a question of *investing for the greatest community benefit*.
• *Public goods*	Public goods are goods that are available to every member of the community who want to use it and do not deplete with use (eg, knowledge).
• *Spillovers*	Spillovers are impacts that 'leak' to other economic agents as a result of an agent's actions.
Risk (page 3)	There are two kinds of risk that affects private firms' investment decisions in RD&E.
• *Technical risk*	The first is risk caused by the technical complexity of the research ('technical risk'). Essentially, technical risk is where there is uncertainty about the research outcome given current knowledge and tools.
• *Market risk*	The second type of risk is market risk. This is applicable to private sector RD&E decisions but not to the public sector. Market risk is the uncertainty of revealed demand for an innovation.
• *Risk is higher at the beginning of the RD&E cycle*	Technical and market risk appears to be higher earlier in the RD&E cycle because of the 'cutting edge' nature of the research.

The RD&E cycle (page 4)

The RD&E cycle can be segmented into different 'phases'

- *Basic research*

  The RD&E cycle starts when a researcher observes a natural phenomenon and decides to investigate it.

- *'Proof of concept' or generic technologies*

  The first step to applying basic research findings to technological development involves a 'proof of concept' or generic technologies stage.

- *Applied research*

  If an idea has been demonstrated to have technological applications, researchers are now able to develop the idea further by refining the concept for specific applications.

- *Dissemination*

  The next stage is to disseminate the technology, for example, either through the market (ie, commercialisation) or extension.

- *However, RD&E is not a linear process*

  RD&E is not a linear process but is instead non-linear where different phases may 'feed' off or reinforce each other.

Government involvement is strongly justified at the earliest stage of cycle (page 6)

Government involvement has the most impact at the basic research end where there is greatest potential to produce public good and spillover benefits.

- *Generic technologies may justify government investment*

  Government involvement may be justified at the generic technologies stage because this involves substantial technical risk and may generate valuable economy-wide spillovers.

- *Public investment in applied research depends on a case-by-case basis*

  Both government and the private sector can undertake applied research. However, the extent of government involvement revolves around how much of the expected benefits are public good or spillover in nature.

- *Dissemination by government if there are public benefits*

  If there is no revealed demand (eg, no market for end-users to signal demand) but the technology is expected to generate public good or spillover benefits, than there is a market failure — in this case there is a clear role for government to disseminate the technology.

2. *Why incentives in RD&E are important (page 10)*	RD&E rely on the creativity and training of scientific and technological researchers. However, even the most brilliant scientist could be unproductive if given the wrong incentives. Conversely, average researchers may make significant findings if rewarded for producing good science.
• *Institutional context*	The discussion that follows is all couched within the institutional context of a 'mission-oriented' government agency
• *Multiple principals*	Individual researchers' may be answerable to multiple stakeholders or investors (ie, *principals* in the incentive literature)
• *Multiple tasks*	Another complication to the incentive problem is the *multi-task* nature of research. This causes problems because some tasks may be neglected for tasks that the researchers may consider more important or beneficial for future career prospects
Basic incentive concepts (page 11)	
• *Asymmetric information*	Asymmetric information in the RD&E context is where the researcher has more information than the investor in terms of how to solve a scientific problem.
• *Moral hazard*	The *moral hazard* problem at its most basic level is how does the investor encourage the researcher to spend time solving her scientific problems when the researcher's actions are not observable?
• *Risk and incentives*	Risk and incentives are linked together in how to reduce moral hazard.
• *High-powered incentives*	Incentives are high-powered if rewards are linked to observable output. For example, if project funding was only paid once research results are published.

• *Low-powered incentives*	Conversely, low-powered incentives are rewards that are not linked to observable output. For example, salaries with no performance-linked element.
• *Trade-off between risk and RD&E*	The flip-side of using risk to strengthen incentives is that it may dissuade researchers from undertaking projects where they bear a disproportionate amount of risk.
Multiple principals and multiple tasks (page 12)	Many researchers work in an environment where they are answerable to more than one investor — ie, multiple principals. Researchers' jobs are also multi-dimensional, this may require the individual researcher to make trade-offs between tasks.
• *Multiple principals*	Multiple principals can cause incentive problems by influencing how the researcher allocates their time. For example, government investors may be neglected for industry investors because they may make credible threats to withdraw funding whereas public investors may be unable to do so.
• *Multiple tasks*	Multiple tasks can distract researchers from other essential tasks. This can lead to researchers favouring one type of task over another, especially if the tasks are *substitutes* rather than *complementary.*
• *Multiple principals and tasks*	When considering incentive problems in a multiple principal and task context, the power of incentives need to be considered when understanding the causes of moral hazard.
Potential solutions	We outline some potential solutions to moral hazard in RD&E using our understanding of how researchers behave.
Incentives for disclosure (page 14)	Disclosure can reduce moral hazard by subjecting researchers to rigorous peer review and providing implicit or explicit rewards for disclosure.
• *Rule of priority*	Rule of Priority includes an expectation that new research results should be disclosed as rapidly as possible to subject them to scrutiny. Researchers who have made a significant finding are rewarded through higher esteem among their peers and improved future career prospects.

- *Intellectual property rights (IPR)*

  IPR are useful mechanisms to encourage disclosure at the more applied end of the spectrum, especially applications close to market.

- *However, IPRs require careful design*

  Unfortunately, IPRs provide incentives to pursue research which are closer to market and with less public benefits.The use of IPR in the public sector needs to take account of all these incentives to minimize moral hazard while promoting disclosure.

- *Disclosure can increase the power of project funding*

  Researchers' careers are enhanced if they are allowed to disclose their research results. Projects that allow disclosure not only offer project funding but also an opportunity to enhance the researchers' reputation and career prospects.

Grouping complementary activities (page 16)

Grouping principals with similar interests reduces moral hazard in government agencies. This is because these principals have an incentive to cooperate with each other to align the incentive of the agent with their interests rather than compete for the researcher's time.

Monitoring (page 17)

Monitoring reduces moral hazard through the partial removal of asymmetric information.

Project time horizon (page 18)

A short-term project is desirable to the investor because it limits costs and risks. Conversely, a long-term project is desirable to a researcher because the risk is transferred to the investor and more time is available to complete the project. Moral hazard is more likely under longer-term contracts because the investor effectively 'insures' the researcher's risk.

Credible commitment (page 19)

Credible commitment is when an individual is better off from restraining himself from certain actions. Credibility creates an expectation that the individual would follow through with threats (or promises) which deters moral hazard. An example of credible commitment is when the investor terminates projects that are deemed non-performing according to some pre-determined and commonly understood rule.

Increasing the power of funding schedules (page 20)	The rule of priority can be used by investors to incorporate high-powered incentives into funding arrangements.
Rewards for good research (page 21)	Linking rewards with priority, the investor is able to reward research that has been verified as 'good' by members of the science community. Non-monetary rewards can be used to reward researchers for performance such as tenure of employment, sabbaticals or opportunities to pursue collaborative work.
Summary of possible solutions (page 22)	Most of these solutions use high-powered incentives and credible commitment to solve the moral hazard problem.
Applying incentive theory to Victorian DPI (page 24)	Researchers face competing incentives in a public sector agency with multiple objectives (such as DPI). On the one hand, researchers face high-powered incentives from their external peers to contribute to knowledge production. On the other hand, researchers face less powerful incentives from government to produce policy-relevant research. Also, many researchers also have incentives to seek external funding from external funding bodies (eg, RIRCs) who also offer high-powered incentives.
• *Outcome of this arrangement*	If a researcher is required to seek external funding, more effort would be allocated towards externally-funded projects. However, if external funding is not required, then the researcher is likely to allocate more effort to peer esteemed research over DPI-funded projects.
• *The appropriateness of external funding*	To ensure that researchers' efforts are aligned with government policy it may be appropriate to not require all researchers to obtain external funding, especially those who are engaged in research that generates mostly public benefits.

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1. Introduction

This technical paper is designed to provide a conceptual basis on the economics of research, development and extension (RD&E) of public research institutions. It is the first in a series of technical papers by the Branch in establishing an economic framework for public sector RD&E. The main motivation is to provide an economics framework that could be used to examine proposals on how a public research institution should be organised. The basis of this motivation was in the analysis of Victorian DPI's research and extension. However, we have written this paper in a deliberately general way to focus on the key concepts. This paper examines two basic concepts relevant to publicly-funded RD&E. The first is *role of government*; this is a strategic concept outlining where government can have the greatest impact on RD&E. The second concept is tactical; it is about *incentives* of researchers. This deals with how researchers work and what motivates them. The implications are then drawn out.

2. Role of Government

Should government intervene in RD&E? Or to put the question another way, would RD&E improve if only the private sector undertook it? The role of government refers to where government intervention can generate the most benefits rather than an ideological principle — it is a question of *investing for the greatest community benefit*. Here, we will explain where government can make the most economic impact by investing in RD&E.

2.1. Public Good and Spillovers

For government intervention to be justified on economic grounds, the intervention must be expected to produce net benefits for the broader community, not private individuals. That is, the intervention generates public goods or spillover benefits.

Public goods are goods that are available to every member of the community who wants to use it and do not deplete with use. An example of a public good from RD&E is basic research that is publicly available (eg, through academic journals). Basic research is a public good because the research explains how an observed phenomenon occur and/or what other phenomena influence or caused it. Such research can inform further basic research or technological development that attempts to harness the phenomenon. Basic research forms the knowledge foundation from which new technologies are developed. From this example, the benefits from public goods are the broad-based benefits from disseminating the research to many people. For this reason, private sector firms underinvest in public goods because it is difficult to appropriate all public goods benefits[1].

However, there is a limit to how much public good benefits are generated depending on the 'absorptive capacity' of an economy (Pavitt 1991; Salter and Martin 2001). To access scientific and technological knowledge requires a minimum level of scientific or technological training. To maximise the benefits from RD&E research also requires investment in scientific and technological capabilities.

Spillovers (or 'externalities' in economic jargon) are impacts that 'leak' to other economic agents as a result of an agent's actions. Impacts of spillovers can be either positive or negative. In terms of RD&E, the spillover benefits are usually positive because of the beneficial effects of increasing knowledge, improving product specifications, etc. Spillover benefits do not accrue solely to the innovator because it is difficult to appropriate all the benefits. Because of this, private sector innovators underinvest in RD&E because they are unable to capture the full benefits from their investment. An example is training RD&E personnel which not only enhances their research productivity but also improves their employment value elsewhere. Highly skilled RD&E personnel are more likely to change employers because of greater outside job opportunities. The spillovers are transfer of firm and researcher specific knowledge through the movement of researchers to different organisations (Salter and Martin 2001;

[1] Private firms do invest in basic research to the extent that it improves their RD&E capabilities. For example, AT&T is noted for its basic research capabilities.

Tassey 2005). Research collaborations are also another way of generating spillovers from RD&E (Salter and Martin 2001; Ruegg and Feller 2003). Spillovers are a commonly cited reason for market failure in the science and technology fields. Intellectual property protection mechanisms (eg, patents) correct this to a large extent for technological innovation by turning some spillover benefits into private benefit. But such mechanisms are limited to protecting technology embodied in new products. Furthermore, such mechanisms are not effective in promoting basic research and technological research with public good benefits (David, Mowery and Steinmueller 1992; Dasgupta and David 1994; Navaretti, Dasgupta, Maler and Siniscalco 1996).

The nature of the benefits in RD&E determines if government intervention is desirable: if there are public good and spillover benefits, there is a clear role for government. However, whether government intervention produces net benefits (and its magnitude) depends on the type of intervention.

2.2. Risk — Role of Technical and Market Risk

RD&E is an inherently risky activity more than most economic activities. Essentially, RD&E furthers the boundaries of human knowledge and capabilities. However, the level of risk varies depending on what stage in the RD&E process we are analysing. The level of risk also determines when there exists an economic role for government because high levels of risk can cause market failure (Tassey 2005).

There are two kinds of risk that affects private firms' investment decisions in RD&E. The first is risk caused by the technical complexity of the research ('technical risk'). Essentially, technical risk is where there is uncertainty of the research problem being solvable given current knowledge and tools. For example, Tassey (2005) argues that one of the main reasons for the high failure rate of biotechnology startups is because these firms attempted to leap from basic research findings to product development without developing the generic technologies (eg, production processes) needed to enable applications. This example also highlights a possible market failure: the underinvestment in generic technologies. Generic technologies are technology platforms that form a link between basic research and new products/processes. The reason why there is underinvestment in generic technologies is because there are public good benefits; generic technologies can have applications beyond a firm's commercial focus and so not all benefits from developing generic technologies are appropriable.

The second type of risk is market risk. This is applicable to private sector RD&E decisions but not to the public sector. Market risk is the uncertainty of revealed demand[2] for an innovation. If demand is too low, all the funds sunk into RD&E may not be recovered. This discourages private sector investment earlier in the RD&E cycle because it is unknown what type of applications can be produced from the basic research phase, or early technology development phase. However, as RD&E progresses, more

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[2] Demand is revealed in the interaction between demand and supply through prices. However, not all demand can be revealed such as the public's demand for environmental amenities because the price mechanism cannot be used to coordinate the interaction of demand and supply (Stiglitz 1988).

information on the type of possible applications is generated which allows firms to forecast future demand better (Tassey 2005).

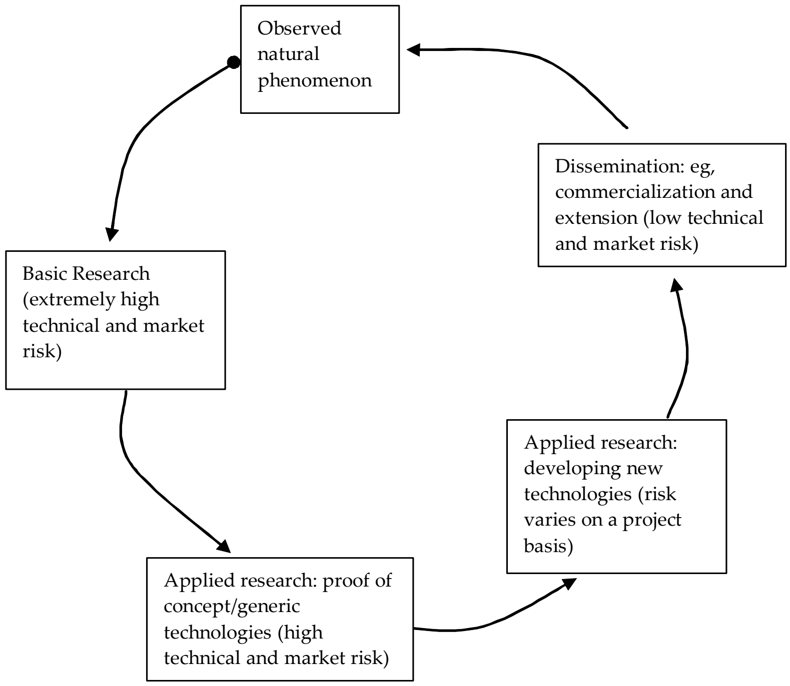
Technical and market risk appears to be higher the earlier in the RD&E cycle because of the 'cutting edge' nature of the research. As a result, this implies that government intervention may be better targeted earlier in the cycle because of the high risk. Conversely, it also suggests that private firms have an incentive to invest in RD&E as technical and market risk declines. When this occurs, there is no need for government to intervene if there are no public good benefits or spillover benefits.

2.3. Science and Technology

The RD&E cycle can be segmented into different 'phases' as shown in Figure 1. The RD&E cycle starts when a researcher observes a natural phenomenon and decides to investigate it. This phase is called 'basic research' because it involves asking basic questions of this phenomenon such as (inter alia) how to define it and what causes it. A classic example of a basic research project is Albert Einstein's Theory of Relativity which became the cornerstone of modern physics and the foundation of numerous applications. This example also highlights the importance of basic research to RD&E efforts that follows. Without the basic understanding of a phenomenon, ensuing technological innovation would not occur. As a result, the benefits from basic research should be thought of in terms of the *option* to exploit technological development opportunities stemming from understanding a given phenomenon rather than as 'knowledge for knowledge's sake'. Notice the public good element of basic research: if such research is publicly available[3], such ideas would spread faster and may trigger more technological development than if such knowledge was proprietary. Basic research is often undertaken by publicly-funded universities and research institutes (although some basic research is carried out in the private sector). Such research is also extremely risky because it is essentially investigating the unknown. As a result of extreme technical and market risks and lack of appropriability, the private sector is unlikely to carry out such research. Furthermore, the payback periods for the research can be very long because at this stage the researchers would not know what applications were possible (Dasgupta and David 1994; Navaretti *et al.* 1996; Tassey 2005).

[3] Navaretti et al (1996) argue that academic institutions incorporate incentives to disseminate knowledge through publicly available journals. This contrasts with the incentives for technological research that promotes secrecy.

Figure 1 The RD&E Cycle



After enough knowledge about the phenomena has been generated, researchers may attempt to exploit this knowledge to develop new technologies. The first step to applying basic research findings to technological development involves a 'proof of concept' or generic technologies stage. An example of a generic technology project was the discovery of electricity (Kay and Llwellyn Smith 1985). This stage is important for demonstrating the application of basic research findings but does not actually generate new technologies for market. This does not mean this stage is dispensable; on the contrary, it is an important phase in demonstrating the viability of a new idea. Both public and private sector researchers undertake proof of concept research. However, the high level of technical risk may discourage private sector investment (Tassey 2005).

If an idea has been demonstrated to have technological applications, researchers are now able to develop the idea further by refining the concept for specific applications. At this stage, technologies could be developed for profit or to fulfil government objectives (eg, military technologies). The level of risk varies between projects depending on the complexity of the technology and whether or not there exists demand for such technologies. At this stage, both the private and public sector develops technologies.

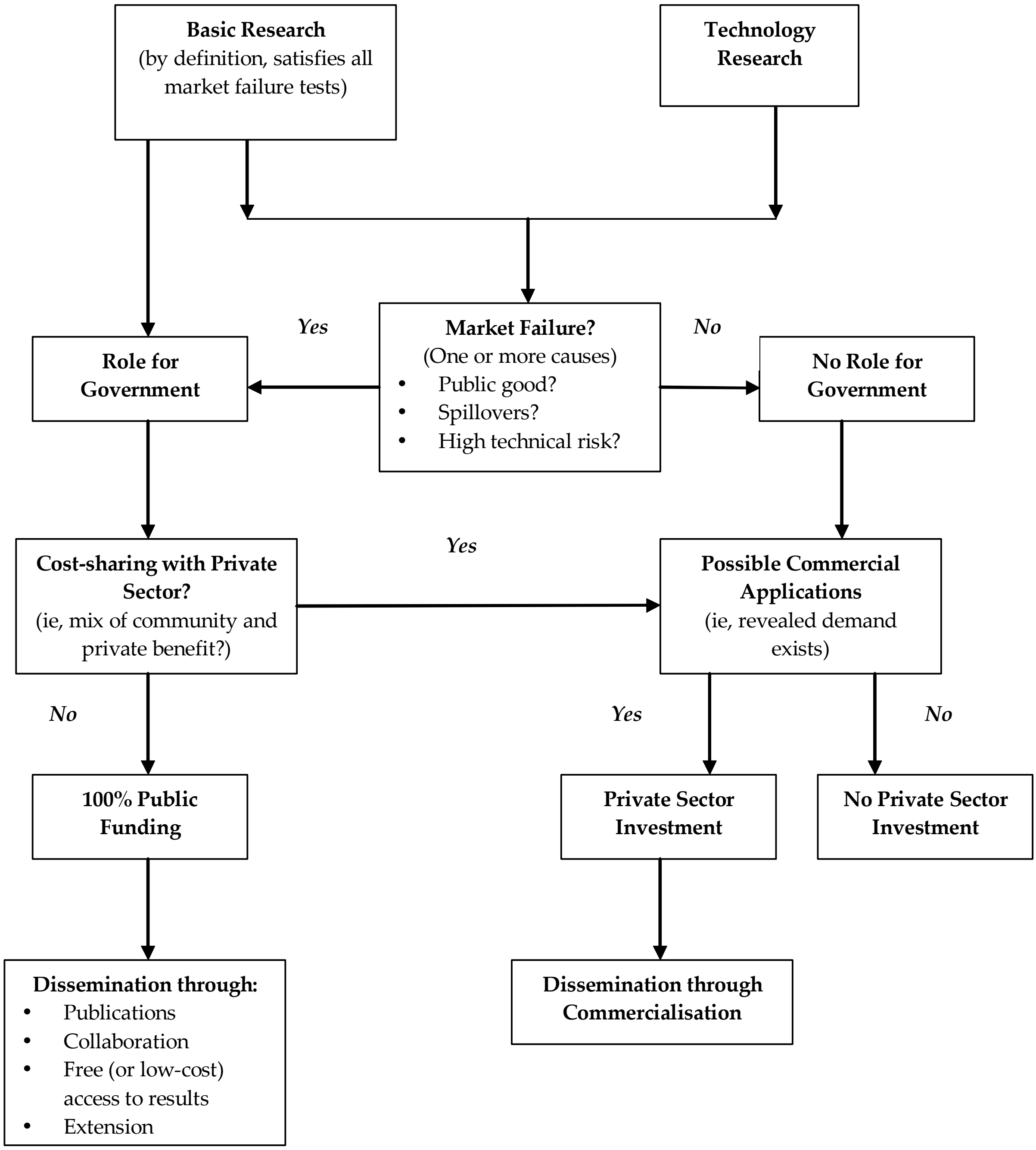
When a new technology has been developed, the next stage is to disseminate the technology, for example, either through the market (ie, commercialisation) or extension. At this point, technical issues are not the problem, market risk is. Much of the economic benefits from RD&E are generated at this stage because if a technology is utilised widely the benefits from reducing production costs, provide more consumer choice, generation of public good benefits, etc are greater the wider the adoption. How it is disseminated depends if demand exists for the technology. If there is revealed demand for such a technology, commercialisation is the obvious means of disseminating such technologies — typically, this is the domain of the private sector. If there is no revealed demand but adoption would produce broad community benefits, extension activities would be appropriate. Extension can be carried out by both the public and private sector (Alston, Norton and Pardey 1995).

From Figure 1, notice the RD&E cycle is drawn in a circular fashion. This is because RD&E is not a linear process but is instead non-linear where different phases may 'feed' off or reinforce each other. For example, the development of a new technology may accidentally discover a previously unknown natural phenomenon. Also, RD&E may proceed on a trial and error basis. Some research paths may encounter 'dead ends'. This is not necessarily a waste of resources if other researchers can draw on this research on which paths to avoid and why; ie, research may yield 'intelligent failures'. Another way technological and scientific research may feed off each other is when scientific research may be unable to proceed unless appropriate technological instruments have been developed (Pavitt 1991). Admittedly, Figure 1 is a gross simplification of the actual RD&E cycle but it does illuminate the relationship between the phases and helps highlight the areas where government can intervene to produce beneficial economic impacts.

2.4. Role of Government in RD&E

From the above discussion it is clear, from an economic perspective, where government intervention in RD&E can have a positive impact and where the private sector has the greatest incentives to undertake RD&E. Government involvement is strongly justified at the earliest stages of the RD&E cycle but diminishes as technical risk declines and/or as benefits become more appropriable. Notice that government intervention is not justified if market risk is high, but technical risk is low. In such a case, the costs and benefits can be appropriable by private firms. Private underinvestment occurs in this case because it is not a commercially valuable investment not because it was caused by market failure. Figure 2 summarises the relationship between the key variables affecting whether or not there is an economic rationale for government intervention in RD&E. Table 1 summarises the outcome of the above discussion.

Figure 2 Relationship of Key Variables Affecting Role of Government in RD&E



From Table 1, government involvement has the most impact at the basic research end where there is greatest potential to produce public good and spillover benefits. This is where the private sector is most unlikely to invest because of the high risk and lack of clear private benefits.

Government involvement may be justified at the generic technologies stage because this involves substantial technical risk and may generate valuable economy-wide spillovers. At this stage, important enabling technologies are developed to advance applied research such as the invention of important instruments and measurement standards — these technologies are called *infrastructure technologies* (or *infra-technologies*). This does not mean the private sector does not have an incentive to invest in generic technologies;

in some cases firms can appropriate benefits from generic technologies (eg, technology standards such as the video cassette recorder standard battle between VHS and Beta). However, there is likely to be an issue of under-investment (or market failure) at this stage because of the high technical risk and the non-appropriable nature of the benefits generated which justifies government involvement in developing generic technologies.

Both government and the private sector can undertake applied research. However, the extent of government involvement revolves around how much of the expected benefits are public good or spillover in nature. Market risk is the main source of uncertainty rather than technical risk — the implication is that technical risk is no longer an economic justification for government involvement. From an economic perspective, the government should not insure market risk since the costs and benefits are private in nature[4]. If there are clear public good and spillover benefits from developing a given technology, there is a clear rationale for government involvement. How much funding depends on how much of the benefit is public relative to the private component. If there is a mix of benefits, cost-sharing is appropriate, but determining the appropriate cost-sharing ratio between government and beneficiaries may be contentious[5]. However, if the benefits are entirely public then total public funding is appropriate. Conversely, if the benefits from a given technology project are entirely private, than there is no need for public funding (see Figure 2).

How a technology is disseminated depends if there is revealed demand for it or not. If there is revealed demand, it is appropriate for private firms to commercialise technologies since the private benefit from doing so provides the firms with the incentives to market the technology. However, the converse does not apply if there is no revealed demand: lack of demand does not necessarily imply market failure. If there is no revealed demand but the technology is expected to generate public good or spillover benefits, than there is a market failure — in this case there is a clear role for government to disseminate the technology.

[4] However, an appropriate response to correcting market failure caused by risk may be to design policies to permit the private sector to supply insurance rather than government supplying insurance (Stiglitz 1988).

[5] Economic valuation of the appropriate cost-sharing ratio can only provide a broad indication, not an exact determination of such a ratio.

Table 1: Role of Government in RD&E

RD&E Phase	Benefits	Sources of benefits	Who should undertake
Basic Research	Public good and spillovers: understanding natural phenomena	Production of basic knowledge	Publicly funded bodies: universities and government researchers
Proof of Concept/Generic technologies	Public good and spillovers: demonstrate possible applications of basic research	Firms and researchers can build on this knowledge to develop applications or other research paths	Publicly funded bodies and private firms
Applied Research – Public Good	Public good and spillovers	From use of technology; augmented by dissemination	Public good: government
Applied Research – Private Benefits	Private Benefit	From use of technology; augmented by dissemination	Private benefit: private sector
Applied Research – Mix of Public and Private Benefits	Mix of public good and private beneftis	From use of technology; augmented by dissemination	Mix: cost-share between government and private sector
Dissemination: Private benefit and revealed demand	Private benefit	Revenue from sale of technology	Private sector firms through commercialisation
Dissemination: Public good but no revealed demand	Public good and spillovers	Use of technology generates public good and spillover benefits	Government extension activities

The summary of the discussion can be used as a filter for allocating public funding (Table 1 and Figure 2). It can also be used to analyse the portfolio of DPI's RD&E projects to determine if the composition of projects needs to be adjusted. The policy implication is that the stage of research, level of technical risk and nature of benefits are important determinants if there is a role for government in a specific RD&E project.

3. Incentives for Research

RD&E rely on the creativity and training of scientific and technological researchers. However, even the most brilliant scientist could be unproductive if given the wrong incentives. Conversely, average researchers may make significant findings if rewarded for producing good science. Incentives are the reward that encourages a desired behaviour. Incentives can also be perverse (or unintentional) by rewarding undesirable behaviour. Incentives can be punishments that act as a deterrent against undesirable behaviour. Finally, incentives can be explicit or implicit. For example, managers of a research organisation may attempt to explicitly promote research excellence but the culture of the organisation may implicitly punish people for 'standing out' through social and professional exclusion.

The discussion that follows is all couched within the institutional context of a 'mission-oriented' government agency (Wilson 1989). That is, the agency exists to solve a subset of society's problems. This means the agency may have multiple, some times conflicting, objectives (Dixit 1997; Burgess and Ratto 2003). This may be from the nature of its portfolio of functions (eg, the former Department of Natural Resources and Environment had both natural resource exploitation and conservation functions) and/or the objectives of its stakeholders (eg, farmers and environmentalists). In terms of RD&E, this means the rationale of maintaining scientific capabilities is to contribute to resolving society's problems using scientific research. What this means for individual researchers' incentives is that they may be answerable to multiple stakeholders or investors (ie, *principals* in the incentive literature — we will use this term to mean stakeholders or investors) and it is within their discretion on how they allocate time between competing objectives.

Another issue that complicates incentive design is the multi-dimensional nature of researchers' jobs, especially the more senior their position. Research is one task that researchers undertake. Fund-raising can be extremely time-consuming depending on the complexity of funding proposals demanded by investors. Administration of projects may be another major task depending on the nature of reporting requirements. Project development requires liaising and researching the problem to define it appropriately in funding proposals. Management of junior staff is an important task in improving a research team's capabilities and the probability of future findings. Furthermore, research is actually a 'bundle' of tasks that may include the use of different scientific disciplines and techniques. Given this description of researchers' jobs, another complication to the incentive problem is the *multi-task* nature of research. This causes problems because some tasks may be neglected for tasks that the researchers may consider more important or beneficial for future career concerns (Dewatripont, Jewitt and Tirole 1999a). For example, researchers may neglect writing their research results for publication because of the need to obtain project funding.

We will discuss how incentives can be applied to public sector research organisations to influence researchers' allocation of time. First, we will describe the basic incentive concepts; specifically the role of information and how that influences researchers' decisions. After we defined the nature of the incentive problem, we will then outline some methods of reducing moral hazard such as harnessing researchers' internal incentives, assigning complementary activities to researchers, monitoring, funding schedules and project time horizons. These first two sections are meant to highlight the relevant concepts required to understand and solve these incentive problems. The last part of this section is to apply these concepts to the case of Victorian DPI to 1) diagnose the problem; 2) examining three different arrangements; and 3) outline a possible solution.

3.1. Basic Incentive Concepts

Researchers, by the nature of their work, are autonomous in their activities from their principals. This means the principals are too remote from the researchers (physically and mentally) to understand if the researcher is allocating enough time to their task. In economics, this difference in understanding over the science process can be seen as *asymmetric information*: this refers to where one side of a transaction (eg, researcher) has more information than the other side (eg, investor). Incentive problems can and do arise in this situation because one party can use their informational advantage to gain some advantage: this broad class of incentive problems is called *moral hazard* (Laffont and Martimort 2002). We will examine this problem in a *principal-agent* framework (Holmstrom 1979; Guston 1996; Laffont and Martimort 2002). The principal (ie, the investor) delegates a task it is unable to conduct to a skilled agent (ie, a researcher). Asymmetric information complicates this problem by providing opportunities for moral hazard.

In this section, we will establish a conceptual framework to first, help define incentive problems, and secondly, assist with reducing incentive problems. We will explain moral hazard in the case of single-task researcher with a single principal. Then we will apply the theory to the more realistic case of a researcher who has multiple tasks and principals.

3.1.1. Moral Hazard in the Single-Task and Principal Case

In a single-task situation, a researcher only has one task and that is to conduct scientific research. Of course, research is actually a bundle of tasks but we will assume that the researcher is only employed for research for one project and not administration, fund-raising, mentoring, etc. Well-designed incentives can encourage the researcher to optimally allocate time (or *effort* in the economics literature) to produce the desirable output[6]. However, when output is only *partially* related to effort, with asymmetric information researchers' allocation of time is unobservable to principals. If a researcher's output level for a task was totally dependent on time allocated, then effort would be observable by observing output. For example, if it was known that 36 weeks were required to produce a scientific finding with certainty and if a researcher failed to make a

[6] Definition of output depends on the institutional context that RD&E is executed in. For example, in the Victorian DPI, outputs are specifically defined in funding agreements. Conversely, in universities, output may be defined by the peer regard of the value of a researcher's findings. Furthermore, output can be defined as a binary value (eg, made finding or have not made finding) or as a continuous value (eg, produced x number of widgets).

finding then it would be possible to claim that moral hazard could be detected by observing what the researcher has delivered. In this case, the investor could design a contract that rewards them only for producing output (ie, link payments to delivered outputs). However, in research it is not possible to state that a scientific finding will take a definite amount of time because researchers are essentially attempting to solve problems that have not been solved before so observing output to determine moral hazard would ignore the risk inherent in RD&E. We mentioned in section 2.2, RD&E can be a risky activity so it is not possible to directly attribute any project failure to lack of time allocated to the task. How does the investor encourage the researcher to apply effort when it is not observable directly or by output? This is the *moral hazard* problem at its most basic level.

How risk is shared between the investor and the researcher can affect moral hazard (Laffont and Martimort 2002). If the researcher bears all the risk of the project, then the researcher is likely to allocate more time. The example of only paying if output is delivered is an example of where the researcher bears all the risk of research — such incentives are called *high-powered*. Conversely, if the investor bore most of the risk for the project, then the researcher is more likely to minimise time allocation — in this case, incentives are *low-powered* (eg, payment of salaries not related to outputs). For example, in the Victorian DPI, researchers bear substantial amount of risk (theoretically) because salaries and other costs (including capital depreciation and maintenance) are funded by project funding, not from a discretionary funding pool[7]. Conversely, researchers would bear less risk if their salaries were paid from a discretionary funding pool because the payment would not be tied to completing projects. In the rest of this section, we will assume that researchers' salaries are paid from project funding.

The flip-side of using risk to strengthen incentives is that it may dissuade researchers from undertaking projects where they bear a disproportionate amount of risk[8]. This means researchers may choose the least risky projects rather than the most technically interesting (and potentially higher value) projects (Huffman and Just 1999, 2000). As a result, risk-sharing decisions between the researchers and the investor may cause a trade off between moral hazard and the value of research (Bardsley 1999).

3.1.2. Moral Hazard with Multiple Tasks and Principals

We will now extend our framework to consider a researcher with multiple tasks and principals. First, we will consider multiple tasks and multiple principals as separate problems. Then we will combine multiple tasks and principals as one problem to consider the incentive for moral hazard.

First, we will consider the problem where there are multiple principals. This situation can arise where a researcher is working on one project with multiple investors. These investors may have different objectives; for example, one investor may be a rural

[7] How much risk researchers bear also depends on how credible the investor is in withholding funds if the project is not delivered (see 3.2.5 for more explanation).

[8] In this paper, we assume researchers are risk-averse. If researchers were risk-neutral, than risk would not be an issue, only expected returns (Mas-Colell, Whinston and Green 1995)

industry research corporation (RIRC) (interested in increasing industry's profitability and productivity) and the other may be a government investor (interested in the public good benefits of RD&E). Having multiple principals can cause incentive problems by influencing how the researcher allocates their time. Principals can influence researchers' time allocation through the rewards they offer researchers. If a principal offered relatively more high-powered rewards than other principals (assuming the rewards are of similar amounts), the researcher would probably allocate more time to that principal (Dixit 1997; Burgess and Ratto 2003). This is because the researcher has to allocate more effort to higher risk activities to receive the reward. Lower-powered incentives, in contrast, do not require the researcher to allocate more time because effort and rewards are not as closely linked as high-powered incentives. As a result, researchers who have multiple principals are likely to allocate more time to the principal that offers the most powerful incentives[9]. Using our previous example of a RIRC and the government jointly investing in a project, a researcher may ensure that all of the RIRC's objectives were achieved in order to secure future project funding while neglecting government objectives.

Multiple tasks can distract researchers from other essential tasks especially if there are differences in incentives. This can lead to researchers favouring one type of task over another, especially if the tasks are *substitutes* rather than *complementary* (Burgess and Ratto 2003). Tasks are substitutes if time used to complete one task takes up time required to complete the other task; ie, they do not contribute to a common objective. For example, researchers may allocate more time to projects than stated in project costing and little to supporting the organisation's on-going activities (eg, science advice to inform policy decisions). In this situation, researchers receive rewards for completing projects but do not receive rewards for supporting the organisation's other functions. Conversely, tasks are complementary if they do contribute to the same objective; ie, time used for two tasks contributes to the achievement of a common objective. For example, developing new projects and publishing research results are complementary in securing future funding. The implication of this distinction for incentive design is that if some tasks have higher-powered rewards, this would perversely encourage researchers to neglect other essential tasks that also contributes to the same objective. In terms of complementary tasks, some tasks may be more measurable than other tasks that contribute to achieving the same goals; for example, completing a research project on time and on budget may be measurable but the benefits from extension may be difficult to measure but they both contribute to achieving some end-user impact such as productivity improvements or producing public goods. As a result, it may make sense to offer a high power reward for completing the measurable task. However, this may have the perverse effect of encouraging researchers to neglect other tasks that may contribute to the overall objective; in our example, the researcher may neglect extension if the completion of the project received a high powered incentive.

[9] Dixit (1997) shows how non-cooperative principals compete for an agent's effort by not only providing higher-powered incentives but deliberately lowering the power of other principals' rewards by insuring the agent. In a sense, this may occur with RIRCs rewarding researchers in the future with future funding.

Now we consider the situation where a researcher has multiple principals and tasks. In this situation, a researcher would be sensitive to differences in incentive power between tasks and principals. Researchers' time allocation problem now becomes more complicated because they have to decide not only which principal or task to allocate more time to, but also have to decide which task for each principal to concentrate effort on. Which task for which principal to concentrate on depends on how powerful incentives are. For example, externally funded projects may have more powerful incentives than government-funded projects. Within each project (externally and publicly-funded) are a bundle of tasks which are explicitly funded by the investor. For example, in Victorian DPI, time spent on research is funded by both the external and internal investor. However, time spent on preparing publication of results in peer-reviewed journals is usually not funded by either investor. In this situation, assuming there were no other incentives that were as powerful as those offered by external and internal investors, researchers would concentrate on research tasks and would neglect publications. This could undermine the benefits from public RD&E capabilities because the dissemination of research results would be implicitly discouraged. When considering incentive problems in a multiple principal and task context, the power of incentives need to be considered when understanding the causes of moral hazard rather than the symptoms. In the rest of this document and subsequent documents in this series, we will assume researchers have multiple principals and tasks.

3.2. Potential Methods of Reducing Moral Hazard

From our discussion in 3.1.2, the potential for moral hazard appears to be strong. Because of the unobservable nature of how researchers allocate effort, there will always be opportunities to engage in moral hazard. However, there are ways to reduce the incidence of moral hazard by utilizing the intrinsic incentives of researchers and by adjusting some elements of projects. In this section we will describe potential solutions to moral hazard.

3.2.1. Incentives for Disclosure: Rule of Priority and Intellectual Property Rights

Disclosure of research findings is important for improving the community's understanding of a phenomena or how to improve the design of existing technologies. Such knowledge (embodied or disembodied) has public good characteristics in terms of having broad benefits for society. Disclosure can also reduce moral hazard by subjecting researchers to rigorous peer review and providing implicit or explicit rewards for disclosure. When scientific research (ie, extending the boundaries of knowledge) is being undertaken, the rule of priority is appropriate because this institution[10] rewards new scientific findings as we will explain below. When technological research (ie, using scientific knowledge to make new products) is being undertaken, intellectual property rights (IPR) is appropriate because it rewards disclosure of how the innovation was

[10] An institution is an implicit or explicit set of rules that establish parameters for acceptable behaviours and incorporates incentives to enforce desirable behaviour. The rule of priority is an implicit institution whereas intellectual property rights are an explicit institution (Navaretti *et al.* 1996).

designed and what science was used. In the following discussion, we will explain why rule of priority or IPR is more appropriate.

The rule of priority is the name for professionally accepted norms of behaviour that scientific researchers have developed to encourage rapid dissemination of research results (Navaretti *et al.* 1996). These norms include an expectation that new research results should be disclosed as rapidly as possible to subject them to scrutiny by their peers. For example, a common method of disclosure is publication of research results in a peer-reviewed journal. The rule of priority also is *incentive-compatible*[11] in the sense that researchers who have made a significant finding are rewarded through higher esteem among their peers (eg, recognition as an expert in their field by invitations to expert bodies) and improved future career prospects. The rule of priority is an implicit set of rules and incentives that is in the background of all research bodies. How research managers and investors design explicit or implicit incentives (that apply to their researchers) could influence the incentive power of the rule of priority in reducing moral hazard.

The rule of priority is a means for the community of scientific researchers to use high-powered incentives to limit moral hazard *and* to disclose research results. Priority effectively transfers 'moral possession' of the findings to the researcher(s) (ie, by attributing and naming the finding after the researcher — eg, Einstein's Theory of Relativity) while also allowing free access to the findings by any one who wants to use it. Furthermore, by publicising their findings and allowing independent verification of their results, priority also enhances their future career prospects by providing a strong indication of their research abilities (Dewatripont *et al.* 1999a).

IPR (eg, patents) are used by many governments to allow owners of beneficial research findings to appropriate some benefits (through royalty fees or exclusive ownership of the findings) from disclosing their research findings (Navaretti *et al.* 1996). IPR are useful mechanisms to encourage disclosure at the more applied end of the spectrum, especially applications close to market. These mechanisms are useful if the benefits can be appropriable through the sale of products that embody such technology. The public good benefits from using IPR is that it encourages the disclosure of otherwise secret research findings. This allows other researchers to build on this knowledge when developing improvements or furthering research. However, it comes at the cost of restraining competition because firms with IPR are granted exclusive use of their findings, and it may reduce overall research.

However, as we argued in Section 2 public sector funding can have the greatest impact in technologies that have public good and spillover benefits. It may be appropriate to use IPR to ensure publicly-funded technology is diffused widely for little or no royalty charges. Otherwise, another researcher may patent this technology without investing any research effort. Given the nature of IPR, using them in the public sector may cause significant moral hazard risks if researchers are allowed to set royalty rates. It is clear

[11] Incentive-compatibility is when rewards (or punishments) that use a researcher's preferences (eg, career concerns) to achieve (or prevent) a desired objective (eg, completion of a project) (Laffont and Martimort 2002).

the researcher is financially better off from charging as high a royalty as possible. This may skew projects away from technologies or science that generate public good and spillover benefits and those that are likely to generate significant commercial benefits. In a public sector research context, IPR can provide incentives for moral hazard by encouraging researchers to spend more time on research that generates IPR at the expense of research that generates public good benefits. The use of IPR in the public sector needs to take account of all these incentives to minimize moral hazard while promoting disclosure. This depends on who owns the IP among other matters.

Moral hazard may mean different things to research peers and investors. The rule of priority and IPR was designed to encourage the disclosure of genuine research results. As such, moral hazard to research peers would be the fabrication of research results (eg, a physicist publishing fraudulent mathematical proofs). To investors, moral hazard would be spending less time on their project than they believe they have paid for. However, incentives for disclosure and investors' objectives are not inconsistent if new scientific or technological research is important to investors. If this is true, investors can then make their projects more attractive to researchers by allowing them to disclose any research findings from the project (eg, through publication); ie, such projects not only offer project funding but also an opportunity to enhance the researchers' reputation and career prospects. In a sense, project funding is *complementary* to disclosure. If novel research is not important, investors could discourage disclosure through confidentiality clauses in contracts. However, this would be at the cost of offering researchers enhanced reputations and improved career prospects. As such, when investors do not want to encourage disclosure, researchers would need to be compensated with more funding. In this case, project funding from this investor is *competing* with disclosure.

3.2.2. Grouping Complementary Activities

As we explained in the above discussion on multiple principals and tasks (3.1.2), multiple tasks for multiple principals are either complements or substitutes to each other. If they are substitutes, moral hazard is likely to occur if the incentive power between tasks and principals differ. On the other hand, if tasks are complements, then provided that no task has higher incentives than other complementary tasks, moral hazard is unlikely to occur (Burgess and Ratto 2003).

Dixit (1997) argued that grouping principals with similar interests reduces moral hazard in government agencies. This is because these principals are better off from cooperating with each other to align the incentive of the agent with their interests. As such, the principals would provide higher powered incentives to the tasks that they jointly consider important. Grouping principals with similar interests reduces moral hazard in government agencies. This is because these principals are better off from cooperating with each other to align the incentive of the agent with their interests. For example, investing for productivity improvements in the grains industry could be done with the Grains Research and Development Corporation and State Agriculture agencies with low risk of moral hazard. However, investment in on-farm technologies to reduce effluent runoff between an agricultural agency, industry investor and environmental agency is likely to have serious moral hazard problems because these three agencies are unlikely to share a common view on what they want to achieve from the project. For example, the environmental agency may desire zero effluent discharge being the goal of the research whereas the agricultural agency may desire lower discharge rates without substantially affecting profitability and productivity. In this situation, the investors may compete between themselves to ensure the researcher achieves their objectives.

Even if investors have similar interests, moral hazard can still occur if individual investors do not agree which tasks are important. For example, investors may have different reporting requirements. One investor may require regular reporting at six-monthly intervals of a non-technical nature, whereas other investors may require more frequent reporting of a more technical nature. Moral hazard could arise with researchers spending more time on tasks that have higher-powered incentives. If such a situation is likely, grouping these similar tasks together could reduce the potential for moral hazard.

3.2.3. Monitoring

One way to reduce the opportunities for moral hazard is to use monitoring mechanisms to improve information on how researchers allocate their time. In universities, peer review is commonly used to monitor researchers (Chubin 1994; Kostoff 1994; Guston 1996; Navaretti *et al.* 1996; Victorian Department of Natural Resources 1999; Ruegg and Feller 2003). Monitoring mechanisms can enhance incentive design (or vice versa) because they can be designed to complement each other. However, depending on the mechanism and the extent of coverage, monitoring may be costly.

Monitoring reduces moral hazard through the partial removal of asymmetric information. In RD&E, this requires the use of personnel who are familiar with the subject matter and methodology to implement properly. This is because the research process and output can only be monitored by fellow researchers due to the technical content. For example, a researcher may deliberately use technical language to confuse a layperson on the value of their project. However, such a deception would be less likely to succeed with a fellow researcher.

Peer review mechanisms are essentially delegating the problem of monitoring to more knowledgeable individuals. It is similar to how investors delegate scientific and technological research to skilled researchers. This delegation has the potential to cause principal-agent problems. Peer review mechanisms can be useful in reducing moral hazard but also need to be monitored or provided with appropriate incentives as well, otherwise the reviewers engage in moral hazard as well (Chubin 1994; Kostoff 1994; Guston 1996; Victorian Department of Natural Resources 1999). One way to do this is by making the results of peer review transparent so individuals who want to challenge decisions can demand an explanation. A researcher who missed out on funding may be one party who has an incentive to challenge funding decisions if they do not follow prescribed rules. More formal monitoring can be used such as parliamentary oversight. For example, in the case of the Advanced Technology Program (ATP), funding decisions are monitored by a committee of the US Congress (Ruegg and Feller 2003).

Transparency of peer review decisions is important to reduce moral hazard through peer review (Chubin 1994).

The benefits of peer review mechanisms may be undermined if there are few qualified researchers that can be used as peer reviewers. This could occur in areas that are emerging research areas such as genomics. The size of the potential peer review pool may give a reviewer the opportunity to determine research direction according to their preferences rather than in the public interest's. For example, peer reviewers may be more risk averse than a government agency may be and so may inefficiently discourage research in risky areas (Just and Huffman 1992; Huffman and Just 1999, 2000). This can be seen as a potential source of moral hazard by peer reviewers where they use their privileged position to manipulate public research decisions to their private benefit.

Real options valuation is a methodology that combines monitoring with project management and selection (Panayi and Trigeorgis 1998; Vonortas and Hertzfeld 1998). The idea is that when a project is selected, the end value of the project is poorly defined because of lack of information. However, as time passes and milestones are completed, information is generated that helps inform valuation of the project. This new information is used to revalue the project; if the project's expected rate of return still exceeds a pre-determined threshold then the project is allowed to continue. If not, it is terminated because the project is no longer financially desirable. Real options valuation does share some of the difficulties with cost-benefit methodology (ie, it is susceptible to parameter sensitivity) but it incorporates revaluation as a means to reduce the costs of over-optimistic ex ante evaluation. This feature of real options valuation can be incorporated in public sector scientific and technology research management (Vonortas and Hertzfeld 1998). Linking monitoring with a decision to terminate a project can help reduce moral hazard by linking continued project funding with achieving milestones.

Monitoring mechanisms are available and have been tested in science and technology research. However, these mechanisms effectiveness in reducing moral hazard should not be overstated. At best, monitoring mechanisms can reduce moral hazard to a very low level. At worst, moral hazard may actually increase if monitoring is not implemented properly. Any monitoring mechanism needs to be accompanied with incentives that deters moral hazard (see 3.2.5 for more details).

3.2.4. Project Time Horizon

A project can be seen as the formalisation of a relationship between an investor and the researcher — ie, a project is a contract between the researcher and the investor. For a given RD&E project, the length of a relationship can have positive and negative effects on moral hazard. The impact of project length on moral hazard again depends on the interplay between risk and incentives. A short-term project is desirable to the investor because it limits costs and risks. However, a short-term project allocates more research and funding risk on the researcher because of the shorter amount of time available to complete the project, which may encourage the researcher to neglect some tasks (eg, writing up publication results if time is unfunded). Conversely, a long-term project is desirable to a researcher because the risk is transferred to the investor and more time is available to complete the project. Moral hazard is more likely under longer-term contracts because the investor effectively 'insures' the researcher's risk.

According to the contract design literature, short-term projects can be designed to emulate long-term projects (in terms of risk) if researchers are allowed to save their surplus without the attendant moral hazard problems (Salanie 1997; Stole 2001). This allows the researchers to 'self-insure' against a project's risk. While this may not be the most cost-effective option, because researchers consciously build in fat into their budgets, allowing researchers flexibility to manage risk can also confer incentives to refrain from moral hazard. As a result, if researchers are allowed to keep surplus funds from projects and carry over to other projects, this provides researchers with a risk-management tool and reduces the incentives to engage in moral hazard. Furthermore, this could also increase the value of public research to the community by enabling researchers to undertake more risky research, without bearing all the risk but at the same time not imposing too much risk on investors (Bardsley 1999).

3.2.5. Credible Commitment

How committed an investor is to the continuance of a project can be an important source of risk that researchers face. Lack of commitment may encourage moral hazard because if a project is unlikely to be continued there is no point in a researcher working hard because that time may be wasted. Another example of a lack of commitment is where an investor may be unable to credibly threaten to withdraw funding if moral hazard is detected. In this case, this encourages moral hazard because there is no real threat of being punished.

Commitment is the ability of an investor to voluntarily restrain from some actions (Salanie 1997). *Credible commitment* is when an individual is better off from restraining himself from certain actions (Laffont and Tirole 1993). There is a distinction between credible and non-credible commitment because they can have different incentive effects. Credibility creates an expectation that the individual would follow through with threats (or promises) which deters moral hazard. Non-credibility has the opposite effect. In the previous paragraph we presented examples of non-credible commitment. An example of credible commitment is when the investor terminates projects that are deemed non-performing according to some pre-determined and commonly understood rule. This makes the investor better off if the project was unlikely to succeed or was using resources that could be better invested elsewhere. Furthermore, demonstrating credible commitment can deter moral hazard in the future.

We use commitment in reference to the investor's ability to administer his or her portfolio. This highlights that moral hazard by researchers can be a reaction to an investor's commitment credibility. An investor needs to be aware of this impact in how she administers her portfolio, as well as the incentive structures, when attempting to reduce incentives for moral hazard.

3.2.6. Increasing the Power of Funding Schedules

The timing of funding payments and the amount paid can affect the incidence of moral hazard. Linking funding with observed performance can reduce moral hazard if performance can be monitored (Laffont and Martimort 2002). However, for RD&E projects researchers' actions may not be *verifiable* — ie, actions may not be observable but results are, but the causal link between actions and results cannot be verified by an independent third party. As a result, RD&E is not generally amenable to high-powered incentives such as sales commission which rewards verifiable actions.

Conversely, to use low-powered incentives such as untied grants for funding purposes may encourage moral hazard. This is because untied grants are not linked explicitly to any observable actions or outputs; this is essentially risk-free funding. In effect, such funding is purely discretionary and would not be useful in aligning the objectives of researchers with investors.

The timing of payments can also affect incentives for moral hazard. If more of total project funding is to be paid at the beginning of the project, the scope for moral hazard is greater; this is because the costs of foregoing future payments is lower. If more of total project funding is paid later, this could reduce moral hazard because the investor can threaten to withhold future funding if moral hazard is detected. However, this threat is only credible if there is a monitoring system that could reliably detect moral hazard. As a result, timing of payments may have no incentive effect if the payments are not tied to the verifiable monitoring of actions or outputs (Dixit 1997, 2000; Ha, Strappazzon, Crowe and Todd 2004).

Given the information limitation investors face in verifying researchers' actions and the incentives for moral hazard that 'low-powered' incentives (eg, untied grants) have, it would seem that there is little an investor could do to eliminate moral hazard. This is not true because the rule of priority can be used to monitor researchers and increasing the incentive power of a given funding schedule (Dasgupta and David 1994; Navaretti *et al.* 1996). The rule of priority can be used by investors to incorporate high-powered incentives into funding arrangements. For example, a significant proportion of a project's funding is paid if the research finding is accepted for publication in a peer-reviewed journal. Given the rule of priority, funding arrangements could be used to limit moral hazard among scientific researchers.

Could funding incorporate high-powered incentives for technology researchers also? The incentives for technology researchers are different than those for scientific researchers (Navaretti *et al.* 1996). Unlike the outputs from science research, technology outputs have tangible value to end-users (eg, the dairy industry). They can be commercial or have spillover and public good benefits. The economics literature has concentrated on incentives for technological development that have a commercial value (Dasgupta and Stiglitz 1980; Grossman and Hart 1986; Dasgupta and Maskin 1987; Grossman 1990; Besen and Raskind 1991; Scotchmer 1991; Aghion and Tirole 1994a, 1994b; Robb 1994; Mansfield 1996; Ottoo 1998; Trajtenberg 2000; Hofmann and Wangenheim 2003; Erkal 2004; Tassey 2005; Thursby, Thursby and Mukherjee 2005). The general conclusion of this literature is that some kind of intellectual protection mechanism (eg, patents) is needed to encourage private funding of technology research. Intellectual property rights effectively gives the innovating firm monopoly rights to license the technology. In the case of commercial technologies, intellectual property rights are appropriate to encourage the development of technologies with private benefit.

The rule of priority could be applied to public sector technology researchers by allowing disclosure and linking funding milestones to disclosure. Intellectual property rights are only granted if the technology is a novel innovation which can be seen as a signal of high quality research (Navaretti *et al.* 1996). Investors could use the intellectual property rights system to gather evidence that a technological project produced an innovation. Furthermore, the investor can tie funding to researchers being able to secure intellectual property rights. By using existing intellectual property rights mechanism, the investor can use a third party to monitor the researchers. Disclosure is also incentive-compatible for researchers because it allows them to signal their expertise to the wider research community in a similar way to publications as a way of enhancing their career prospects. Incentives could be further reinforced by permitting researchers to publicise their innovation through journal articles and conference presentations.

Funding schedules for both scientific and technological research can incorporate high-powered incentives by using disclosure incentives. As a result, moral hazard can be reduced by incorporating existing monitoring mechanisms. However, high-power incentives involve higher risk for researchers. The researchers' risk can be reduced by guaranteeing a large part or all of researchers' salaries to share the risk between the investor and the researchers. This may also have the additional benefit of retaining researchers who may have otherwise insecure funding.

3.2.7. Rewards for Good Research

We mentioned above how disclosure could be used to monitor a project's final output and to incorporate high-power incentives in a funding schedule. Similarly, priority can also be used as a measure of overall performance for researchers. Promotions and pay rises can be tied to publishing research findings or successfully filing for a patent. By linking rewards with priority, the investor is able to reward research that has been verified as 'good' by members of the science community.

Non-monetary rewards can be used to reward researchers for performance. Outstanding and consistent researchers could be rewarded tenure of employment for producing high quality research over a long period. Tenure may have the unfortunate side effect of encouraging moral hazard after tenure is awarded (Carmichael 1988; Thursby *et al.* 2005).

Another non-monetary incentive is to award sabbaticals, or opportunities to pursue collaborative work, to allow researchers to pursue 'pet projects' for a pre-determined time on-site or at another research institution. This can be desirable from DPI's point of view because it allows researchers to refine their research skills by working with different researchers and learning new techniques. Sabbaticals could be used to reward and to also enhance the research capabilities of DPI's researchers.

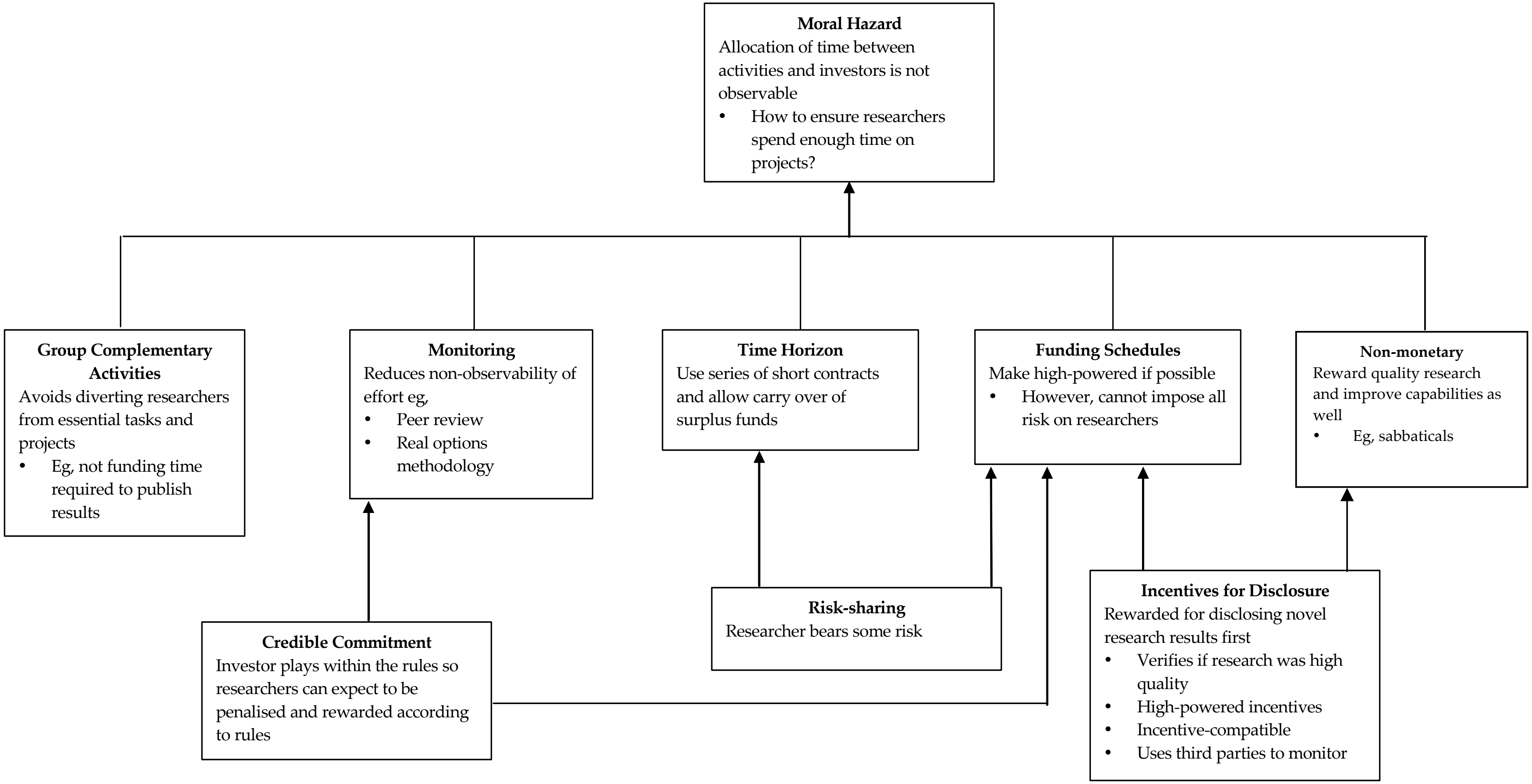
3.2.8. Summary of Potential Solutions to Moral Hazard

Figure 3 summarises our discussion on solving the moral hazard problem. This diagram can be broken down into three parts starting at the top. At the top is a re-phrasing of the moral hazard problem in the context of public RD&E. Notice that the arrows from the middle tier all lead up to moral hazard. This is because these possible solutions can all provide incentives for researchers to refrain from moral hazard despite their actions being unobservable.

In the middle of the diagram are possible solutions that can be used to reduce moral hazard. Most of these solutions rely on using risk and high-powered incentives and credible commitment to solve the moral hazard problem. Monitoring activity may have diminishing effectiveness the more intensive it is; however, coupled with high-powered incentives, light monitoring could be more effective in restraining moral hazard compared to a situation where the investor relies on heavy monitoring. The length of a project has implications for how much risk the researcher bears because the longer (shorter) a project the more (less) time they have to deliver. Funding schedules, for a given amount, can increase their incentive powers by tying payment to observed output or later in a project so that the risk is shared between the researcher and investor. Non-monetary incentives can reduce moral hazard by using the researcher's peers as monitoring instruments and also by increasing incentive power by rewarding research output with an enhanced reputation and improved career prospects. Grouping complementary activities also helps by minimising the extent of diversion between investors and tasks rather than adjusting incentive power. Moral hazard is reduced because the tasks the researcher undertakes are now consistent with the investors' objectives and does not allow the possibility of the researcher pursuing objectives inconsistent with her investors.

At the bottom of the diagram are three key concepts that relate to how monitoring, time horizon, funding schedules and non-monetary rewards can increase their incentive power. Monitoring can increase their incentive power through an investor's credible commitment to rewarding and penalising observed output or breaches according to predetermined rules. Monitoring would have no effect on a researcher's decision in allocating time if it is not credible. Time horizon can have their incentive power increased by sharing risk between researchers and investors which is a function of project length. Funding schedules can have their incentive power increased by allocating more risk onto the researchers by either tying payments to specific outputs or having payments later in a project. One way funding schedules can be tied to specific outputs is by using disclosure to the wider scientific community which allows for verification of the research results as well as confer non-financial rewards on the researcher from her peers. Finally, disclosure can increase the power of non-monetary incentives by using researchers' desire to be recognised as experts by their peers and also allows them to reinforce this reputation by opening up opportunities for collaboration.

Figure 3 Possible Solutions to Moral Hazard by Researchers



3.3. Aligning RD&E with Government Policy: the Case of Victorian DPI

High quality research (from research peers' perspective) may not be required by government policy in all cases, especially in the more applied end of the RD&E continuum. In this case, the incentives outlined above may not be incentive-compatible since research peers may not value work that is intended to solve government policy problems rather than scientific problems. As a result, using researchers' desire to gain peer esteem may be ineffective for policy-oriented research. In a sense, this form of moral hazard is a public-sector wide problem. For example, scientists may consider policy-oriented research to be inconsistent with the direction of scientific research and may allocate more effort towards more attractive research projects.

This highlights the competing incentives researchers face in a public sector agency with multiple objectives. On the one hand, researchers face high-power incentives from their external peers to contribute to knowledge production. Researchers face less powerful incentives from government to produce policy-relevant research that may not involve the discovery of new knowledge. Also, many researchers also have incentives to seek external funding from external funding bodies (eg, RIRCs) who also offer high-power incentives. In this environment, researchers have multiple masters; ie, they have multiple-principals (Dixit 1997; Dewatripont, Jewitt and Tirole 1999b; Dixit 2000; Burgess and Ratto 2003). This is a problem common in the public sector where officials often face competing interests when making decisions: eg, the balance between public and industry benefit when making allocation decisions.

When there are multiple-principals, researchers would devote more effort to the projects that offers the most attractive incentives. In the case of DPI's RD&E, this would depend on the balance between risk and rewards of the competing interests. The risk-reward balance depends on how the factors highlighted in Figure 3 interact with each other. We can summarise the incentive and risk-properties of the competing interests as follows:

- Peer esteem (rule of priority). *Rewards output that produces new knowledge and solves long-standing problems common within the respective specialisation. As such, the rewards are high through enhancement of reputation and career prospects but the risks are also high in terms of reputation.*
- External funding. *Project funding from external sources. If a researcher does not deliver the project of required quality and cost, the researcher may lose a valuable source of future funding. There may also be potential reputation repercussions for non-delivery. External funding may confer high rewards in terms of continued future funding but the risks may be high because of the potential to lose future funding from that external funder (and possibly others if the reputational damage is great enough).*
- DPI funding. *Funding is allocated by Agricultural Development (AD) Division within DPI. Like external funding, funds are allocated on a project-basis. However, unlike external funders, AD cannot credibly commit to not funding researchers who have a record of non-delivery because of restrictions in ending a public sector researchers' employment. As such,*

> *DPI funding is lower risk than the other types of funding. As for rewards, it is arguable that DPI funding is low-powered in the sense that rewards are not linked to project delivery. To some extent, DPI funding can be seen as a fixed part of the researchers' budget.*

Researchers would allocate the most effort to the principal that offers the highest reward (or harshest punishment) (Dixit 2000; Burgess and Ratto 2003). This may depend on the need of the researcher to secure external funding. If a researcher is required to seek external funding, more effort would be allocated towards externally-funded projects. This is because external funding allows opportunities that would not otherwise be available. However, if external funding is not required, then the researcher is likely to allocate more effort to peer esteemed research over DPI-funded projects. This is not a problem if the incentives of peer esteemed research are consistent with DPI-funded policy-oriented research (see 3.2.1).

Dixit (2000) argues the problem of multiple-principals can be reduced by assigning complementary objectives to the researcher. For example, external funding may be complementary for DPI objectives if there are projects available that both external and DPI investors are willing to invest in. The two sources of funding may be complementary for some research such as plant and animal productivity research. However, not all types of research would ensure complementarity between the two sources of funding. In such cases, to ensure that researchers' efforts are aligned with government policy it may be appropriate to not require all researchers to obtain external funding.

To examine how different institutional settings could affect moral hazard, we will compare DPI's current system of financing RD&E to two extreme cases: first, the case where researchers are funded solely by government (ie, the 'government case'); and secondly, where researchers are funded totally by the private sector (ie, the 'consultancy case')[12]. In the government case, the extent of moral hazard depends on how researchers are funded. If researchers receive all funds on an unconditional basis (ie, block-funding) then moral hazard is likely especially if there is a divergence between the objectives of government and researchers[13]. In the case of block-funding, researchers would allocate all their time to research that would gain the most peer esteem and enhances their career prospects regardless of the degree of congruence in government and researchers' objectives. This is because government is unable to use funding to encourage researchers to pursue government objectives. However, the disciplining effect of rule of priority may align government long-term objectives with researchers by encouraging more public good benefit research. But this is at the cost of the short-term government objectives. If other funding methods were used that required more conditionality, the

[12] This was originally suggested by Dr John Mullen.

[13] We assume that government's objectives are well defined for the sake of this example. However, there is substantial evidence that governments are unable to clearly articulate its objectives (Wilson 1989). In this case, scientists' professionalism may determine a government department's objectives. For example, Wilson (1989) presents examples where the recruiting policies of public organisations helped define the organisation's objectives in an operational sense. As a result, professionalism may be beneficial for the organisation in terms of providing high-powered incentives in a public sector context (Dewatripont *et al.* 1999b).

extent of moral hazard may be reduced. We will not examine other mechanisms due to space and time constraints.

In the consultancy case, the degree of moral hazard depends on the congruency of objectives between government and industry. The rule of priority is a secondary consideration because in this case, funding and short-term employment prospects are more important for the researcher than reputation and future career concerns. Assuming a typical consultancy case where every piece of funding comes via project funding by either government or industry sources, the extent of moral hazard depends on the relative power of incentives between these two sources. If there are differences in power, then researchers would allocate more time to the investor that offers more high-power incentives. If we assume that government is non-credible in withholding funding if researchers fail to deliver whereas industry are credible, then we would expect researchers to allocate more time to industry projects. In this case, researchers would pursue relatively more projects that generated industry benefit rather than projects with DPI funding.

This discussion on aligning government objectives with researchers' incentives highlights the need to consider all the incentives that researchers face when determining the cause of incentive problems. Without considering explicit and implicit incentives, the resulting solution may exacerbate moral hazard.

3.4. Summary

Incentives for good research are an inherently difficult problem because of the difficulty of influencing unobservable behaviour. This problem can be partly ameliorated by utilising the professionalism of researchers — ie, using the 'rule of priority' to encourage researchers to allocate more time to policy-oriented research. Financial incentives can be used in conjunction with the rule of priority but care needs to be applied to avoid inadvertently rewarding undesirable behaviour. When designing incentives for good research, understanding how different rewards and penalties encourage or discourage moral hazard is critical. Knowledge of the behavioural drivers of researchers is important as well as understanding how financial incentives, and project specifications and governance interact with researchers' professionalism and future career concerns. As a result, any design of incentives for researchers needs to consider how various incentives interact to encourage or discourage moral hazard.

We applied incentive theory to DPI's funding framework. This highlighted the potentially competing nature of funding sources on researchers' incentives. It also highlighted the potential conflict between researchers' incentives to gain peer esteem and investors' objectives. This illustrates the multi-dimensional nature of the incentive problem and the importance of considering how incentives interact together as opposed to partial analysis of the problem.

4. Conclusions

In this paper we have started establishing a framework for analysing public sector scientific research agencies by introducing two basic concepts: role of government and incentives. These two concepts form the foundation of our analytical framework because they will underpin subsequent analysis of important parts of a publicly-funded RD&E organisation.

Role of government is an important strategic concept that helps focus priorities in areas where government can generate the most benefit for the public. By understanding role of government and how it relates to investment decision-making, public sector RD&E agencies can focus on research that delivers public benefits rather than supplant private investment in industry-benefit research.

Incentives are important from an operational perspective. RD&E is a creative and complex activity that cannot be easily monitored by laypeople. How does a government align the incentives of skilled workers towards a government policy objective? This depends on the degree of consistency between researchers' incentives and government policy. It also depends on other incentives that researchers may face such as the need to secure external funding.

Role of government and incentives may also affect each other. Incentives for external funding or the rule of priority may divert researchers from policy-relevant research. As a result, competing incentives may undermine the public benefit of output produced by the organisation. Market failure may affect incentives if investors consistently apply this framework in project selection. Conversely, if the framework is not applied consistently, researchers may not understand how their research contributes to achieving government policy objectives.

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