From R&D to Productivity Growth
— Investigating the role of innovation adoption in Australian agriculture —

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From R&D to Productivity Growth:
Investigating the role of innovation adoption in Australian agriculture

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Foreword

A slowdown in the rate of productivity growth in the agriculture sector in recent years is largely a result of drought, but is likely to also reflect other challenges for Australian agriculture such as the reduction in R&D intensity and limited supplies of skilled labour. There has been a widespread call for a renewed emphasis on productivity growth and the potential role for innovation in developing new product varieties, improving ICT and internet infrastructure, and increasing training and skills development within the sector.

Farmers in Australia are highly innovative. However, a broad set of factors influence the availability of suitable innovations and the willingness and ability of farmers to adopt these innovations and integrate them into existing production systems. Innovation adoption results from a complex interaction between researchers, consultants, input suppliers and government policymakers.

This report conceptualises the innovation process and evaluates its usefulness for guiding investment and policy decisions for improving the development, diffusion and adoption of agricultural technologies and knowledge. The framework used presents a complex and dynamic model for understanding innovation processes. Investment in R&D for the development of new technologies and knowledge is an inherent and indispensable part of the innovation process.

The contribution of this report lies in the insights gained though taking a broader perspective of innovation and by evaluating a range of mechanisms that could be effective in influencing innovation adoption and productivity growth in Australia’s agriculture sector. It will be a useful basis for evaluating investment and policy decisions. In particular, it will help in planning RIRDC’s future R&D priorities and in developing practical solutions to lifting productivity growth.

This project was funded from RIRDC Core Funds, which are provided by the Australian Government.

This report, an addition to RIRDC’s diverse range of over 2000 research publications, forms part of our Global Challenges R&D program, which aims to identify impediments to the development of a globally competitive Australian agriculture sector and supports research investments on options and strategies for removing those impediments.

Most of RIRDC’s publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation
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Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABARES</td>
<td>Australian Bureau of Agricultural and Resource Economics and Sciences</td>
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<td>ABS</td>
<td>Australian Bureau of Statistics</td>
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<td>ASTI</td>
<td>Agricultural Science and Technology Indicators</td>
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<tr>
<td>CRC</td>
<td>Cooperative Research Centre</td>
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<tr>
<td>CTF</td>
<td>controlled traffic farming</td>
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<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
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<tr>
<td>DAFF</td>
<td>Department of Agriculture, Fisheries and Forestry</td>
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<tr>
<td>DSE</td>
<td>dry sheep equivalent</td>
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<tr>
<td>GCARD</td>
<td>Global Conferences for Agricultural Research for Development</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>ICT</td>
<td>information and communications technology</td>
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<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
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<td>PC</td>
<td>Productivity Commission</td>
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<tr>
<td>R&amp;D</td>
<td>research and development</td>
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<td>RD&amp;E</td>
<td>research, development and extension</td>
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<tr>
<td>RDC</td>
<td>Research and Development Corporation</td>
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<td>TFP</td>
<td>total factor productivity</td>
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Executive summary

What is the report about

Innovation is a key driver of productivity and economic growth and of the competitiveness of agriculture and other industries. However, because the innovation process is complex and innovation data is limited, its links with R&D investment and its effects on productivity are difficult to quantify.

This report evaluates the role of innovation adoption within the agricultural innovation process. Specifically, a conceptual framework is developed to assess the innovation process and the interacting drivers influencing innovation adoption and productivity, including R&D investment.

By taking a broader perspective of the innovation process, this research can contribute to guiding agricultural R&D investments and other measures aimed at improving long term productivity growth.

Who is the report targeted at?

This report is targeted at Rural R&D Corporations and policymakers at the national, state and regional levels with an interest in better targeting investments and policies aimed at increasing productivity growth. It is also relevant for researchers working to understand productivity trends and drivers.

Background

Productivity growth in Australia’s agricultural industries has begun to slow relative to the strong growth achieved during the 1980s and early 1990s. As productivity growth is the main driver of agricultural gross value of production (Mullen 2007), this has raised concern among decision-makers in industry and government. A better understanding of productivity determinants is therefore required.

Many economists have examined the relationship between R&D investment and productivity growth. However, a statistically significant relationship has been difficult to identify, partly because the effect of R&D investment takes a long time to realise and partly because many other factors are influential in the process. One major factor is the adoption of innovations by farm managers. R&D expenditure affects productivity growth only if innovations are adopted by farms and used to improve production processes. However, many innovations are not fully adopted and increasing uptake is one potential mechanism for improving productivity gains.

While innovation adoption by farms is an important determinant of the productivity gains from R&D investment, relatively little is known about its extent and determinants. Periodical farm innovation survey data are rarely available. In 2008, ABARES (formally ABARE) collected data on farm business innovation for broadacre and dairy industries as an addendum to its regular farm survey. These data provide a starting point to evaluate innovation adoption in Australian agriculture.

Aims/objectives

The aim of this project is to improve understanding of the role that Rural R&D Corporations and governments might play in influencing productivity growth. While R&D is a major driver of productivity growth, its influence on productivity is indirect and relies on dynamic interactions between other aspects of the innovation process. The role of these factors is not well understood.

The objectives of this project were to:

• describe innovation adoption patterns in Australian broadacre and dairy industries
• develop a conceptual framework for analysing the relationships between R&D expenditure, the development and diffusion of innovations, innovation adoption by farm managers and agricultural productivity.

Methods

The research consisted of three main components:

• analysis of farm business innovation data collected for the first time by ABARES (formally ABARE) in 2008 as part of its long-term farm surveys program of broadacre and dairy industries

• a review of information and literature to assist the development of a conceptual framework for evaluating R&D, innovation and productivity growth relevant to Australian agriculture

• an evaluation of the feasibility of modelling the conceptual framework outlined and an assessment of data requirements for further understanding innovation in Australian agricultural industries.

Key findings

Innovation in Australian broadacre and dairy industries

More than 80 per cent of broadacre and dairy farms adopted at least one innovation between 2006–07 and 2007–08. Cropping and mixed crop–livestock enterprises were the most innovative, followed by sheep–beef, beef and sheep. Similarly, productivity growth is highest in cropping and mixed crop–livestock industries relative to broadacre livestock enterprises. However, causality is difficult to quantify and is not evaluated in the report.

Product and process innovations were more frequently adopted compared with organisational and marketing innovations. These types of innovations are more likely to occur on an ongoing basis with developments in technology and changes in operating environments. Changes in farm organisation, management, labour use or marketing arrangement are likely to be less frequent.

The most common innovation activities undertaken by broadacre farmers were the introduction of new cropping and new soil management practices. Adoption of these innovations is likely to reflect several factors such as lower prices for imported machinery and ongoing dry conditions (which necessitated a shift in soil management to better manage limited water availability) (Liao and Martin 2009).

Conceptualising the innovation process

Agricultural innovation is often conceptualised as a step-wise (or linear) process whereby external firms invest in R&D and develop innovations, these innovations are then disseminated through extension and finally adopted by farms. Adoption of innovations may then have some impacts for productivity and other objectives, such as improved market access or environmental quality.

However, these models are not an adequate representation of the agricultural innovation process. The linear model assumes independence between factors and excludes the many complex interactions influencing research and innovation decisions. It also fails to account for backwards linkages within the innovation process. The linear model is hence limited in its ability to contribute to R&D planning and evaluation.

Recognising these limitations, many researchers have shifted to a more complex model of the ‘innovation system’. An innovation system consists of a set of organisations, institutions, enterprises, individuals and policies that are involved in the exchange of knowledge and technologies, and has been widely used to describe innovation processes at a national level.
The report develops a conceptual framework of the innovation process in Australian agriculture. Interacting components of the innovation system include the agricultural research system, bridging institutions, farm businesses, value-chain actors, agricultural education and training systems, and agricultural policies and investments. Influences from the external operating environment, including international markets, infrastructure, rural environments and other sectors of the economy, are also represented in the system. The forward and backward linkages between innovation and productivity (as well as other rural objectives) are also included.

By moving towards an innovation systems framework of agricultural innovation, the focus for industry and government shifts from building R&D capacity to building innovation capacity. This presents additional opportunities and challenges for investment and policy decisions.

**Modelling the innovation process**

Methods and data availability for empirical estimation of agricultural innovation processes remain in their infancy. Past modelling work has simplified the process by using a simplified linear model or by isolating one aspect of the process for analysis. Both approaches have advantages and limitations.

Linking aggregate R&D data with farm-level innovation and productivity data is an inappropriate method for evaluating public or private R&D efforts. If suitable data were collected, an adapted version of the popular linear model of innovation at the firm level—developed initially by Crepón, Duguet and Mairese (1998)—could be used. This model would evaluate farm investment in innovation (for example, levies, licences, training required to adapt and incorporate innovations) rather than external R&D spending. The impact of this investment on innovation adoption and innovation outcomes could then be estimated.

Potential for empirical modelling of innovation systems also remains limited. There is a need for continued research to improve econometric tools and understanding of economic behaviour and its interrelationships with innovation and adoption. Most importantly, farm innovation indicators are not available from existing data in Australia or elsewhere.

However, before an innovation system can be measured, it is necessary to understand the types of influences within the innovation process and their likely effects. The conceptual framework is useful in recognising the role of R&D, innovation adoption and various other factors for productivity. Additional collection and analysis of farm-level innovation data is likely to assist in further informing the framework. More than any other factor, productivity growth is a reflection of farm business decision-making and the willingness and abilities of farm managers to take advantage of technological opportunities as they arise.

**Implications for relevant stakeholders**

Productivity growth is a key determinant of industry performance and affects the capacity of agricultural enterprises to respond to evolving environmental and market pressures. The study provides researchers, industry and policymakers with a framework to understand the relationships between R&D, innovation and productivity growth in Australian agriculture.

Australia’s Rural Research and Development Corporations (RDCs) and other research centres are under growing pressure to enhance their contribution to rural objectives—such as productivity growth, environmental management, climate change mitigation and food security—and to demonstrate the on-farm impacts of their contributions. However, these organisations operate within a complex, dynamic and evolving operating environment.

The conceptual framework presented in the report identifies a wider set of opportunities for enhancing agricultural productivity growth. It also allows for researchers, organisations and policymakers to identify how they might interact with the innovation system to influence productivity growth and target...
investment to where potential gains may occur. These opportunities for supporting innovation capacity can be broadly characterised as:

- creating new innovations (for example, R&D, regional adaptation of technologies)
- increasing awareness of existing innovations (for example, trials, education, extension, attitude change)
- improving innovation capabilities (for example, addressing high entry costs, increasing skills, improving market access).

However, the complexity of innovation systems suggests that attributing productivity changes to individual investments or mechanisms in a simple linear fashion will be infeasible in most cases.

**Recommendations**

Several strategies are likely to be useful in further evaluating the innovation processes and the role of R&D and innovation adoption for productivity growth. These include actions to:

- promote wider use of an innovation system framework to assess the underlying processes involved in communicating research to users and how this might be improved
- conduct a series of case studies of components within the innovation system to understand their role and how their effectiveness in stimulating innovation adoption and productivity growth might be improved
- expand data collection to cover a greater set of innovation determinants at the farm level to improve the ability of analysts to measure and evaluate innovation adoption and productivity growth drivers and linkages.
1. Introduction

Productivity growth has been the main driver of economic growth in the agriculture sector. Recent indications that agricultural productivity growth has fallen below its long-term trend have raised concern among those in government and industry seeking to maintain the competitiveness of the sector while also adapting to climate change and assisting global food security efforts. Given these circumstances, a better understanding of productivity determinants and their relative contribution is required to determine how to effectively accelerate productivity gains.

Research has for many years recognised the link between weak productivity growth and lacklustre development and diffusion of new technologies and knowledge (Hall 2005; Hanel 2008). R&D leads to the development of innovations that are the main contributor to technological progress and hence long-term productivity growth. The relationship between rural R&D investment and productivity growth has been the focus of several studies which have unambiguously identified a positive relationship (Alston et al. 2000; Mullen and Crean 2007).

In conjunction with the invaluable role of R&D investments, there are other aspects of the innovation process that contribute to productivity growth. Given the renewed focus by governments and industry on lifting productivity growth, it is necessary to explore the possible effectiveness of other strategies in influencing innovation and productivity improvements. There are limited tools available to evaluate agricultural innovation systems and these scarcely recognise how dynamic, responsive and competitive agricultural sectors are (Spielman and Kelemework 2009).

The innovation system in agriculture comprises organisations, farm businesses, farm managers, institutions and policies that interact to generate innovations, influence farm decision-making, introduce innovations into farm production processes and ultimately affect farm performance. Assessing the innovation system in Australian agriculture could assist in identifying areas where innovativeness could be improved to generate productivity gains. For example, slow innovation adoption could be a result of barriers relating to information, finance, local environment, policies or institutions that can act as an incentive or disincentive to innovate. Alternatively, farm managers could be lacking the skills, training or motivation required to innovate. Some experts have suggested that there could be insufficient domestic or global R&D towards productivity-enhancing innovations, advocating that further emphasis on creating new, substantial, technological advancements is required (Pardey 2009).

One concept that has been underexplored in Australia is the role of innovation adoption in improving agricultural productivity growth. R&D expenditure affects productivity only if innovations are developed, adopted by farmers and used to improve production processes. Given the host of factors affecting adoption decisions, the development of innovations rarely guarantees their use by farmers. Increasing the adoption of innovations already ‘on the shelf’ is recognised as one strategy for increasing industry productivity (Nossal and Gooday 2009; Productivity Commission 2008). However, little research has been done to evaluate the contribution this strategy may have for productivity growth. Improving innovation uptake could supplement R&D investments to amplify productivity gains, particularly in the short term.

The lack of research in this area appears to have been associated with the limited availability of data on farm innovation. The recent ABARES survey on farm business innovation in Australian broadacre and dairy industries (Liao and Martin 2009) provides the first indications of the types of innovations and the extent of their adoption by broadacre farmers in Australia. These data provide a starting point for assessing innovation adoption in Australian agriculture and devising a framework for evaluating productivity impacts.
This report highlights the role of innovation in improving productivity growth by examining the relationships between innovation development, diffusion and adoption decisions and the effects of these and other processes on farm productivity.

Following the objectives outlined below, the report will discuss the importance of productivity and innovation in agricultural industries, evaluate the innovative performance of Australian agricultural industries, develop a framework for conceptualising the innovation process and provide a deeper understanding of the drivers of innovation and productivity. The later sections will discuss prospects for modelling innovation relationships and highlight the implications of the findings for governments, RDCs and private sector organisations seeking to improve innovation adoption, productivity growth and, ultimately, the performance of Australian agricultural industries.
2. Objectives

This project aims to conceptualise the innovation process in agriculture, focusing on the role of innovation adoption for achieving productivity growth. There are two specific objectives of the study:

- to describe patterns of innovation adoption in Australian broadacre industries based on data collected by ABARES (formally ABARE) in 2008
- to develop a conceptual framework for analysing the relationships between R&D expenditure, the development and diffusion of innovations, innovation adoption by farm managers and the effects on agricultural productivity.

By taking a broader perspective of the innovation process, the study will be useful in guiding agricultural R&D investment and other measures by policymakers and industry bodies aimed at improving long-term productivity growth. The report will also identify opportunities for improving the quality of farm innovation data in the future.
3. Innovation and productivity concepts

Why do we need productivity growth?

Productivity is a measure of how efficiently farms are transforming inputs into outputs. Ongoing productivity improvements have allowed Australian agricultural industries to expand the production of goods and services without significantly increasing overall use of land and other resources. Over the long term it has become possible for farms to produce the same output using fewer inputs or, alternatively, additional output for a given input use.

Productivity growth accounts for most of the increases in production, improvements in profitability and growth in real income within the agriculture sector over the long term. As Australia is a price taker on global agricultural markets, productivity growth has been vital to offset long-term declining terms of trade and maintaining international competitiveness (Figure A). Over the past two decades, average annual productivity growth in agriculture has been double average annual productivity growth in the overall market sector (ABS 2010). However, there are indications that productivity growth in major agricultural industries is slowing down (Nossal and Gooday 2009).

Figure A: Broadacre productivity growth and farmers' terms of trade

Australian agriculture faces a number of emerging and longstanding challenges, including drought and climate change, reduced land and water availability, market access concerns, population ageing and labour shortages. Higher productivity growth (above the current long-term average) is an important part of overcoming these challenges and maintaining international competitiveness and viability as a supplier of food and fibre under changing market and environmental conditions (Nossal and Gooday 2009).

Several measures of productivity are commonly used. Yield (output per hectare) and labour productivity (output per worker) are two common measures for the agriculture sector. However, neither is a good indicator of farm performance. For example, improvements in labour productivity are often the result of additional capital investment and yield improvements can often be the result of increases in the use of materials such as fertiliser and chemicals. Total factor productivity (TFP)—also referred to as multifactor productivity—measures total outputs relative to the total inputs used in production, including land, labour, capital and materials and services. TFP growth captures the growth in output exceeding growth in all inputs and is a more comprehensive indicator of production efficiency. The productivity referred to in this report is TFP.
Long-term productivity growth is largely a measure of technological progress. That is, new technologies (and other innovations) enable additional outputs to be produced from the same or fewer inputs (Productivity Commission 2009). Productivity growth can be influenced by many factors, including seasonal conditions, changes in efficiency, enterprise mix, economies of scale, farm entry and exit and changes in capacity utilisation. Innovation, through the development and diffusion of new technologies and knowledge, is considered to be a key driver of productivity growth.

How does innovation affect productivity growth?

The development and diffusion of innovations are fundamental to growth in productivity and output (Hanel 2008; Rao et al. 2002). Innovations have enabled agriculture to increase both the quantity and quality of farm outputs over time, while releasing land, labour and other resources to other areas of the economy. They have therefore been a main factor driving productivity growth and long term economic growth in agriculture.

According to economic theory, innovation and technological change affect productivity growth directly, as well as through the accumulation of physical capital and human capital (Figure B). These determinants of productivity growth are highly interactive and tend to be complementary. It is the quantity and quality of these factors and the way they are organised, managed and utilised within the farm sector that determines productivity performance (Rao et al. 2002).

Figure B: Determinants of productivity growth

Source: Rao et al. (2002)

Physical capital includes the machinery and equipment used in farm production, while human capital is the stock of knowledge and skills available to the farm manager and workers. It is the rate of technological change and growth in physical and human capital—through the acquisition of new machinery or skills in the labour force—that facilitates productivity growth.

The operating environment also helps to drive productivity growth. For agriculture, this includes competition, trade and market access, developments in financial markets, property rights, land and water quality and environmental pressures such as drought or climate change. More broadly, the policies relating to science and technology and the effectiveness of institutions and other organisations
in recognising research and innovation challenges are critical (World Bank 2006a). These factors can enable or inhibit innovation and productivity growth.

Innovations are generated through investments in science and technology, new ideas and knowledge, and physical and human capital. Farms may innovate by purchasing new products, capital goods or materials or by acquiring and implementing new knowledge about production techniques or practices. Innovation can be defined as the implementation of a new or significantly improved product, process, marketing method or organisational system (OECD 2005; Schumpeter 1934). For farms, this indicates any change or reorganisation to the farm business and its operating practice and often results from the integration of new knowledge and technologies into farming systems.

A wide range of new technologies and production practices have contributed to growth in agricultural output and reductions in inputs. These innovations can be considered as output-enhancing, input-saving, or a combination. For example, the adoption of no-till cropping systems has improved productivity on some farms by reducing seeding time, increasing organic matter retention and reducing soil erosion risks.

As well as improving productivity, innovations in agriculture have contributed to other social and environmental objectives by improving sustainable resource use, assisting farms to respond and adapt to climate change, reducing waste, reducing labour-intensity and burden, increasing amenity values and meeting other production, consumer, societal and environmental demands.

**Innovation types**

Four innovation types have been defined by the OECD’s *Oslo Manual on innovation* (OECD 2005). These are: product innovation; process innovation; organisational innovation; and marketing innovation. Each innovation type can lead to productivity improvements by increasing production efficiency, improving production processes or expanding demand for products (Box 1).

Product and process innovation are most closely linked to technological development. Product innovation is the introduction of a good or service that is new or significantly improved in terms of characteristics or intended use. It includes new knowledge and technologies, as well as new uses or combinations of existing knowledge and technologies.

Process innovation is the implementation of new or improved production methods, such as changes in the techniques, equipment or software used in farm production. These innovations are typically adopted to reduce costs, to increase quality or to enable new outputs to be produced effectively.

Organisation innovation relates to improvements in business practices. This can include changes in structure, management techniques or staffing. These innovations can reduce administration costs, improve workplace satisfaction and labour productivity, improve access to external knowledge or reduce costs of supplies or transactions.

Marketing innovations include changes aimed at addressing consumer demands, opening up new markets, or better positioning Australian farms to increase sales in international markets. At the farm level, changes to market arrangements may include forward selling or the use of contract sales to reduce uncertainty.

Classifying innovations into these four categories can be difficult. Some product innovations (for example, introducing a new crop) also require new processes (for example, new or altered rotation system). Major or incremental innovations can accompany the diffusion and adoption of innovations and both are important components of the innovation process and overall technological progress (Rao et al. 2002).
Many farm innovations are also sequential, building on previous knowledge or technologies. For example, new livestock breeds can stem from previous advances. This can make it difficult to attribute productivity gains to specific innovations.

### Box 1: Innovations and their productivity benefits

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<tr>
<th>Innovation type</th>
<th>Example innovation activity</th>
<th>Possible productivity impacts</th>
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<tbody>
<tr>
<td>Product</td>
<td>New crop/seed varieties</td>
<td>Higher yields, reduced pest or disease susceptibility, lower chemical requirements, resistance to drought/cold/salt</td>
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<tr>
<td></td>
<td>New types of animal feed</td>
<td>Reduced input use, improved slaughter weights</td>
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<tr>
<td>Process</td>
<td>Precision agriculture techniques</td>
<td>Higher yield, reduced water, fertiliser, pesticides and energy use</td>
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<td></td>
<td>No-till cropping systems</td>
<td>Reduced seeding times (saved labour), improved soil</td>
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<tr>
<td></td>
<td>Changed irrigation practices (new infrastructure, timing etc.)</td>
<td>Improved water-use efficiency, reduced yield loss</td>
</tr>
<tr>
<td>Organisational</td>
<td>Increase or decrease in permanent labour or use of contractors</td>
<td>Reduced labour costs, improved efficiency</td>
</tr>
<tr>
<td></td>
<td>Change in management team (e.g. hired management consultant)</td>
<td>Improved management skills and knowledge stock</td>
</tr>
<tr>
<td>Marketing</td>
<td>Forward selling of products or contracting sales</td>
<td>Improved management systems, reduced risk</td>
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</table>

### Innovation sources

The agriculture sector is made up of many small farms, which typically lack the scale of operations required to undertake research internally. While some innovations are developed and tested on-farm, most are created through external R&D. In this sense, many economists consider technological progress in agriculture to be supplier dominated (Pavitt 1984).

There are many reasons why farms rarely engage in organised R&D. These include high fixed costs, long development and implementation lags, uncertain results, lack of appropriate skills, and the public good nature of innovations. Knowledge in science and technology is often characterised by public good attributes of non-rivalry and non-excludability—that is, it cannot be fully appropriated by those who have invested to produce it. Therefore, R&D is prone to market failure.

Given the very low levels of internally created innovations, agricultural productivity growth in Australia relies on a growing network of public and private innovation sources. The Rural RDCs, funded by industry levies and government co-contributions, are a major source of R&D and innovation. Various other innovation sources include public research institutions (such as CSIRO), universities, state departments concerned with agriculture, private companies and international sources. Cooperative Research Centres (CRCs) undertake industry-oriented research co-funded by public and private sources. There are 14 CRCs currently servicing agriculture and rural-based manufacturing industries.

Nevertheless, technological progress would not occur without farms adopting and implementing agricultural innovations. It is only when (and if) innovations are adopted that the benefits will be realised (Karshenas and Stoneman 1995). Agricultural innovation is often considered a two-step process, where innovations are created via R&D and then adopted by farm users (Chavas et al. 1997). However, an additional middle step is generally recognised to involve the dissemination of information, knowledge and technologies from the innovation creators (R&D organisations and companies) to the innovation adopters (farmers).
As knowledge and technology is rarely supplied from a single source, the diffusion process is complicated and dynamic interactions are required for innovations to be effectively created, disseminated and adopted. For example, the diffusion of process innovations is often regional, depending on the local farming environment and the ability of farmers to see first-hand the results from adoption on neighbouring properties.

More recently, there has been greater emphasis on private consultants in agriculture to facilitate innovation diffusion and adoption. Agricultural consultants have improved the dissemination of knowledge and technologies—but rarely hold the capacity for creating innovations.

**Innovation adoption and farm decision-making**

Perhaps most importantly, productivity improvements stem from innovative behaviour. That is, farms must decide to innovate and develop or adopt new technologies or production systems. The innovation process relies on business decision-making by farm managers, particularly decisions about time, money and effort to spend on exploring new ideas, gaining new skills and knowledge, improving capabilities and advancing farm technology. The process is ongoing and often cumulative in building productive (or innovative) capacity.

Accordingly, the adoption of innovations can depend on a wide range of economic, situational and personal factors. As these vary from farm to farm, innovation adoption is highly uneven, with some innovations adopted more readily than others and some farm managers more likely to innovate than others (Marsh 2010). Consequently, many innovations with demonstrated and promoted benefits are not fully adopted or utilised to their full capacity (Guerin and Guerin 1994). In addition, adoption is typically slow, often expanding for several decades (Rosenberg 1972).

These tendencies have led researchers to visualise diffusion of innovations among potential adopters as an S-shaped curve over time (Marsh et al. 2000; Rogers 2003) (Figure C). Diffusion curves can vary in terms of start time, adoption rates and adoption thresholds depending on the characteristics of the innovation or the adopters. For example, different regions may have different tendencies or incentives to adopt.

A farm’s individual adoption decision can depend on the profit motives, competition and innovation capacity. Innovation capacity reflects knowledge capital as well as the infrastructure and institutions available to a farm. It also reflects financial capacity to support innovation.

Given the role of information in innovation decisions, many economists have viewed the diffusion and adoption process as one of uncertainty. For new innovations, uncertainty about the potential advantages it may have is high. Uncertainty about the benefits, costs or life expectancy of the technology can influence innovation (Hall 2003). As information is gathered and farmers adjust perceptions, uncertainty falls and adoption increases. Furthermore, as adoption increases, the cost of acquiring information becomes less for those farmers yet to adopt (Abadi Ghadim et al. 2005; Marra et al. 2003). However, information barriers are only one constraint to innovation adoption.
The reasons why adoption decisions vary have been widely examined. For example, Pannell et al. (1999, 2006) review a variety of factors related to a farm’s decision to adopt a new farming system. Awareness, observability, trialability, and perceived benefits of the innovation are brought forward as key determinants of innovation adoption.

Perhaps the most obvious decision factor is the relative advantage of the innovation. Potential innovators are only likely to change their production system if they perceive their current system to be inadequate or if they recognise an opportunity for improvement. This reflects the cost and uncertainty associated with the innovation process (Hanel 2008). The greater the perceived relative advantage of the innovation, the more likely a farmer is to adopt (Pannell et al. 2006; Rogers 2003).

There are many reasons why a farmer might perceive a relative advantage. These include the expected improvements in output, reductions in inputs costs or changes in riskiness or lifestyle. Improvements in output could be in terms of higher yields or improved quality, while a reduction in costs could be due to using fewer inputs or simply a changed input mix. Both adjustments can improve productivity. Compatibility of innovations with existing farming systems, the adjustment costs associated with adoption, the complexity of the innovation and the effect on competitiveness, personal lifestyle and attitudes or the environment are also likely to influence the perceived benefits of innovating (Pannell et al. 2006).

Unlike other industries, agriculture is also subject to a high degree of site-specificity. Because of the biological nature of production, the suitability of innovations and returns to innovating can vary with changes in climate, soil type, location, farm size and distance from markets. The variability in farm environments can increase overall innovating costs, particularly where innovations must be adapted to local conditions. These characteristics of agricultural production can also restrict the potential for knowledge spillovers.

The benefits of innovating can also be susceptible to biological factors, such as weather and pests, as production processes take time after resources are committed. Innovation outcomes and advantages are unpredictable, adding another degree of uncertainty.

A more simplified approach considers innovation adoption to be driven by three factors: abilities, needs and opportunities. For example, wealthier farms have a greater ability to innovate, while farms
suffering the effects of drought may innovate out of need or necessity to maintain viability. The need to innovate depends on the current socioeconomic and resource situation as well as previous innovative efforts. Opportunities to innovate may come from policy incentives or changes in marketing arrangements.

More broadly, the innovative behaviour of a farm is likely to depend on characteristics of the innovation, the farm, the farm manager and the operating environment. Some relevant characteristics can be found in Table 1 and are reviewed in more detail in several studies (see Fernandez-Cornejo 2007; Marsh 2010; Pannell et al. 2006). Above most factors, heterogeneity among farms and farm managers typically explains why not all farmers adopt an innovation.

Table 1: Characteristics affecting innovative behaviour

<table>
<thead>
<tr>
<th></th>
<th>Examples of relevant characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation</td>
<td>Profitability, relevance, complexity, observability</td>
</tr>
<tr>
<td>Farm</td>
<td>Land availability, skilled labour, capital stock, knowledge stock, access to credit, financial capacity</td>
</tr>
<tr>
<td>Farm manager</td>
<td>Personality, age, family structure, individual values, beliefs and goals, off-farm income, attitude to risk, education, culture</td>
</tr>
<tr>
<td>Operating environment</td>
<td>Communication networks, legal constraints, access to market, cultural factors, government policies, incentives (institutional, public, private)</td>
</tr>
</tbody>
</table>

Source: Marsh (2010)

Policymakers often give more emphasis and support to the creation of innovations than to their diffusion and adoption. Productivity growth can be as much about increasing the productivity performance of laggards, or their exit, as it is about developing and implementing frontier technologies (Productivity Commission 2008). It is the rate of development and adoption of innovation that facilitates productivity growth. For these reasons, the Cutler review concluded that ‘significant focus should go towards increasing the capacity of firms to apply the products of research’ (Cutler and Company 2008).

The patterns and drivers of innovation behaviour in Australian agriculture are discussed further in Chapter 4.
4. Innovation in Australian agriculture

Innovation in agriculture has become important for maintaining as well as increasing productivity performance and farm production. The production environment for agriculture is evolving in a dynamic and diverse way, with emerging pest and diseases problems, changes to global competition and trade, emergence of biofuels, demand for agriculture to respond to health concerns, environmental pressures and climate change (Pardey 2009). Continuous innovation is necessary for agriculture to compete and retain viability (World Bank 2006b).

A farm innovation survey was conducted by ABARES (formally ABARE) in 2008 as part of the 2007–08 Australian agricultural and grazing industry survey and Australian dairy industry survey. The innovation survey was the first to look across industries and states at the innovation activities undertaken by farms. The survey collected information on the extent of innovation adoption across a broad range of innovative activities undertaken between 2006–07 and 2007–08. Preliminary results of the survey for a subset of farms were published in November 2009 (Liao and Martin 2009).

The Australian agricultural and grazing industry survey targets broadacre farms in Australia producing crops, beef, sheep or a combination of these. The Australian dairy industry survey targets farms engaged in dairy farming. The broadacre and dairy sector collectively represents around 70 per cent of Australia’s commercial-scale farms and more than 60 per cent of the gross value of Australian farm production (ABS 2009).

Following the Oslo Manual (OECD 2005), innovation was defined in the survey to include the implementation of new practices or technologies not previously used by the farm business and which are likely to be used on a continuing basis. Innovation activities included product, process, organisational and marketing innovations. Farm managers ranked the extent to which they had adopted innovations as making ‘little or no change’, ‘changes to some extent’ or ‘changes to a great extent’.

Between 2006–07 and 2007–08, 85 per cent of broadacre and dairy farms adopted at least one innovation to at least some extent (Figure D). Within the broadacre industry, cropping and mixed crop–livestock farms were the most innovative, followed by sheep–beef, beef and sheep farms. It is not reliable to link only one year of innovation data with long term productivity growth. However, based on simple tabular analysis it appears that industries with higher innovativeness have also had higher long-term productivity growth (Nossal and Sheng 2010). Higher productivity growth could improve capacity for innovation adoption by farmers or, alternatively, innovative farmers could be more productive. Further research is required to investigate these relationships and the direction of the causality.

Innovation types were compared across industries (Figure E). Process innovations were the most popular innovative change among both broadacre and dairy farmers, followed by product, organisational and marketing innovations. While the types of innovation undertaken by each industry vary, the pattern is consistent with overall innovation behaviour, with broadacre cropping industries adopting more innovations than broadacre livestock industries.

More than 45 per cent of cropping and mixed crop–livestock farms adopted product innovations, compared with 36 per cent of beef farms and less than 30 per cent of sheep farms. While this suggests that cropping enterprises are more innovative, this could be as much about off-farm R&D as on-farm adoption behaviour. There are likely to be a greater number of innovation opportunities through the adoption of new crop cultivars and crop types compared with new livestock breeds and types.

Marketing innovations were adopted by 35 per cent of broadacre farmers, compared with only 10 per cent of dairy farmers. Notably, changes to marketing arrangements were common among cropping and mixed crop–livestock farms. This may reflect the additional options made available for
grains marketing in recent years. Comparatively, the dairy industry is heavily reliant on milk production, for which few alternative market options are available (Liao and Martin 2009).

Figure D: Share of farms adopting innovations, by industry

![Figure D](image)

Figure E: Proportion of farms innovating, by innovation type

![Figure E](image)

The innovation activities undertaken by broadacre and dairy farmers were diverse (Table 2). The most common innovations among broadacre farmers were in cropping equipment, soil management practices and new crop cultivars (Figure F). Lower prices for imported machinery, particularly in 2007–08, are likely to have made opportunities for innovation more attractive.

Nearly one-third of farms also changed their soil management practices over the two years to 2007–08. Ongoing dry conditions became severe in 2006–07 and persisted across most of southern Australia in 2007–08 (Martin et al. 2009). Many farm managers were motivated to change soil
management practices, such as tillage and crop-sowing practices, to produce some crop despite a lack of soil moisture.

Introducing new crop cultivars is common among grain growers. New cultivars generally represent an incremental change in cropping technology and farmers perceive relatively low risk from adopting new cultivars on a regular basis as scientific improvements are made. However, grains farmers have indicated that these incremental benefits are not sufficient to generate substantial productivity gains, and have suggested that further R&D is required to develop advanced plant breeding technologies (Jackson 2010).

As data for only one survey period are available, it is unclear whether the adoption of crop cultivars reflects a consistent innovative change made by broadacre farmers or if it is perhaps in response to industry-wide strategies to control diseases such as cereal rusts. Weed, pest and disease management practices also ranked highly among innovative changes between 2006–07 and 2007–08.

Popular innovations among dairy farmers included new practices for fodder conservation and use and irrigation and water management (Figure G). Dairy farms were affected by local drought conditions and restricted availability of irrigation water during 2006–07 and 2007–08. Many farms were required to change their irrigation practices during this period. Limited pasture growth also demanded that many farms increase fodder purchases. Given the large increase in prices for feed grains, hay and silage over the period, expenditure on purchased fodder was the largest component of dairy farm input costs. Increases in purchased fodder and feed grains inputs are likely to be one factor inhibiting productivity growth in the dairy industry (Nossal and Sheng 2010).

Dry seasonal conditions, restricted pasture growth, increasing input costs and a reduction in productivity provided a strong incentive for farms to change their practices for fodder conservation and use. More than 40 per cent of Australian dairy farms undertook this innovation activity. For similar reasons, more than 35 per cent of dairy farms also adopted new pasture types.

**Figure F: Proportion of farms adopting specific innovations, broadacre**
## Table 2: Extent of innovation adoption between 2006–07 and 2007–08, broadacre and dairy farms

<table>
<thead>
<tr>
<th>Category</th>
<th>Broadacre farms</th>
<th>Dairy farms</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not at all</td>
<td>to some extent</td>
<td>to a great extent</td>
<td>not at all</td>
<td>to some extent</td>
</tr>
<tr>
<td>Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New crop types</td>
<td>%</td>
<td>78</td>
<td>18</td>
<td>3</td>
<td>67</td>
</tr>
<tr>
<td>New crop cultivars</td>
<td>%</td>
<td>71</td>
<td>26</td>
<td>3</td>
<td>79</td>
</tr>
<tr>
<td>New livestock types</td>
<td>%</td>
<td>90</td>
<td>8</td>
<td>2</td>
<td>94</td>
</tr>
<tr>
<td>New livestock breeds</td>
<td>%</td>
<td>80</td>
<td>16</td>
<td>4</td>
<td>87</td>
</tr>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural resource management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed-related NRM</td>
<td>%</td>
<td>78</td>
<td>18</td>
<td>4</td>
<td>68</td>
</tr>
<tr>
<td>Pest-related NRM</td>
<td>%</td>
<td>85</td>
<td>12</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>Soil-related NRM</td>
<td>%</td>
<td>77</td>
<td>18</td>
<td>5</td>
<td>72</td>
</tr>
<tr>
<td>Cropping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser practice</td>
<td>%</td>
<td>77</td>
<td>17</td>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>Soil management practice</td>
<td>%</td>
<td>71</td>
<td>23</td>
<td>6</td>
<td>na</td>
</tr>
<tr>
<td>Weed, pest and disease management practices</td>
<td>%</td>
<td>74</td>
<td>22</td>
<td>4</td>
<td>na</td>
</tr>
<tr>
<td>Equipment for cultivation, planting, fertilising, spraying and harvesting</td>
<td>%</td>
<td>66</td>
<td>26</td>
<td>8</td>
<td>na</td>
</tr>
<tr>
<td>Other crop practices</td>
<td>%</td>
<td>92</td>
<td>6</td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Livestock feeding practice</td>
<td>%</td>
<td>83</td>
<td>14</td>
<td>3</td>
<td>66</td>
</tr>
<tr>
<td>Fodder conversation and use practice</td>
<td>%</td>
<td>89</td>
<td>10</td>
<td>1</td>
<td>58</td>
</tr>
<tr>
<td>Livestock handling practice</td>
<td>%</td>
<td>87</td>
<td>10</td>
<td>3</td>
<td>89</td>
</tr>
<tr>
<td>Livestock health practice</td>
<td>%</td>
<td>85</td>
<td>12</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>Grazing management practice</td>
<td>%</td>
<td>84</td>
<td>13</td>
<td>3</td>
<td>71</td>
</tr>
<tr>
<td>Other livestock practices</td>
<td>%</td>
<td>93</td>
<td>5</td>
<td>1</td>
<td>94</td>
</tr>
<tr>
<td>Pasture type</td>
<td>%</td>
<td>81</td>
<td>16</td>
<td>3</td>
<td>63</td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation and water management practices</td>
<td>%</td>
<td>79</td>
<td>15</td>
<td>6</td>
<td>58</td>
</tr>
<tr>
<td>Organisational</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New approach to labour use</td>
<td>%</td>
<td>82</td>
<td>14</td>
<td>4</td>
<td>76</td>
</tr>
<tr>
<td>New members to farm management</td>
<td>%</td>
<td>92</td>
<td>6</td>
<td>3</td>
<td>91</td>
</tr>
<tr>
<td>Marketing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New approach to marketing farm’s production</td>
<td>%</td>
<td>75</td>
<td>19</td>
<td>6</td>
<td>90</td>
</tr>
</tbody>
</table>
Innovation adoption by farm size—measured by dry sheep equivalent (DSE)—is shown in Figure H. In general, innovation adoption was higher among larger farms than smaller farms. Around 67 per cent of very small farms innovated, compared with more than 90 per cent of large and very large farms. This result is not surprising given that large farm businesses generally have greater capacity for innovation and might achieve better economies of scale from innovation adoption.

Age showed an inverse relationship with innovation adoption among broadacre farmers, with older farm managers less likely to innovate (Figure I). Younger people are perhaps more interested in adopting new technologies and knowledge. The reduction in innovativeness among older farmers is a concern for long-term productivity growth, as Australia’s farm population is ageing and there are fewer young people entering the industry. Workshops with grains growers in 2009 highlighted the fact that the reduced flow of young people had severely restricted the flow of human capital and new skills into agricultural industries (Jackson 2010).

The value of attracting skilled and well-educated labour to build human capital and knowledge in agricultural industries is further emphasised in Figure J. Farm managers with a higher educational attainment were also more likely to innovate compared with less educated farm managers. Skills and
training are important for building innovative capacity, reducing information gaps and increasing the ability and willingness of farmers to innovate.

**Figure J: Innovation adoption by education level, broadacre farms**

Although the survey has found that farms with larger size, younger managers and managers with higher education were generally more innovative, farm innovativeness is unlikely to be consistent over time. These results represent innovation adoption between 2006–07 and 2007–08 only. While farms innovating during this period could be more innovative generally, it is difficult to determine whether innovation adoption measured in the survey represents sporadic or ongoing innovation efforts. The incentive for farms to innovate is likely to vary over time based on farm-specific and farmer-specific characteristics, as well as changes in the operating environment as discussed in the previous section.

It should also be observed that while these results suggest that the majority of Australia’s broadacre and dairy farms are undertaking some innovation, they do not indicate whether innovation adoption is at an appropriate level. In addition, it is not possible to determine whether a different combination of innovative activities would have greater benefits for productivity growth. Ongoing collection of innovation data over a number of years is required to enable analysis of these issues.
5. Dynamics of the innovation process

From R&D to productivity growth

Innovation is not easy to measure. Many studies of agriculture, as well as other industries, have used R&D as a proxy for innovation. Because R&D increases the stock of knowledge and technology available to farms, it is considered a major input into the innovation process.

The most commonly used measure of R&D effort (or input) is R&D expenditure. Other proxy measures include the number of scientists or the knowledge stock (often defined via a lagged function of research expenditure). Models of R&D and performance have incorporated R&D measures as an ‘input’ into the farm production process using a production function approach (Evenson 2000; Mullen and Crean 2006). Other studies use an ‘economic surplus approach’, defined by Griliches (1957), to attribute changes in supply to the impact of new technology and the returns from investment.

Such assessments have commonly identified high returns from public and private agricultural R&D expenditure in Australia and globally (Alston et al. 2000; Alston et al. 1995; Mullen and Cox 1995; Shanks and Zheng 2006). The results have been used to determine how technologies influence productivity and to provide evidence of social returns to investment, particularly for public-funded R&D (Alston et al. 1995). In many cases, these assessments have been useful and necessary.

However, several issues have led to substantial debate about the use of these methods for decision-making, particularly given the dramatic rates of return found in some studies (ranging from 19 per cent to 95 per cent) (Alston et al. 1995; Evenson 2001; Fuglie and Heisey 2007; Huffman 2009; Mullen and Cox 1995). Some of the issues associated with interpreting the results of such studies are discussed in Box 2. These issues largely arise because of data measurement issues. In particular, current R&D expenditure is likely to be a poor indicator of new knowledge and technology entering the production system.

Box 2: R&D and productivity: difficulties in measuring and interpreting linkages

There are several difficulties in interpreting the results of studies that estimate the rates of return or productivity impacts of agricultural research using R&D expenditure. These have been widely discussed and acknowledge by a number of sources (Alston et al. 2009; Mullen and Cox 1995; Mullen and Crean 2007; Rajeswari 1995).

A summary of issues includes the following.

- Short-term shocks affecting farm production impede the ability to observe a stable long-term relationship between R&D and productivity growth.

- The public sector supply of research, extension and regulatory services is typically joined so it is not possible to isolate the cost data for ‘research’.

- There are long lags between research investment, research outputs, innovation processes and agricultural production impacts. These lags can extend for several decades before eventual changes in farm productivity or performance.

- Shifts in the type of research, such as basic, applied, experimental or technological research, can lead to shifts in the relationship to productivity. Each research type is likely to have a different lag structure, which is not accounted for in most modelling.

- ‘Intermediate processes’ between research expenditure and productivity impacts (including research, development, commercialisation, trialling, diffusion and adoption) are implicitly assumed to be operating effectively and cannot be evaluated separately. The flow from research to productivity impact is often assumed to depend purely on R&D expenditure, despite a range of other influences.
Changes in research effort or organisation may have large impacts on rural research and agricultural production systems, regardless of total expenditure. Expenditure measures alone might overestimate the level of research effort if R&D resources are underutilised (Rajeswari 1995). Alternatively, R&D expenditure measures could underestimate research effort because complementary research in other sectors and by farms themselves is not considered. Spillovers from research in other industries or overseas may contribute up to half of the productivity gains achieved by an industry or nation (Alston 2002).

Despite the disadvantages of R&D expenditure measures, alternative measures of research effort are also difficult to identify as research outputs enter various stages of the farm system, both directly and indirectly, through embodied and disembodied technology (Rajeswari 1995).

Given the extent of complexities, most studies are unable to find a consistent robust measure of the effect of R&D on productivity and typically concede a high degree of judgement (Rajeswari 1995; Shanks and Zheng 2006). This is consistent with the conclusion made by Hallam (1990) 20 years ago, that there are doubts ‘any meaningful relationship can be established from the available data’, backing earlier claims that researchers and decision-makers were asking too much of the data (Griliches 1979).

**Linear models of the innovation process**

Agricultural R&D measures reflect the supply-side of innovations. Without external (that is, off-farm) R&D, technological developments in agriculture are likely to be limited. However, R&D has limited ability to measure innovation processes, particularly on-farm innovation adoption. The demand for innovations determines their adoption and integration into production systems. Therefore it is the innovative behaviour of farm managers, and other inputs into the adoption process, that determines the eventual impact of innovations for productivity growth.

The determinants of innovation adoption have been the focus of extensive analysis, including in Australia, and will not be detailed here. Some useful references include Diederen et al. (2003), Feder et al. (1985), Fernandez-Cornejo (2007) and Pannell (1999). Fewer studies have examined the overall agricultural innovation process or the productivity impact associated with innovation adoption in agriculture. This means there is little information available to Australia’s governments and research organisations for evaluating the expected impacts of different R&D or innovation incentives.

The collection of national innovation data in the 1990s improved studies of innovation at the firm level. These studies often use a linear model of the innovation process of a firm, similar to that defined by Crepon, Duguet and Mairesse (1998). In their model (known as the CDM model), data is used to evaluate the likelihood a firm will invest in R&D based on the firm’s characteristics. The impact of R&D effort on ‘innovation outputs’ is then evaluated, followed by the impact of innovation output on productivity (Figure K) (Crepon et al. 1998). Innovation outputs include innovative sales (sales resulting from the new products introduced), changes in market share, number of patents or publications or other similar measures.

These linear models of innovation explicitly account for the fact that innovation output increases productivity, rather than innovation ‘inputs’ or R&D directly (Crepon et al. 1998). As such, they illustrate that the effects of R&D depend critically on the innovative capacity of firms. They also allow for different types of R&D to have different productivity impacts.
This framework has been used to analyse manufacturing and other sectors in which firms undertake their own R&D and use it to produce a marketable product. In an Australian study of businesses (excluding agriculture) using ABS data, determinants of R&D intensity included market share, regulations, profitability, size, age, collaboration arrangements and other sources of ideas (Wong et al. 2007). R&D intensity was found to influence innovation output measured as the change in sales attributed to the innovation (for product innovations) or the use of an innovation (for process, organisational and marketing innovations). Innovation output was also affected by opportunities and incentives to innovate, human capital and labour skills and other firm characteristics. Productivity (measured as labour productivity) was only weakly linked to innovation output, probably because of lags and measurement errors.

Despite the appeal of the framework, the CDM model is not well suited to agriculture. Only an insignificant number of agricultural producers are likely to be involved in formal R&D. Of those that do undertake R&D, an even smaller number are likely to have patents, and it is difficult to attribute changes in sales (or farm production) to a particular innovation given that many are complementary in nature. Data of this kind is therefore not available or suitable for modelling agricultural innovation processes.

Some linear models have been conceptually adapted to the agriculture sector. Under these frameworks, R&D expenditure leads to innovations which are disseminated by extension staff and adopted by farmers, leading to performance impacts (Figure L).

However, aside from issues related to limited data availability, these models are still an inadequate representation of agricultural innovation processes. The linear model also assumes independence between variables throughout the innovation processes and excludes the complex interactions affecting agricultural production and performance. For example, it assumes that institutional arrangements and broader interactions are functioning effectively throughout the innovation process (Hall et al. 2001). A linear model also fails to account for the backward linkages within the innovation process.

Furthermore, there are a host of factors other than R&D influencing on-farm innovation decisions. In evaluating R&D investment decisions (by particular RDCs, universities or governments), their relationship to productivity might not be the most useful indicator given the lags and limited explanatory power as well as the inability to inform directions for targeting investments or policy.

Over the past decade, the linear model has become almost obsolete following recognition that a dynamic model could better reflect the complex relationship between research, innovation and productivity (Crepon et al. 1998). The linear model helps to examine the outcomes of research, but is limited in its ability to contribute to R&D planning and evaluation. Economists and other researchers
have begun to move beyond the ‘black box’ approach of innovation inputs and outputs to better focus on the underlying processes contributing to innovative capacity (Spielman and Kelemework 2009). These processes include a dynamic set of interactions and influences beyond R&D that affect the creation, diffusion, adoption and outcomes of innovation.

**A more complex framework of the innovation process**

More complex models of the innovation process acknowledge the interaction between systems of organisations, institutions, enterprises, individuals and policies that are involved in the exchange of knowledge and technologies (Freeman 1987; Metcalf 1995; Nelson 1993). The heterogeneity in these interactions over time is also recognised, particularly as knowledge stocks evolve and operating conditions change.

The innovation systems approach reflects technological changes as a process of innovation creation, diffusion and adoption leading to an improvement in production possibility and a reduction in costs (Schumpeter 1934). It also recognises different innovation types and the role of policy and institutions in influencing technological opportunities (Metcalf 1998; Schumpeter 1939). These concepts have been developed into a national innovation systems concept which has been used internationally (OECD 1997) and domestically (Cutler and Company 2008) to strengthen understanding of innovation at the national, regional and sectoral levels.

More recently, the innovation systems approach has been used to understand agricultural innovation systems (Chairatana 2000; Hall 2007; Hall et al. 2001; Spielman and Birner 2008). Many agricultural innovations are brought into use via the interaction between individual farmers and the various institutions, policies and environmental conditions that directly or indirectly influence farmer decision-making and technological change. The diversity of these relationships suggests that there will be different influences facilitating or impeding innovation adoption. The recognition of multiple agents also allows for feedback of information, rather than a unidirectional process, which can be used to improve innovations and their suitability across different users.

The innovation systems framework also recognises the multiple sources of innovation. For example, innovation can originate from a researcher, but also from an issue (such as a disease or an environmental problem), a market opportunity, a policy or a consumer demand.

Conceptualising agricultural innovation in this way enables a shift from viewing the farm as an independent innovator (as in CDM-type models), to recognising the broader linkages between clusters of firms, organisations and the economy. This framework is an appropriate tool for policymakers and R&D providers aiming to evaluate the linkages between innovation extension and adoption, the impediments to knowledge flows, opportunities for and constraints to innovating and the influence of policies within the system.
6. An integrated framework of the innovation process in Australian agriculture

The innovation system in agriculture can be defined as the context-specific factors, knowledge, practices, institutions and policies needed to put innovations into productive use in response to an evolving set of challenges, opportunities and operating contexts (Hall 2005). Heterogeneity in these factors can often explain why farms do or do not adopt an innovation and why adoption rates and patterns can differ so significantly (Fernandez-Cornejo 2007).

The growing complexity of Australia’s innovation system led the Cutler review to conclude that an innovation renewal was required (Cutler and Company 2008). The review found that while the innovation policy framework of the 1980s sought to increase supply and commercialisation of research, less attention was paid to improving the capacity of firms to adapt and apply innovations. The linkages and complexity of Australia’s rural R&D system need to be fully considered in developing an evaluation framework for rural R&D (Mallawaarachchi et al. 2009). An agricultural innovation system framework seeks to capture this concept by integrating research, extension and farming networks. It suggests that improving components of the system and the interactions between components could enable higher productivity growth within the sector.

In this chapter, a conceptual framework of the innovation process in Australian agriculture is developed. This framework forms a starting point for further analysis that extends beyond individual farms or industries to capture the wider range of factors, interactions, institutions and policies that influence farm responses to innovation opportunities (Spielman 2006b). These interactions further determine the innovation priorities, opportunities and needs for Australian agriculture to benefit from improving productivity growth and competitiveness.

The main components of the Australian agricultural innovation system are summarised in Figure M. These are the research providers, bridging institutions, farm businesses, value-chain actors and consumers. Interactions between these organisations and factors are influenced by overarching impacts relating to agricultural education and communication systems, agricultural policies and investments and other aspects of the operating environment. R&D expenditure alone is unlikely to lead to productivity improvements which depend on effective functioning of the overall innovation system. Furthermore, an effectively operating innovation system may lead to positive impacts for industry, markets, rural development and the environment.

**Agricultural research system**

‘Farm productivity impacts’ represent the suppliers of research and the creation of innovations (shown in Figure M). Approximately $1.6 billion is invested in primary industries R&D each year by the Australian Government and the private sector (Mallawaarachchi et al. 2009). The Australian Government supports agricultural innovation through funding to CSIRO, CRCs and universities. Much of this funding is directed through the Rural RDCs, which invest in agricultural research, development and extension (RD&E) on behalf of the government and industry. The RDCs are co-funded by industry through compulsory producer levies. The structure and scope of Australia’s agricultural research system are discussed in detail in Mallawaarachchi et al. (2009).

Business investment in agricultural R&D has been increasing (Figure N). Large firms focus on those innovations for which they can appropriate benefits through licences or property rights. As the research can be protected to some extent, innovators are able to generate profits. The private sector, including overseas firms, has been a major source of product innovations such as seeds, fertilisers, pesticides and large farm machinery. These have contributed to substantial improvements in innovative capacity and
productivity in Australian agriculture. A significant share of innovation in agriculture has been supply-driven through new product innovations.

**Figure M: A conceptual framework of the Australian agricultural innovation system**

Source: adapted from Spielman and Birner (2008) and Arnold and Bell (2001)
These product innovations are typically marketed to farmers by private companies. As well as the $3.8 billion spent by the agriculture sector on services in 2005–06 (including financial, management, consultancy and contracting), other industries provided significant material inputs to the sector. These inputs include medicinal and pharmaceutical products, including pesticides ($1.4 billion), basic chemicals ($1.1 billion), other food products ($959 million) and petroleum and coal products ($885 million) (Table 3).

**Table 3: Key industries supplying inputs to the agriculture sector, 2005–06**

<table>
<thead>
<tr>
<th>Supplying industry</th>
<th>Supply ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services to agriculture, hunting and trapping</td>
<td>3 766</td>
</tr>
<tr>
<td>Medicinal and pharmaceutical products, pesticides</td>
<td>1 446</td>
</tr>
<tr>
<td>Basic chemicals</td>
<td>1 157</td>
</tr>
<tr>
<td>Other food products</td>
<td>959</td>
</tr>
<tr>
<td>Wholesale trade</td>
<td>918</td>
</tr>
<tr>
<td>Petroleum and coal products</td>
<td>885</td>
</tr>
<tr>
<td>Road and rail transport</td>
<td>726</td>
</tr>
<tr>
<td>Legal, accounting, marketing and business management services</td>
<td>589</td>
</tr>
<tr>
<td>Banking</td>
<td>451</td>
</tr>
<tr>
<td>Services to finance, investment and insurance</td>
<td>335</td>
</tr>
<tr>
<td>Water supply, sewerage and drainage services</td>
<td>289</td>
</tr>
<tr>
<td>Services to transport, storage</td>
<td>279</td>
</tr>
<tr>
<td>Communication services</td>
<td>252</td>
</tr>
<tr>
<td>Scientific research, technical and computer services</td>
<td>246</td>
</tr>
<tr>
<td><strong>Total intermediate supply</strong></td>
<td><strong>13 285</strong></td>
</tr>
</tbody>
</table>

*Source: ABS (2009), Australian National Accounts, 2005–06*
Bridging institutions

A set of formal and informal bridging institutions contribute to the dissemination of new technologies and knowledge to farm businesses. These include governments, private input suppliers and agribusiness consultants. Informal extension and knowledge through social interaction is also a valuable source of information. The RDCs are also involved in information dissemination, skills development and changing farm practices.

Given the many fragments of innovation development, disparity in farm environments and innovation suitability and the complexity of appropriating innovation benefits, public–private partnerships are a common feature of agricultural innovation systems. The Rural RDCs in Australia are one partnership source of innovation, funded by industry levies and government co-contributions. The RDCs play a key role in linking the developers and users of innovation.

Extension organisations and individuals provide information to growers through many means of communication. Many farmers are part of a local cooperative or grower group, or participate in local field days. The internet is a growing source of information and knowledge for agricultural producers in some areas. One-on-one extension is the most costly means of disseminating innovations, although the improvements in knowledge and awareness of suitable innovations are likely to be greatest.

Over the past decade, there has been greater take-up of private consultants in agriculture to facilitate innovation diffusion and adoption. This has, in part, offset the decline in the number of state extension officers performing these functions. Given the personalised nature of private consultancy services, this shift has improved the dissemination of knowledge and technologies. In particular, consultants may be able to help reduce farm managers’ uncertainty about certain innovations and improve knowledge and decision-making capacity by identifying innovations suitable to specific farmers, based on their existing technologies, knowledge and production systems.

Ensuring innovations are disseminated requires effective communication channels between researchers and farm producers. Bridging institutions can provide a good intermediary for ensuring that the outputs of research translate into on-farm adoption and corresponding productivity impacts.

Other bridging institutions include social networks, grower groups and farm organisations, political parties and the business environment. These institutions, and their proximity and relationship to farm adopters, affect the responses of farmers to R&D and changes in the economic environment. Adoption can also depend on the relationship of the farm manager to extension agents, scientists, other farmers or researchers and other information networks. Bridging institutions can also affect how knowledge is transferred and used and influence research priorities. They can also heavily influence the way R&D is disseminated, evaluated and accounted for by society (Hall 2003; Pannell et al. 2006). In agriculture, informal links are particularly useful as they reduce the transaction costs of knowledge access and use.

Farm businesses

It was noted earlier that innovation adoption by farm businesses is critical to agricultural productivity. Innovation adoption by farms can lead to a reduction in overall input requirements or increase farm output from a given level of inputs. These changes lead to productivity growth. There may also be other impacts from on-farm innovation adoption. For example, changing farming practices and farm inputs might improve production of environmental services such as biodiversity, improved water quality or carbon sequestration. Increased production can increase farm returns and profits and can also have positive spillover benefits for rural communities.

The challenge for farmers is to effectively use information, institutions and policies to inform on-farm knowledge and decision-making and improve performance.
The value chain

Value-chain actors and organisations include the upstream and downstream businesses involved in farm innovation processes, as well as consumers as the final users of farm production.

Input suppliers have already been discussed as a major source of innovation. Input suppliers may influence the innovation process by disseminating new technologies. Technological ideas might originate from overseas, from the suppliers themselves or through consultation with farmers. Farmers influence input suppliers through changing demands for particular products (such as increased demand for purchased feed during drought years), or through demanding improved product quality that enhances yield or responds to particular pest, disease or environmental pressures such as drought or frost.

Processors, distributors and wholesale and retail trade sectors can influence farm innovation through their downstream demands for particular innovations such as livestock breeds or longer shelf-life for fruit and vegetable products. These demands usually reflect the willingness of downstream operators to better market farm produce and improve consumer value. Innovation demands along the value chain can also reflect industry plans to improve transportability or manufacturing efficiency.

Farmers continue to respond to changing consumer demands. These have evolved over the past few decades with changes in consumer awareness and preferences, particularly about health and the environment. Changing consumer preferences have also influenced the direction of agricultural innovations.

Agricultural policies and investments

Australian Government involvement in agricultural innovation has been mostly targeted at R&D. Government intervention in R&D reflects the positive spillover effects of research, whereby research benefits spread beyond those directly involved in the research (Mallawaarachchi et al. 2009). These spillovers provide a disincentive to private research investment because the full benefits cannot be captured and others are likely to ‘free-ride’. Australian governments have responded to this issue through funding R&D through the RDCs, providing incentives (for example, tax credits) for private R&D and enforcing intellectual property rights to better protect returns to the innovators.

Both the quantity and allocation of government R&D investments can have wide implications for innovation. However, efficient allocation of R&D investment that maximises the expected social benefits from research is a challenging task given the difficulties in measuring returns. Social returns include increases in agricultural productivity, as well as environmental benefits and spillovers to other sectors (Mallawaarachchi et al. 2009).

Australian governments also influence the innovation process and the innovative capacity of farms through laws, regulations and policies that affect the feasibility and incentives for innovating. These policies may relate to trade, investment incentives, environmental regulations, biosafety protocols, intellectual property rights or a range of other policies that influence the development and use of innovations.

Innovative capacity can be significantly enhanced by government efforts in removing impediments to innovation or tailoring innovation incentives to particular sectors. The Cutler review concluded that significant focus should be placed on improving the capacity of firms to apply the products of science and research (Cutler and Company 2008). In particular, areas with potential for government support in promoting innovation include improving human capital, information and knowledge infrastructure (such as broadband access) and ensuring that access to R&D outcomes is not overly costly to farm businesses. Regulatory barriers to agricultural innovation, such as those implemented by certain states relating to genetically modified crops and vegetation management, are examples of where governments could be dampening innovation effort.
Agricultural education, learning and communication systems

Agricultural education systems depend on a combination of scientific, technical, entrepreneurial, communication and managerial skills. The ability of actors within the innovation system to communicate and share skills is required for effective innovation adoption.

A strong, fundamental, rural research system is essential for Australia to have the innovation capacity required for productivity growth. This depends on rural education at primary, secondary, post-secondary and tertiary levels. This education system is also necessary to skill staff in extension organisations and at the farm level. Education has been found to be a key determinant of innovation adoption, with educated farmers more likely to innovate. Lack of knowledge about increasingly complex farming systems has also been raised by farmers as a constraint to long-term productivity growth (Jackson 2010).

Operating environment

Other aspects of the operating environment can enhance or hamper competition, cooperation and learning. In Australian agriculture, characteristics of rural communities and biophysical environments can significantly affect innovation capacity. For example, water scarcity, soil quality and climate variability have led to major shifts in research priorities and technological development.

Broad developments in science and technology, and associated policies, have also contributed to farm productivity. For example, innovations in ICT, biotechnology and global positioning system (GPS) technology developed in the broader scientific community have enabled more specific agricultural applications. There are more than 600 farm-specific software programs and several developments in biotech crops and precision agriculture using GPS. However, the adoption of these innovations requires an appropriate policy framework and communication mechanism for transferring these innovations to farmers and improving the capacity for them to be effectively integrated into farming systems.

New pressures and opportunities for innovation have risen from globalisation. For example, price volatility on global commodity markets creates inherent risks in agricultural production and can distort production and innovation decisions.

International factors and overseas flows of knowledge and technology are an increasing source of productivity gains for Australia as a small, open economy (Productivity Commission 2007). Global investment in innovation has increased significantly over the past decade as a result of an increasingly competitive global marketplace. Given Australia’s small domestic R&D capacity, involvement in strategic collaborative research will enable Australia to take advantage of technologies, experience and strategies developed overseas to generate productivity benefits.

Foreign agri-business companies are already heavily involved in the creation, distribution and adoption of agricultural innovations in Australia, as well as in the production, processing, marketing and distribution of agricultural inputs and outputs.

Backward linkages

While the discussion has focused on the forward linkages from innovation creation, diffusion and adoption, backward linkages have also been important to the innovation system. For example, both consumer and farm producer demands have led to the development of new crop varieties with higher yields or different traits. Market preferences have led to innovations in organics, biotechnology and crop varieties with advanced properties such as drought tolerance and enhanced nutritional value. Agricultural innovations are also increasingly focused towards addressing environmental concerns, such as soil quality. The feedback and ground-level knowledge passed from farmers to researchers is invaluable in an effective innovation system.
The innovation systems approach develops from the linear framework to recognise the constant interactions between organisations and individuals who create and use knowledge and technologies. Effective communication between these factors, through formal and informal networks and partnerships, is important for innovation adoption and productivity growth.

Most often, research and analysis seeking to improve productivity growth has focused on improving research capacity. A key challenge remains also in improving innovation capacity and identifying new ways to do so. Innovation capacity emerges through a system of interactions which can determine innovation adoption and impacts (Lundval 1992).

**Innovation adoption and productivity impacts**

While innovation is required for changes in farm productivity, it does not guarantee productivity improvements. There can be several stages of the innovation adoption process affecting eventual productivity impacts. These include the initial decision to innovate, the extent of innovation (innovation intensity), the output of innovation (change in inputs or outputs or other factors) and then the performance impact (Figure O). The productivity impact depends on the extent to which changes in total outputs exceed changes in total input use.

Many innovations involve substantial upfront costs. As a result, farms are likely to experience an increase in total input use when they initially innovate. Comparatively, changes in output or production are likely to be more gradual, depending on the production system and product mix among other farm-specific factors. As a result, productivity can fall in the short term as a result of innovation adoption and there are likely to be lags between innovation adoption and productivity growth. Nevertheless, adoption suggests that the overall gains from innovating are expected to outweigh these short-term costs.

There are also feedbacks within this part of the innovation system. For example, high productivity growth and improvements in performance can affect future adoption behaviour and innovation expenditure. Productivity growth can significantly affect farm innovation capacity and vice versa.

**Figure O: Innovation adoption and farm performance**

![Diagram](source: adapted from Kemp et al. (2003))
7. Modelling agricultural innovation processes

There has been a major increase in research on innovation in recent decades. The shift towards innovation analysis reflects two main factors. The first is the developing idea that innovation is an important aspect of productivity growth and economic performance, yet is not well understood. The second is the collection of data through national innovation surveys, which have expanded analytical capabilities. These surveys have recently been adapted to cover agricultural industries, including in Australia (Diederen et al. 2002; Liao and Martin 2009; Spielman and Kelemework 2009). Yet methods for empirical estimation of agricultural innovation remain in their infancy.

There has been limited empirical work evaluating the effect of innovation systems for productivity growth in agriculture. Some work has overcome data and methodological constraints by simplifying the process (using a linear model of R&D and productivity), or by isolating one aspect of the innovation process for analysis (for example, determinants of farm innovation adoption by farmers).

Both styles of analysis have limitations. As discussed in chapters 5 and 6, it is unlikely to be possible to generalise a simplified expression of agricultural innovation as a relationship between R&D expenditure and productivity growth. Similarly, investigating one aspect of the process, such as innovation adoption, is unlikely to reflect the diversity and dynamics of the innovation system. In evaluating R&D investment decisions (by particular RDCs, CRCs, universities or governments), their relationship to productivity might not be the most useful indicator for targeting investments or policy, given the lags and limited explanatory power as well as the inability to capture the innovation behaviour of farms and the influence this may have on productivity growth.

Adapting the CDM model to Australian agriculture

A linear, CDM-type model—as proposed by Crepón, Duguet and Mairese (1998)—for Australian agriculture would ideally look at the relationship between R&D expenditure, innovation adoption and productivity growth. However, such studies are constrained by a lack of farm-level data on innovation inputs, outputs and impacts and difficulties in isolating the effects of individual factors such as innovation creation, diffusion and adoption. R&D investments are mostly off-farm and data is highly aggregated and not separable to a farm-level indicator. Patenting and other typical innovation output indicators are also not relevant at the farm level. Innovation studies have therefore typically assessed macro level or industry relationships, making it difficult to identify sources or obstacles to innovation (Hanel 2008).

Innovation surveys have improved innovation data availability. It is now possible to assess the innovation activities of farms and the extent of innovation adoption and the distribution of innovation behaviours within an industry. However, it remains inappropriate to evaluate public R&D or extension efforts on a per farm basis, and it is difficult to deflate these investments by the number of farms (Huffman 2009). The difficulties in disaggregating the benefits of research and extension are well documented (Huffman 1978; Norton et al. 1984; Huffman and Evenson 1993).

Given a database on ‘Current Research Information Systems’ (CRIS), the United States Department of Agriculture has been able to evaluate how R&D investments are allocated across research projects. Further analysis is then done based on those R&D projects likely to influence productivity at a state level (Huffman 2009). The relationship between R&D and productivity growth is likely to be more realistic using this disaggregated data; however, key aspects of innovation diffusion and adoption processes are not reflected.
While farm innovation surveys have been designed to better capture the innovation process, they are only an imperfect representation of the process. Most importantly, these data cannot be easily linked with aggregate R&D expenditure data. Alternatively, the farm-level processes within the innovation system can be evaluated with a CDM model. This model excludes R&D expenditure as an innovation input which is rarely undertaken at the farm level. Instead, farm-level innovation inputs are considered. Innovation adoption is not costless and typically involves some investment in technology, levies, licences, training or advice from consultants.

An adapted CDM model could compare:

i. the factors determining a farmer’s decision to adopt an innovation

ii. the investment (at the farm level) in innovation adoption as a measure of innovation ‘intensity’

iii. the innovation adoption itself as a measure of the innovation process

iv. the innovation output in terms of changes in production, reduction in costs and so on

v. the outcomes for farm-level productivity growth.

Existing ABARES data enables analysis of (i) and (iii). However, innovation intensity has not been measured (apart from a qualitative indication of ‘extent of innovativeness’). Innovation impacts have also not been measured and might be difficult for farmers to personally assess. This is certainly the case for innovations that are complementary, or those that take several years to influence performance.

It is possible to expand on this approach to capture some aspects of innovation systems by also examining the determinants of innovation intensity (Kemp et al. 2003; Klomg and Van Leeuwen; Loof et al. 2001). These include obstacles to innovation, information used for innovating, innovation objectives and access to cooperation. These factors have had variable influences on innovation intensity and innovation outcomes in different countries and industries. Data on these factors are not available for Australian agriculture at this stage.

A farm-level analysis of innovation adoption could capture part of the broader influences affecting farm innovation adoption decisions and their impacts, including the effect of R&D decisions. Data collection required to undertake such analysis is discussed in Box 3. These data will improve the ability to understand farm-level processes that translate R&D and other factors into realised productivity gains, particularly if farm-level innovation data can be linked to influences relating to economic, institutional, policy, environmental and technological developments. However, it is not able to explicitly estimate the linkages between R&D expenditure, innovation adoption and productivity growth.

Despite the likely shortcomings in terms of attribution, there remains high value in collecting and analysing farm-level innovation data. More than any other factor, productivity growth is a reflection of farm-level decisions relating to inputs and outputs, and hence the willingness and ability of farm managers to take advantage of technological opportunities.

Differences in innovation adoption decisions can lead to substantial variability in productivity between farms and can indicate significant scope for improving productivity growth beyond the development of radically new technologies (Productivity Commission 2005, 2008). Innovation data can therefore assist in understanding the opportunities for lifting productivity through increased adoption of existing technologies and knowledge, or through exit of farms with little innovativeness.

Any studies of these kinds need to carefully consider the implicit assumptions about changes in technologies, preferences and institutions (Lundvall, 1995). In some cases, the broader conceptual platform of the innovation system may be more useful in overcoming these limitations and evaluating the reasons behind innovation adoption and productivity growth.
Modelling agricultural innovation systems

Broader conceptualisation of the innovation process under an innovation systems framework has become commonplace. The system is one of many factors and influences interacting within an operating environment. The conceptualisation of innovation systems is quite advanced, yet empirical testing of these systems remains limited. Application of innovation systems for informing policy decisions and developing mechanisms to strengthen innovation adoption is therefore lacking (Spielman 2006b; Spielman and Kelemework 2009).

Understanding and estimating the relationships between innovation systems and productivity requires that several factors be considered in addition to R&D. However, estimating any kind of broad analytical framework always poses difficulties. There is no framework for assessing the innovation system analogous to the production economics framework for assessing production impacts. The inputs and outputs into the process are too numerous and qualitatively variable to be analysed by an econometric model (Horton 1986). Productivity analysis is ill-equipped to analyse these factors and their impact in driving or constraining productivity growth, and empirical information on their effects is limited. There is a need for continued research to improve data, econometric tools and understanding of economic behaviour and relationships.

There remains great potential to expand analysis of innovation systems if methodological and data constraints are overcome. Developing this field is important for sensible comparisons of investment and policy options aimed at increasing agricultural productivity growth. Identifying a clear linkage between

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**Box 3: Future data requirements for innovation and productivity analysis**

Recent efforts to improve data on innovation need to be maintained. At this stage, ABARES innovation data cover only two years so it is not possible to determine the relationship between farm ‘innovativeness’ and productivity growth, given the long-term nature of productivity impacts. It is also not yet possible to gauge how farm innovativeness has changed over time. Collection of this data on a biennial basis is required to develop understanding in this area.

Data collection currently covers innovation activities and their extent. But there are also other variables that could further develop analytical capacity in understanding of farm innovation and its effect on performance. Data on these variables would allow for a farm-level analysis of innovation adoption and productivity growth similar to the CDM framework used for large-scale firms. The survey questions listed below are commonly included in some form in national innovation surveys (for example, ABS 2005)

Survey questions that would add valuable knowledge in this area are:

- **Innovation acquisition**—how was innovation acquired? Examples include equipment purchase, employing new skilled staff, paid advisor or consultant.

- **Innovation costs**—what are the costs to farms of innovating? For example, levies, licences, training, consultants related to innovation activities.

- **Innovation objectives**—why do farms adopt certain innovations? For example, to improve productivity, profitability, environmental management or for other objectives.

- **Innovation obstacles**—what are the barriers to innovation adoption? Examples include costliness, skills, economic risks, availability of credit, government regulations or standards, lack of consumer demand, lack of information.

- **Sources of innovation information**—where did the farm source its innovation? Examples include clients, customers, input suppliers, RDCs, government agencies, private consultants and training activities such as conferences, meetings and private research.

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research and adoption of innovation and ensuring a strong connectivity between the two is important in allowing the best use of R&D resources (Mallawaarachchi et al. 2009).

Initial work towards benchmarking innovativeness in agriculture has been conducted by the Agricultural Science and Technology Indicators (ASTI) initiative led by the International Food Policy Research Institute (ASTI 2009). As with other organisations, ASTI has recently shifted its focus from R&D to the broader innovation system to better reflect the information needs of policy decision-makers and stakeholders. However, developing appropriate innovation indicators to reflect the innovation system perspective remains a challenge. Data sources are unlikely to be sufficient for capturing the subtle characteristics of an innovation system (Spielman and Kelemework 2009).

Spielman et al. (2009) outline the first application of an innovation index for agriculture. The components of the index are: knowledge and education; bridging institutions; business and enterprise; and the enabling environment. Existing data has been used where possible, although proxies are often used to capture aspects of the innovation system and in many instances no suitable proxy is available. As full coverage is likely to be time-consuming and expensive, the ASTI initiative has restricted further work to assessing agricultural R&D. This includes the inputs into R&D agencies, R&D process and R&D outputs from these agencies. However, the work will be limited to R&D systems, as expanding analysis to consider R&D linkages to the broader innovation systems was found to be too complex and cumbersome. A similar program to evaluate the effectiveness of rural R&D programs in Australia could be initiated if survey participation from private and public research agencies was agreed to.

Nevertheless, before the innovation system can be measured, it is necessary to understand the types of influences on innovation processes and their likely effects. For example, the interacting forces in the agricultural innovation and productivity system have increased over the past few decades with developments in policy, IT, labour mobility, globalisation and environmental conditions and awareness. Conceptually, documenting these processes (as in Chapter 6) is the first stage of recognising the role of R&D, innovation adoption and various other factors influencing productivity growth in Australian agriculture.

It is likely that productivity growth could improve through targeted effort in these areas, but it is unclear where efforts should be targeted. It is likely that other complementary tools are required to assist in decisions about funding, research direction and appropriate extension systems, as well as for individual farms in deciding which innovations to adopt and to what extent. Multiple assessment methods, including surveys, case studies, adoption studies, econometric analysis and further qualitative work, could contribute to improved understanding of innovation systems in Australian agriculture.
8. Implications

Understanding the relationships between R&D, innovation and productivity growth in agriculture is important for ongoing growth, viability and competitiveness, yet these are still poorly understood. As recognition of its importance spread, innovation has become a popular topic internationally (Hall 2005; OECD 1997; Spielman and Birner 2008) and in Australia (Cutler and Company 2008; Productivity Commission 2007) with respect to both agriculture and the broader economy.

Australia’s rural RDCs and other research centres are under growing pressure to enhance their contribution to rural objectives—including productivity growth, farm performance, environmental protection, climate change mitigation and food security—and to demonstrate the on-farm impacts of their contributions. However, these organisations operate within a complex, dynamic and evolving operating environment. Changes in the environment can influence the demands on research organisations, the way they operate and how they interact with other aspects of the innovation system and the outcomes of their work for productivity.

In identifying a wider set of options for enhancing productivity growth, it then becomes important for researchers, institutions and policymakers to understand their individual contributions to productivity growth. However, the growing interactions and complexity of the innovation system has made attribution to individual investments or research unfeasible in many cases.

Quantitative evaluations of agricultural research investments and decisions have been dominated by economic impact assessments, mostly focusing on R&D and productivity relationships. These have assisted in accountability and public awareness of the role and impact of public research in particular. However, they are less useful in understanding how to best design and target policies and investments to contribute to innovation systems and influence farm performance.

The development of the innovation systems framework has broadened global perspectives about the dynamic forces influencing innovation adoption in agriculture (Hall 2007; Spielman 2006a; World Bank 2006b). Investors in R&D influence productivity growth indirectly as farms realise productivity gains by deciding to adopt or adapt external knowledge and technologies. Investment and institutional factors affect productivity growth and farmers’ innovation capacity, but other factors also affect farmers’ innovative efforts and abilities to put knowledge into productive use.

This report discussed many factors that may influence a farm manager’s decision-making process when deciding whether or not to innovate. Despite some innovations appearing to be particularly beneficial, some farm managers are likely to have legitimate reasons for not adopting. Increasing the adoption of innovations in Australian agriculture will depend, in part, on the ability of governments and institutions to facilitate more rapid diffusion of innovations.

Productivity growth requires efforts to improve innovation capacity, not just R&D capacity for science and technology. As a result, demand for a measure of agricultural innovation has emerged that extends beyond the linear input and output approach to investigate the underlying processes influencing innovation capacity and the creation, diffusion and adoption of knowledge in the agriculture sector (Spielman and Kelemework 2008).

Extending analysis beyond the linear framework can contribute substantial insight to the determinants of productivity growth in Australian agriculture. This report has outlined the links between R&D, innovation, productivity growth and a host of external influences, interactions and feedbacks. Achieving high returns from research depends heavily on the effective functioning of markets, extension, value chains, infrastructure and other institutions. But while the innovation systems framework improves our conceptual understanding, it is not well suited to empirical estimation.
Despite a lack of empirical work, the shift in perspective towards the innovation system is useful in identifying new ways to encourage innovations. It offers insight into the complex relationships between farmers, institutions, public policies and socioeconomic contexts in agriculture (Hanel 2008; Spielman 2006a). For example, innovation capacity is likely to improve if a set of heterogeneous factors make new ideas and knowledge available, if integrative processes of communication, information exchange and learning are supported and if sufficient incentives exist to stimulate innovation adoption by farms. The pathways through which these factors influence productivity growth can be easily visualised using the framework.

Recognition of a wider set of factors has shifted emphasis of the mechanisms which may best strengthen innovation systems and, ultimately, support productivity growth. These can be broadly characterised as follows:

- create opportunities for innovation—new R&D, interaction with related research activities, regional specific innovations
- increase awareness of innovations—focus on attitude change, target misconceptions, promote research outputs, invest in education and extension, reduce information gaps, demonstrate benefits of innovation through trials
- improve innovation capabilities—address high entry costs to innovation, increase skills, encourage farms to put new knowledge to productive use, improve market access.

Integration of research systems has already improved in recent years, with various agencies working together to meet common objectives. The development of a national primary industries RD&E framework is also underway (DAFF 2010). Ongoing productivity growth in agriculture is likely to require a coordinated approach across the innovation system to use funding efficiently and effectively to strengthen innovation capacity. For example, knowledge sharing and dissemination of research outputs is imperative to the innovation system yet has not always been a key component of research proposals. Further development of linkages between extension staff and farmers is likely to improve innovation adoption and productivity growth.

These sentiments have also been emphasised internationally. In March 2010, the Global Conference on Agricultural Research for Development highlighted that access to research was constrained by lack of skills, finance and technology. In addition, efforts to promote broader access to information are affected by underinvestment and a lack of diverse approaches to knowledge sharing (GCARD 2010).
9. Recommendations

A broader conceptual framework, as provided in this report, is the first step in evaluating the impacts of R&D, innovation diffusion and innovation adoption for productivity growth. A combination of analytical methods are likely to be useful in using this framework to further evaluate research and priority setting of rural RDCs and governments aiming to increase productivity growth. In addition, procedures that are cost effective, can incorporate multiple research programs and can assess tradeoffs against multiple objectives are required (Alston et al. 1995). There are three main strategies likely to assist RDCs and governments in further evaluating R&D, innovation and productivity relationships.

Use the innovation systems framework

Australian agricultural research agencies can use the innovation systems framework to improve training and understanding of how research is communicated to users, the underlying processes involved and the importance of innovation adoption for productivity impacts. Under the innovation systems approach, the focus of research agencies broadens beyond R&D and extension to improving linkages, strengthening partnerships, building skills and creating an enabling environment for innovation and productivity growth. These agencies should use the framework as part of program decision-making and evaluation and to develop broad approaches to knowledge transfer that contribute to enhancing the innovation system. This requires that research agencies have the capacity to monitor and evaluate various components of the innovation system to identify measures that will improve the linkages between R&D expenditure and productivity growth. These components may relate to knowledge sources, research systems, extension systems, policy, and institutions or to characteristics of the farm itself.

Australia’s RDCs have a unique capacity as an intermediary between disparate aspects of the innovation system. The RDCs hold experience in RD&E. Expanding their expertise in governing networks, linkages and knowledge transfer would enable them to further stimulate innovation processes.

Evaluate the innovation system in Australian agriculture

A series of case studies of innovation system components could assist in understanding particular aspects or perceived constraints within the innovation system and could enable investments and policies for research and innovation to be better directed towards facilitating productivity growth.

Given the diversity of actors and institutions within the innovation process, the variability in their productivity impacts, and the lack of information on these factors, a case study approach remains the most viable alternative. These case studies could assess the range of influences outlined in the conceptual framework.

Case studies could assist in evaluating the effects of specific policy and investment decisions aimed at research and innovation, as well as devising policies and investments that contribute to higher productivity and economic growth. Given the linkages characterising the innovation system, these effects are likely to change as internal and external circumstances change.

Expand data collection and analysis

Data collections should cover a greater set of innovation determinants at the farm level. This will improve the ability to measure and evaluate innovation adoption and productivity growth drivers and linkages.

There exists insufficient capacity to conduct in-depth data analysis and to disseminate results. Limited data and analytical capacity is restricting opportunities to inform relevant research agencies and
government policymakers about the relationships between R&D and productivity growth and the contribution of various factors within the innovation system. For example, the ABARES farm innovation survey has not been funded on an ongoing basis and risks discontinuation. Irregular surveys or long intervals between surveys means that capacity and experience is often lost.

There remains a need for greater monitoring and evaluation of the impacts of agricultural R&D. The RDCs could assist through expanding data collection and analysis through a consistent format developed under the innovation systems framework.
References


Freeman, C 1987, Technology and economic performance: lessons from Japan, Pinter, London.

Fuglie, KO and Heisey, PW 2007, Economic Returns to Public Agricultural Research, USDA-ERS Economic Brief no. 10.

GCARD 2010, Knowledge, information and advice in agri-foods systems, Global Conferences on Agricultural Research for Development, Montpellier.


Hanel, P 2008, Productivity and innovation: an overview of the issues, Note de Recherche, CIRST, Quebec.


Marsh, SP 2010, Adopting innovations in agricultural industries, paper presented at the ABARE Outlook Conference, Canberra.


——2009, Inquiry into raising the level of productivity growth in the Australian economy, Submission to the House of Representatives Standing Committee on Economics, September 2009.


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Innovation is a key driver of productivity and economic growth and of the competitiveness of agriculture and other industries. However, because the innovation process is complex and innovation data is limited, its links with R&D investment and its effects on productivity are difficult to quantify.

This report evaluates the role of innovation adoption within the agricultural innovation process. Specifically, a conceptual framework is developed to assess the innovation process and the interacting drivers influencing innovation adoption and productivity, including R&D investment.

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