



Promoting productivity in the agriculture and food sector value chain: issues for R&D investment

Thilak Mallawaarachchi, James Walcott, Neal Hughes,
Peter Gooday, Lee Georgeson and Adam Foster

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Australian Bureau of Agricultural and Resource Economics

Postal address GPO Box 1563 Canberra ACT 2601 Australia

Location 7B London Circuit Canberra ACT 2601

Switchboard +61 2 6272 2000

Facsimile +61 2 6272 2001

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Summary

Domestically and internationally, natural resource scarcity and climate change effects are making it increasingly difficult to meet growing demands for food and other farm-based goods and services. For Australian agriculture and food producers to maintain international competitiveness and ensure environmental sustainability, productivity growth is essential. In pursuing these productivity gains, increasing productivity per unit area is becoming more important given the constraints on increasing the area of production.

A key driver of productivity growth is the development and adoption of new production technologies. Australian farming has a strong tradition of innovation and adaptation in response to emerging challenges. Agricultural research, development and extension collectively play a key role in supporting technological innovation in farming systems and other business activities across the value chain. Traditionally, Australian governments have played a significant role in supporting and undertaking research, development and extension activities while private sector investment has performed a complementary role.

Productivity growth in agriculture

What influences productivity?

Productivity measures how well operators combine inputs to produce output. It is an indicator of the efficiency of production processes. Productivity growth is the rate of improvement on previous years' productivity and may be influenced by a wide range of factors, including changes in farm size, the rate of uptake of new technologies, the rate of technological discovery (either dependent on R&D effort or farmers' own experimentation), policy settings, market forces and climate variation.

The influence of climate variability and change on farm productivity is of particular interest. Droughts are expected to lead to declines in measured productivity, such that in the short run productivity may display significant variability. In the long run, productivity growth may be achieved through technological progress, gradual adoption of new technologies on existing farms, as well as lower performing farmers leaving the industry for opportunities elsewhere in the economy.

Recent trends

While agricultural productivity growth fluctuates sharply from year to year, largely in response to seasonal conditions, the long run trend of total factor productivity (TFP) growth in agriculture has remained relatively strong, particularly when compared with the private non-farm economy.

In the past 20 years, the cropping industry has experienced higher productivity growth than the beef, sheep and mixed crop-livestock industries. ABARE analysis of past productivity performance in the broadacre agriculture sector indicates that productivity varies within and between industries and regions.

Productivity growth in broadacre agriculture appears to have slowed over the past decade, and recurring drought has been a major factor behind this downturn. An increase in cropping activity in lower rainfall areas may also have increased the sensitivity of the sector to rainfall variability.

Rural R&D and agricultural productivity

Research and development is a well-known pathway to productivity growth. R&D activities may contribute a range of technological advances and knowledge that may lead to improvements in agricultural productivity in the long run. While there are significant time lags in this response, it is generally acknowledged that:

- expenditure on agricultural research generates new knowledge that eventually leads to improved technology
- improved technology may require new investment and practice change, but technology adoption by farmers increases productivity overall
- higher productivity of agricultural resources lowers production costs, increases output (often involving less land), and releases some resources (such as labour) from agriculture to other sectors of the economy
- higher agricultural production tends to lead to lower commodity prices, passing some of the benefits of innovation on to the food industry and consumers.

Historically, Australian farmers have relied on productivity growth to counter the long-term deterioration in the terms of trade, where input prices have increased at a faster rate than output prices. Since the early 1990s, deterioration in the terms of trade has slowed and recent productivity growth has contributed to real growth in the long-term profitability and competitiveness of the agricultural sector.

Economics of R&D policy

The primary role of R&D is to provide information and knowledge to resolve uncertainties or gaps in understanding. Technological innovation and the adoption of those technologies by farmers may vary depending on the risks farmers face and their ability to benefit from new technologies, including the costs of change. These affect the demand for R&D and influence the incentives to provide R&D. A brief discussion of the economics of research and development policy is provided in this report to help frame possible policy responses to improve future agriculture R&D outcomes.

Government intervention in R&D

Government involvement in agricultural research is typically justified on the basis of a divergence between the private and social benefits of research. The concept of a 'positive spillover' effect— the potential for many parties to obtain a benefit from research, outside of those directly involved in the research— and the public good characteristics of knowledge generated through R&D are two sources of this divergence that justify government intervention in agricultural research and development activities.

Positive spillovers and the public good nature of R&D may allow the social returns to research to exceed the private returns to purchasers of research, resulting in private investment being below the socially optimal level. Governments may adopt a range of policy measures to address this problem and ensure an efficient level of research is undertaken. The Australian approach includes direct funding of research, development of levy collecting research institutions (such as RDCs), incentives for private R&D (tax breaks etc) as well as the enforcement of intellectual property rights (patents) to achieve these benefits. The critical issue for policy is to achieve an efficient balance between the level of protection sufficient to attract investment and the flexibility to ensure wider access to maximise the social benefits of R&D.

Because many parties benefit from R&D, quantifying the returns from R&D is important in prioritising the research effort. Some findings from the empirical literature that attempt to estimate the returns to rural R&D are used in this report to highlight some of the methodological difficulties.

Allocation of research funding

Regardless of the extent or nature of government intervention, the allocation of available R&D funding to specific research projects remains a challenging task. The objective is to allocate research funds to available projects, so as to maximise the expected social benefits from research. Any estimate of expected benefits should incorporate all social benefits: increases in agricultural productivity, positive spillovers to other sectors and any environmental benefits. In practice, estimating the benefits of research projects is difficult because of the fundamentally uncertain nature of research, development and extension processes.

Organisations responsible for allocating research funds face a number of significant challenges. These include: the ability to obtain adequate information on potential research projects at a reasonable cost; trading off the advantages of competitive based approaches (e.g. competitive tenders) with the potentially higher administrative costs involved; ensuring accountability so as to minimise rent seeking behaviour; being conscious of industry and regional spillover effects and therefore ensuring efficient coordination between different research agencies at the industry, local, jurisdictional and international level.

Rural R&D in Australia

The Australian rural R&D system is well-developed and complex. Initially formed as a public service to support the establishment of a local agricultural industry, the system has evolved into a purchaser-provider arrangement involving varying levels of public-private partnerships along the innovation system chain, from basic research to final adoption in commercial and public uses.

In the agriculture and food sector, the government dominates both as a purchaser and provider of R&D. Inevitably, this involves some level of duplication and high transaction costs because objectives differ between agencies that both purchase and provide these services.

Australia's 16 rural R&D corporations and companies (RDCs) are well-connected to the national research system which includes state and territory governments, CSIRO, universities

and the private sector. The RDCs are the primary vehicle for funding rural innovation by the Department of Agriculture, Fisheries and Forestry (DAFF). In 2007–08, the total R&D expenditure by these RDCs was around \$500 million and seven of the 16 rural RDCs fell within the DAFF portfolio responsibilities.

A number of recent studies have assessed patterns, motives and effectiveness of rural R&D. They include: Mapping Australian Science and Innovation, conducted by the then Department of Education, Science and Training in 2003; the Productivity Commission's review of Public Support for Science and Innovation, in 2007; and the Cutler review, *Venturous Australia: building strength in innovation*, in 2008. These studies illustrate the achievements of rural R&D and highlight opportunities for enhancing its effectiveness.

The Productivity Commission noted that the governance design for RDCs may be improved through routine program evaluation employing rigorous and transparent methods. The Cutler review suggested that while the R&D system requires renewal, a significant focus should be on improving the capacity of firms to apply the products of science and research.

Rural R&D has forward and backward linkages to both private business and academic sector research activities, in particular with regard to the initial discovery process that leads to innovations later in the research value chain. The linkages to the broader innovation system and the complexity of the rural R&D system need to be fully considered in designing mechanisms to enhance the effectiveness of rural R&D.

Rural R&D performance

R&D performance data

An examination of ABS data indicates that the data are useful for the purpose of identifying broad areas of scientific effort. However, the data are of limited value for aggregating or scaling up this information to outcome categories, as often required for assessing R&D effectiveness. In particular, it is difficult to derive the contribution of different scientific fields to an outcome such as those relating to yield improvement or reducing the application of an input because the result is derived from a number of fields contributing concurrently and often separately.

Moreover, a number of non-sampling errors may affect the reliability of R&D expenditure data: statistics collected are subjectively allocated to research fields, socio-economic objectives and types of activity by organisations; many organisations provide estimates because of inadequate records on R&D activity; and the estimation of overhead R&D expenditure varies across organisations. For these reasons, the ABS data remain inadequate for the purposes of the Council. The discussions relating to ABS data on research expenditure provided in this report should only be treated as a guide.

Another data source is the Australian Agriculture and Natural Resources Online (AANRO), which is as an integrated database for agriculture and natural resources research. The key drawback with regard to measuring R&D effectiveness with these data is the difficulty in determining the extent to which research outputs are being used. ABARE farm surveys and ABS data relating to agriculture and land use offer key sources of information, in particular for analysing linkages between R&D adoption, productivity and profitability.

In designing a monitoring and evaluation framework for rural R&D, the advantages and weaknesses of existing data sources and their relative costs need to be taken into account.

R&D priorities over the past decade

Ideally, R&D effectiveness may be examined in terms of effort, capacity and quality of outputs. Historical (1992-93 to 2006-07) ABS data on inflation-adjusted R&D expenditure shows a number of broad trends. Expenditure on agricultural R&D has increased slightly over the period 1992-93 to 2007-08. There has been a relative decline in effort by the state agencies, and to a lesser extent the Australian Government, which has been offset by increases from the higher education and business sectors. R&D expenditure on plant production has increased relative to the gross value of production (GVP) of plant based products, while R&D on animal production has declined over the same period.

The emphasis placed by different provider sectors on rural R&D has evolved, with the state agencies maintaining a relatively high emphasis on rural R&D, although their share of national rural R&D has declined from around 52 per cent to 37 per cent over the decade 1996-97 to 2006-07. Overall, rural R&D expenditure as a proportion of total Australian R&D expenditure has declined from 8.6 per cent in 1996-97 to 5.6 per cent in 2006-07.

Moreover, it should be noted that since around 1990, following a global trend, the focus of national R&D priorities shifted to longer term goals such as 'an environmentally sustainable Australia' and 'frontier technologies for building and transforming Australian industries'.

Studies now question whether this focus could have inadvertently imposed a drag on productivity growth in the short to medium term. Realigning objectives and adjusting management practices to address environmental pollution and related concerns involves immediate costs to operators, whereas the benefits may not be realised for many years and may largely accrue to the public. As a consequence, expenditure increases immediately but outcomes are seen gradually.

Moreover, some authors also argue that shifts in expenditure with a focus on environmentally-friendly R&D may have come at the expense of other R&D investment and could have dampened the overall gains from induced technological change.

The higher education, business and non-profit sectors devote a low proportion of their total effort to rural R&D. Nevertheless, the higher education sector plays a dominant role in the provision of basic research and creates opportunities for synergies with other research streams. Their catalytic contribution to R&D-led innovation in the agriculture and food sector could be enhanced through better coordination and governance mechanisms.

Influencing future productivity performance in agriculture

Agriculture, both in Australia and internationally, faces a range of increasing resource and environmental constraints, including land degradation, pests and diseases, climate change impacts and water scarcity. In the long run, agricultural industries must search for productivity improvements to help overcome these resource constraints.

Traditionally, cost efficiencies gained through technological innovations have played an important role. As resource constraints tighten over time and demand pressures intensify, addressing such constraints may come at an increasing cost. Among the feasible options, an ability to produce higher value commodities at a competitive price is likely to become increasingly important.

Experience suggests there may be many options for enhancing productivity in the sector. Historically, agricultural competition in global markets has driven investments in research, education and technology transfer. Overall, innovation in the Australian agriculture and food sector, whether generated through domestic R&D or international research and knowledge diffusion, is a key factor in driving productivity growth. Ensuring that domestic research, development and extension activities are as efficient as possible is crucial in fostering productivity growth in the long term.

Key insights

On the basis of the discussion presented in this report, supported by available data and underpinning economic principles, a number of points can be identified.

- Links between productivity and R&D are strong, and they contribute to collective industry level outcomes and specific practices generating private economic benefits. However, the delays between innovation and adoption can be significant. The longer the duration of such lags, the lower the economic benefits and higher the chances of an innovation becoming obsolete.
- Given most agricultural innovations have benefited from spill-ins from international R&D, a better focus on understanding the heterogeneity of the resource base and identifying emerging technologies to take advantage of local comparative advantage could offer opportunities to improve productivity.
- Understanding productivity drivers, and in particular the determinants that are within and beyond the control of rural businesses, will remain key issues requiring a concerted research effort.
- Despite a notable contraction of rural R&D investment by state governments, the public sector in Australia (which includes both the government and most of the higher education sectors) is the key provider and purchaser of rural R&D. Given the small size of the Australian economy and the diversity of the Australian natural resource base and climate, this public sector dominance is expected as private sector investors have limited opportunities to capture the majority of the benefits from R&D investment.
- While the level of business R&D investment is significant, expenditure is largely directed to meeting business needs relating to increasing direct economic output. In some areas this

expenditure relates to 'quality of life' issues such as pollution, environmental quality and sustainability where they are addressed through various public-private partnerships.

- While it is true that increasing the intensity of agriculture could also increase the risk of related externalities and that private industry has a role in mitigating such externalities, a lack of clarity in the roles of public and private investment in addressing externalities and public good issues appears to be a source of ambiguity and high transaction costs in coordinating partnerships. It may have also created a degree of overcrowding in research activities, thus reducing the overall effectiveness of R&D.
- In terms of output, it is difficult to ascertain the proportion of government spending that contributes to the productivity of rural resource use activities against those that contribute to meeting broader public good outcomes that relate to improving the quality of life of Australians.
- The number of cross-cutting issues needing to be addressed has increased and a growing number of programs are attempting to address those. A clearer definition of objectives, better coordination and more effective risk governance arrangements are necessary to better align R&D expenditure for promoting productivity growth and 'quality of life' benefits from Australia's natural resources linked to the rural sector.

Productivity drivers in a changing policy environment

Linking the discovery and innovation phase of the knowledge economy

In making the best use of available resources, research activities may be viewed as involving two components: basic research and applied research. Basic research provides the means to expand scientific understanding, offering a foundation for applied research to investigate ways to enhance social benefits.

An important process to ensure the best use of R&D resources is to provide a healthy balance and strong connectivity between the discovery and innovation phases of R&D. Given the bulk of rural R&D administered through the RDCs focuses on applied research, these issues require careful consideration when developing the scope for enhancing the effectiveness of R&D in advancing broader agribusiness opportunities for the sector and in generating greater public good benefits for the community.

Enhancing international research spillovers and knowledge sharing

With the increasing integration of the world economy, and a greater appreciation of the regional differences in the productivity mitigating potential of global externalities, such as the influence of climate change on crop yields, there is an increasing need to better utilise the international research system to find locally adaptable solutions. Foreign knowledge flows, both technological and non-technological, are very important for a small open economy like Australia, and their diffusion and adoption is likely to be a major source of productivity gains (Productivity Commission 2007). Policies and mechanisms that foster strategic international collaborations, such as improving access and designing domestic R&D to assist in absorbing foreign technological knowledge flows, will help in acquiring and domesticating imported knowledge for local advantage.

Building adaptive capacity

The capacity of institutions and individuals in agriculture to adapt to changing circumstances improves with human capital, institutional support and technology that are sourced from both national and global sources. The usefulness of a given technology may be affected by regional differences in environment and natural resource availability. Capitalising on regional knowledge and technology spillovers may provide new technologies at a lower cost; however, it also requires local research capacity to comprehensively address local adoption issues and ensure new technologies are customised to local conditions.

Maximising the social benefits of government support

The Productivity Commission, while supporting the role for compulsory levy arrangements to sustain a private-public partnership in rural R&D, has not been convinced that the level of social benefits associated with aspects of rural R&D justifies the extent of public support collectively provided to the sector (Productivity Commission 2007).

The basis behind the commission's concerns is not the public support, but the social outcome of that support. The commission's longstanding preference, as alluded to in Alston et al. (1999), is to encourage rural industries to take greater financial and managerial responsibility for research that provides direct industry benefits, and for government(s) to take full responsibility for and confine its activities to research with predominantly public good characteristics.

The benefits of the research supported by RDCs are well-known and broad ranging. Their influence on innovation in agriculture is unquestionable. Nevertheless, a focus of achieving an appropriate balance between public good and private industry benefits from public R&D is important and timely because, as reiterated by the commission in 2007, the current arrangement may not provide the best mechanism to coordinate a research portfolio that addresses a number of cross-cutting issues with high levels of public good and industry strategic benefits.

The self assessment of the role of RDCs contained in CRDCC (2008) also highlights this inadequacy, and indicates opportunities for realignment of objectives to better deliver social benefits. The social benefits of government support through RDCs may thus be improved through governance reform that reflects emerging circumstances.

A case for an expanded rural R&D scope

If, in the long term, funds for science and innovation become scarcer, then gaining more value out of the R&D dollar across the economy will become increasingly important. One approach to ensure higher returns is to expand opportunities for intersectoral collaboration, particularly in studies on cross-cutting issues with significant spillover benefits. For example, there is a need to ensure adequate research is undertaken on long-term strategic responses to drought and water scarcity at a broad cross industry level, because new opportunities may involve significant realignment of resource use and industry configurations.

Monitoring and evaluation

A key factor in obtaining a greater social outcome from R&D expenditure is to strengthen R&D accountability within and between RDCs and other research providers and the public.

The RDCs already work across functional boundaries, to effectively identify and prioritise emerging research opportunities and develop them to meet market and social needs. However, given the increasing focus on cross-cutting issues that confer widespread strategic and operational benefits, more consideration to research governance, including priority setting, monitoring and evaluation, would be required.

Improved governance arrangements may provide for additional collaboration and co-operation between the different RDCs where there is significant overlap or greater opportunities to gain joint benefits in addressing critical public good issues. It may also provide for greater specialisation, particularly where specific industry groups or commodity lines have common private industry issues to address and pooling of resources would allow economies to be gained. Valuable lessons can be learnt from the CSIRO Flagships Program.

The Rural R&D Council's consideration of a National Australian Strategic Rural R&D Investment Plan and the development of the R&D strategy involve consideration of factors such as emerging needs, market opportunities and emerging science. To ensure adequate returns to the private-public partnership that contribute funds, a number of accountability mechanisms may be considered. They may include, strategies to ensure the optimal delivery of joint research objectives; scope for working with other relevant public research providers; and establishing processes to ensure resource prioritisation and delivery is in line with emerging needs.

Scope for an assessment framework for rural R&D

A monitoring and evaluation framework suitable for ongoing monitoring of rural R&D activities and identifying emerging gaps in R&D effort (at a broad sectoral level) that focus particularly on productivity, would involve a range of considerations:

- ability to identify broad priority needs
- capacity to monitor emerging issues and strategic directions, including emerging needs, markets and technologies
- a framework to inform near, mid and long-term rural R&D priorities and investment directions to drive change in Australia's rural sector.

The Australian agriculture and food sector has long been served by a complex web of rural R&D links spanning from local research stations to international research consortia that have supported a culture of innovation and technological change. A number of these links have been supported by rural research and development corporations that have addressed a range of production and environmental issues specific to the Australian rural sector.

Both the scope of rural R&D and the issues faced by the sector have changed and a number of cross-cutting issues that confront the future ability of the sector to remain competitive are largely in common with the rest of the economy. The recent observations of the volatility in agricultural productivity linked to climate variability may mean that diversification of activities to match changing conditions, as well as developing new outputs that capture higher returns, will be required. Rural industries are well placed to benefit from the new opportunities

presented by the growing incomes and associated diversity in tastes and preferences in the new growth markets in Asia. A key to meeting these challenges and making the best use of new opportunities will be the ability to harness new knowledge and technologies to increase productivity, market intelligence, and thereby profitability and resilience. This involves addressing a number of concerns relating to the functional effectiveness of RDCs and building stronger links with the national innovation system.

1 Introduction

Demands on natural resources are increasing and climate-related stress on the agriculture and food sector¹ is rising. As a result, meeting increasing global food demand and demand for other rural and farm-based goods and services is becoming increasingly difficult. Ensuring these demands are met affordably requires efficient production, processing and marketing that maximises productivity across the value chain.

Historically, expansion in farm production has been derived from an increase in the area of production (horizontal expansion) and an increase in productivity per unit area (vertical expansion). Although area expansion may contribute to economies of size, the increasing financial and environmental costs of new land and water resource developments limit the opportunities for area expansion. As natural resource scarcity and demand pressures increase, the focus in Australia is moving increasingly to vertical expansion as a source of growth in farm production. At the same time, minimising environmental effects of agriculture and food production systems is becoming a central issue for industry growth and development.

Australian farming has evolved to suit the broad variability in climate, soil and landscape conditions that characterise the Australian agricultural production environment. This complex production environment has required a strong tradition of innovation and adaptation amongst Australia's primary producers. The sector has proven to be resilient and competitive in growing international markets. This is particularly notable given low government support and a domestic market open to international competition. Innovation and technological change have been major factors that have contributed to competitive advantage in these markets. Technological innovation is also critical in seeking environmental sustainability goals and achieving 'clean and green' credentials for food and fibre production to satisfy the needs of an increasingly informed consumer community.

In this report, the relationship between rural R&D and productivity growth in agriculture is examined as a way of illustrating the role of research, technological change and innovation in driving productivity and business performance in the agriculture sector. The first stage of the analysis draws on published literature for available evidence to identify sources of productivity gain in the agriculture and food sector across the value chain. This includes defining the scope of rural R&D for the purpose of the Rural R&D Council and the extent of the production value

¹ For the purposes of this paper, 'agriculture' includes agriculture, fisheries and forestry; the 'food sector' specifically means the food processing industry. However, agricultural and fisheries industries are regarded as an integral part of the food supply chain, with many producing foods for consumption in a fresh or minimally processed form. References to the 'industry' or 'the rural sector' include both primary industries and the food industry unless otherwise stated.

chain to be analysed. Rural R&D capacity and effort is assessed and previous studies and research classifications reviewed. The structure of Australia's rural R&D system is examined and some issues for R&D investment for enhancing productivity are identified.

2 Productivity growth in agriculture

In recent years, Australia's primary industries sector has accounted for around \$26 billion² in gross product, representing 2.5 per cent of Australian gross domestic product and \$30 billion in exports, annually. This economic output is produced by more than 150 000 agri-businesses employing around 360 000 people or 4 per cent of the Australian workforce (ABARE 2008).

What is productivity?

Productivity measures how well operators combine inputs to produce output. Growth in productivity reflects increases in the efficiency of production processes which, in turn, occur as a result of improvements in technology or knowledge. Productivity is a contributor to economic growth which can be influenced by policy decisions, such as those affecting public investment in research, extension, human capital development and infrastructure.

Productivity measures are broadly classified as estimates of total factor productivity involving all inputs or estimates of partial productivity involving a specific input or groups of inputs. The most commonly used productivity measurement is total factor productivity (TFP). The TFP estimates that ABARE produces are simply the ratio of the total quantity of outputs produced by a farm to the total quantity of inputs inputs used by that farm.

TFP measurement illustrates trends occurring in productivity and can be used to isolate the factors that might be causing these trends, but it does not demonstrate how or why these factors are important. Trends in TFP are often a trigger for more detailed investigation into how productivity may be improved.

Factors influencing productivity

Productivity, as the rate of output per unit of input, may be influenced by a wide range of factors. In the agricultural context, the primary inputs of production include land, labour, capital and material inputs, while outputs include crop and livestock products. Agricultural productivity levels are determined by the scale, output mix and technical efficiency of farms as well as and the state of available production technology, and are therefore influenced by factors such as: seasonal conditions, enterprise mix, farm size and farm operator human capital (age, education/training etc.).

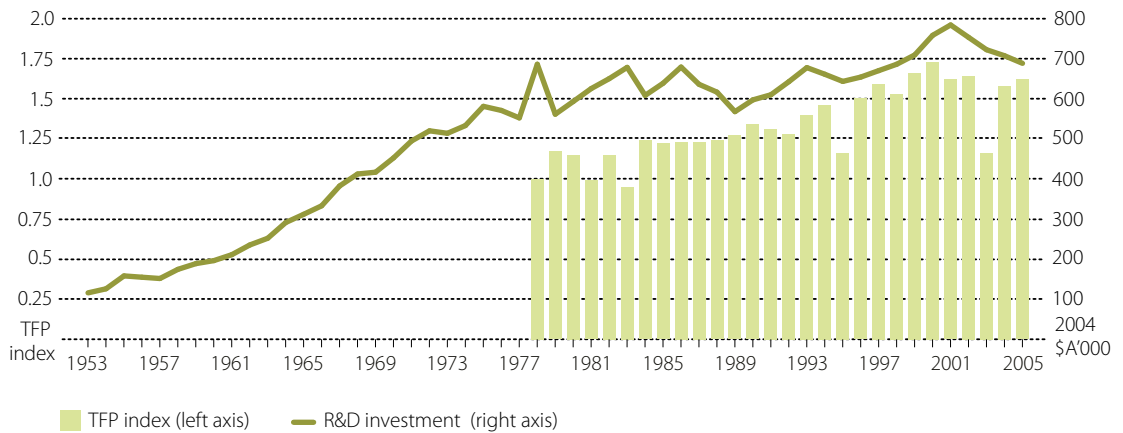
A number of underlying factors, in turn, determine the degree of influence of the above factors. For example, agricultural research, development and extension activities (which contribute to the state of available production technologies and the rate of adoption of new

2 Average gross product over 2000-01 to 2007-08 for farm, forestry, fishing and hunting in real 2007-08 dollars.

technologies by individual farms) are widely acknowledged as key factors in achieving long-term growth in productivity (figures a and b). The relationship between R&D and productivity is discussed in detail in the following chapter.

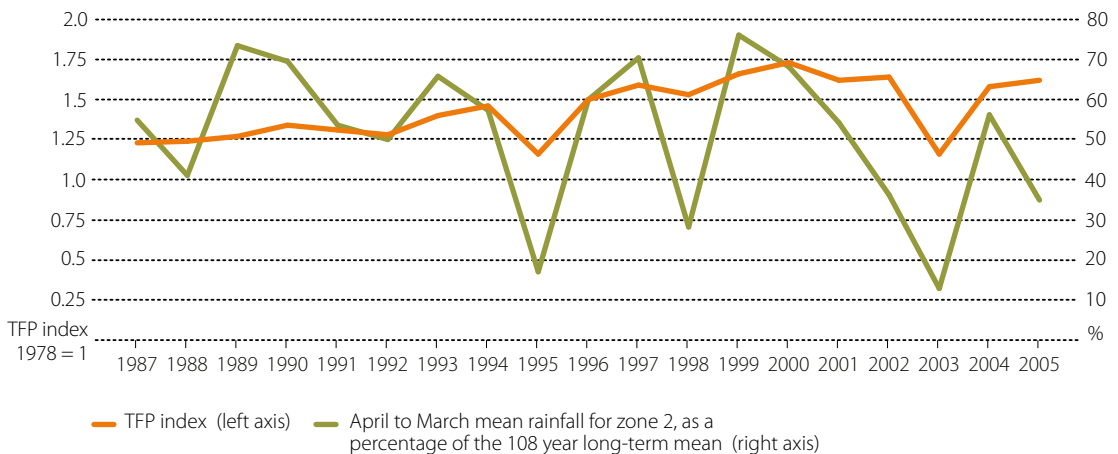
Climate variability is also known to have a significant effect on measured productivity growth, particularly in generating short run (year to year) variation (figure a).

a TFP growth and R&D investment



Source: ABARE and Mullen and Crean (2007).

b TFP growth and rainfall over the sheep-wheat zone



Source: ABARE and BRS.

The benefits of R&D often take some time to eventuate, and may be affected by a number of factors relating to farm structure and the capacity of operators to make informed decisions. These factors may include:

- farm financial characteristics
- biophysical characteristics of the farming system
- innovation uptake
- environmental objectives of society
- social and knowledge networks
- demographics
- infrastructure
- policy settings
- market forces.

In the current context, the influence of climate variability and change on farm productivity is of particular interest. In drought periods, a given level of farm inputs (land, labour, capital etc) will produce a lower level of output than what could be achieved under good seasonal conditions. Such effects do not necessarily reflect pure changes in productivity; rather they reflect the influence of inputs unaccounted for in productivity calculations, such as rainfall. In any case, it is important to recognise that such changes will be reflected in existing measures of agricultural productivity.

At the same time, it should be noted that Australian farmers are well accustomed to adapting to climate variability. Australian farmers have, by necessity, developed the capacity and flexibility required to adjust farming operations (including input levels, input mix and technologies) in response to changes in seasonal conditions (see for example Mallawaarachchi and Foster 2009). In addition, Australian farmers are likely to invest in 'adaptive capacity' by adopting technologies and practices that act to partially mitigate the adverse impacts of poor seasonal conditions. Such adaptability would be expected to offset the effect of poor seasonal conditions on productivity levels.

As emphasised by Alston and Pardey (1996), it is important to be clear about the distinction between measured productivity, as reported by ABARE and the Productivity Commission, and the productivity that is inherent to each production system. Measured productivity rates are influenced by measurement issues and computational issues such as index number problems inherent to long data series.

A key factor influencing agricultural productivity is the extent to which farmers make use of existing technologies. The adoption of technologies by farmers is influenced by a range of factors that determine risks and returns. They include market conditions, suitability as evident from available information, as well as a number of personal attributes such as the education, experience and expertise of individual farmers (box 1). Productivity growth will be higher where the rate of adoption and the diffusion of new technologies by farmers is rapid. Public and private extension activities that provide information to farmers on new technologies are

likely to play an important role in influencing the rate of adoption. Factors influencing the adoption of technology by farmers are considered in more detail in chapter 3.

Productivity improvements may also be achieved through improvements in the allocative efficiency of agricultural inputs. For example, microeconomic reforms, such as removal of barriers to trade in water entitlements, can influence the relative price of inputs and outputs. This will allow farmers to choose the mix of inputs to use and outputs to produce that maximises net returns given the available technology. An improvement in the allocative efficiency of particular inputs, such as water, means that water is used in its most productive uses, permitting increases in aggregate productivity (more will be produced with the available inputs and a given technology).

More generally, the efficient allocation of agricultural inputs by markets, in response to local and global developments, may act as a source of productivity improvement at an aggregate or sectoral level. For example, there may be movement away from low productivity crops or livestock activities towards high productivity ones (allocative efficiency of land). Alternatively, there may be exit from the industry of less efficient farmers and, at the same time, entry of more efficient farmers (allocative efficiency of labour). Further, as has been observed in Australia, there may be amalgamation of farms (increasing farm size), capitalising on potential economies of scale.

box 1 Adoption of technologies

Direct drill technologies in grain farming

There is often a considerable lag in the adoption of technologies once they become available. This lag may represent various refinements that are made to make adoption practical and profitable. Delays are also incurred in learning about a new technology including: testing by individual producers to gain confidence in its use and evaluate its risks, assessing the need to write off previous investments, and undertaking the investments necessary for the full take-up of new technology. This process of awareness, interest, trial and acceptance is variously influenced by how producers view the new technologies in terms of their technical viability, economic feasibility and social acceptability. The conditions that govern these criteria vary across producers, regions and over time.

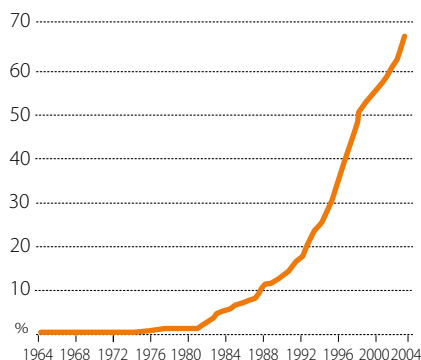
Australia's experience in the adoption of direct drill cropping (including no-till and zero-till) provides useful insights to factors influencing adoption. This form of conservation cropping has been studied over many years since becoming feasible with the development of herbicides in the 1950s. While it was first investigated in the 1960s in Western Australia, developing the initial technologies, addressing significant constraints in terms of specific selectivity and the versatility of herbicides, developing suitable machinery, and assessing economic benefits and compatibility with other practices such as a plant disease management took considerable time (Lewis 2006, Greenwood 1970 and Reeves 1974). Its adoption roughly follows the typical adoption curve (figure 1) with significant uptake beginning around 1980.

A closer analysis of data from the ABS indicates (figure 2) there has been a steady increase in the area planted using direct drill. The adoption has been most widespread in Western Australia, followed by New South Wales. The adoption was also relatively rapid in Western Australia compared with other states, with about 70 per cent adoption compared with 30 per cent or less in other states in 2001 (ABS 2008).

continued...

box 1 Adoption of technologies

1 Cumulative distribution of no-till adoption up to 2004

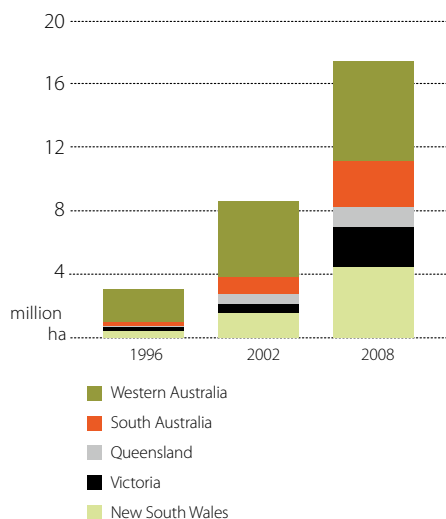


Source: D'Emden et al. 2006.

A number of factors appear to have influenced the adoption pattern of this technology. In Western Australia, the suitability of lighter soils for drilling with the initially-developed machinery, the advantages gained by being able to sow earlier, and the relatively larger farms that enabled economies of size in investing in machinery have been influential. While there is no firm evidence, the increasing frequency of droughts since the 1970s may have had an influence.

The availability of technology, suitability of conditions for adaptation, and the need for adaptation because of climate change has facilitated this adoption. For the southern and eastern states, the experience in WA has proven beneficial, and the increasing frequency of dry conditions, improved machinery and demonstrated productivity benefits appears to have collectively made the adoption possible.

2 Adoption of direct drill over time by state



Source: ABS (Land preparation for crops and pastures - Cultivation - No cultivation (apart from actual sowing operation)).

Wheat varieties

Different R&D outputs have different adoption patterns. For instance, the adoption of a new wheat variety represents a less complex change into an established production system. Many factors would determine the success of adopting a new variety as indicated by a range of different initial rates of adoption, with different peaks and life spans (adoption and obsolescence). Some varieties have low adoption and short life spans of about four to five years from initial release (such as Corella and Quarrion), possibly because of susceptibility to new diseases, change in market quality expectations or poor performance because of climatic conditions. Those that are tolerant of diseases, display consistently good performance and satisfy a broad market have persisted for more than 30 years (e.g. Olympic and Insignia). In between, are many successful varieties suited to different markets and production niches.

On average, varieties reach a peak share in a local area in the fifth year after release but continue to be grown for a further 17 years (Brennan 2001).

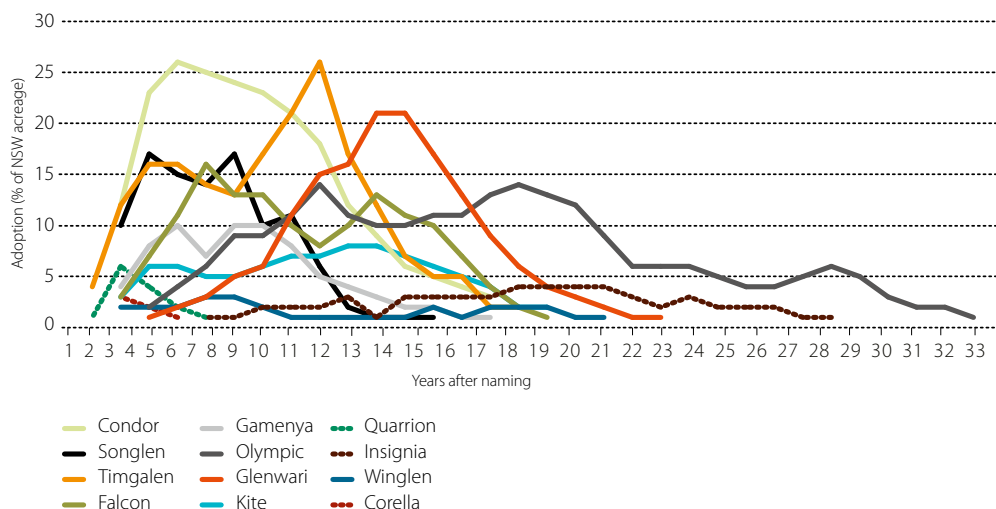
A consequence of this relatively rapid obsolescence and uncertain adoption is that continuing

continued...

box 1 Adoption of technologies

investment in plant breeding is required. Because plant breeders can appropriate the benefits of their innovations through plant breeders rights it is an area of activity suitable for private investment.

3 A comparison of the relative adoption of selected varieties of wheat in NSW between 1950 and 1990



Source: Fitzsimmons (1991).

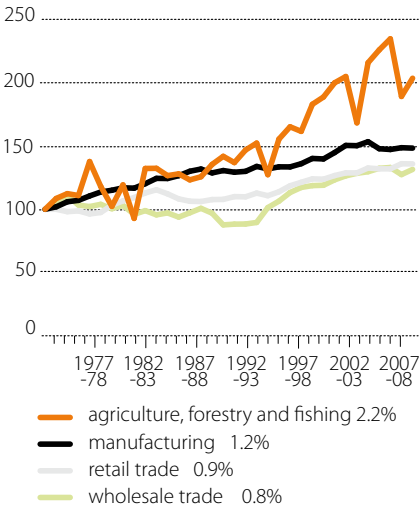
Recent trends

While measured agricultural productivity growth fluctuates sharply from year to year, largely in response to seasonal conditions, the long run trend of TFP growth in agriculture has remained relatively high, particularly when compared with the private non-farm economy (figure c). Since 1980, agricultural output has expanded through increased use of chemical and energy inputs, and despite a decrease in capital, land and labour used.

ABARE analysis of past productivity performance in the broadacre agriculture sector indicates that productivity varies within and between industries and regions. This variability may be explained by a number of factors related to the availability and suitability of technology, the operating environment and the structural characteristics of individual sectors. For example, in the past 20 years, the cropping industry has experienced higher productivity growth than the beef, sheep and mixed crop-livestock industries (figure d).

Productivity growth in broadacre agriculture appears to have slowed over the past decade. Analysis also indicates that the impressive gains made by the cropping and mixed crop-livestock sectors have not been maintained, while the livestock sector, particularly beef,

C Australian productivity growth by sector

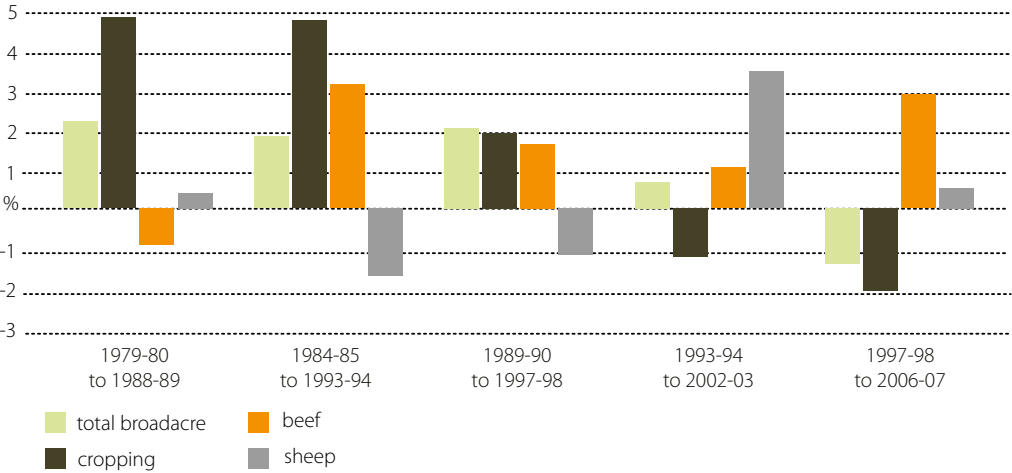


appears to have made significant gains in the past decade.

The continuing drought that affected soil moisture availability across Australian production regions has been a major factor behind this production downturn (map 1). Expansion of cropping into more marginal production regions—regions bordering the specialised wheat sheep-zone, where production is more sensitive to changes in seasonal conditions—at the expense of sheep may have also played a role.

The decline in broadacre productivity, in particular, has occurred at the same time as a decline in rainfall in south-east Australia. This rainfall decline is dominated by a strong and highly significant autumn rainfall decline, which

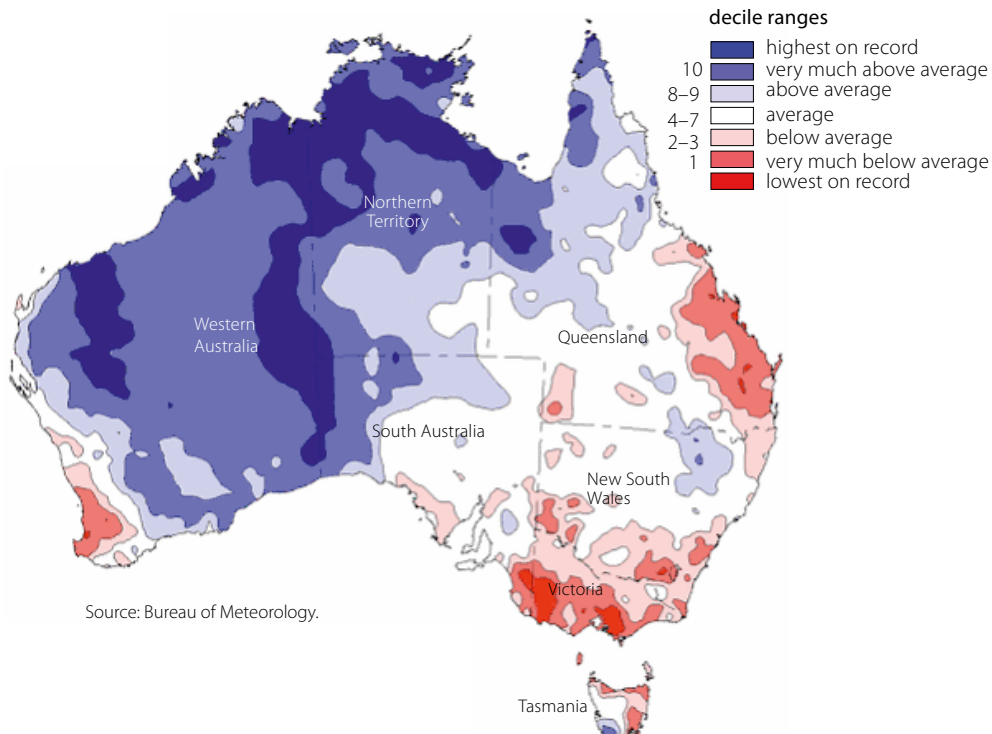
d Industry productivity trends 1979-80 to 2006-07



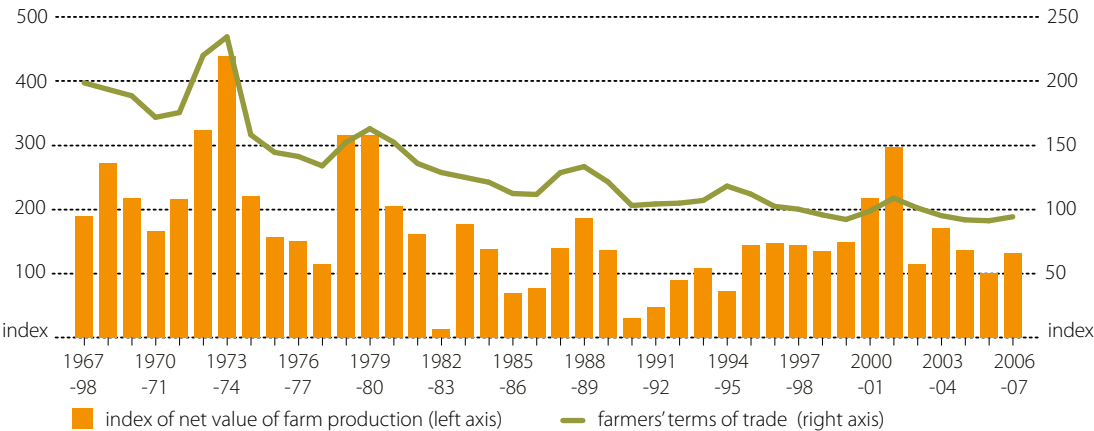
has been supplemented by recent declines in spring, particularly after 2002 (Timbal 2009). These changes may have made cropping areas more vulnerable to a moisture deficit, thus reducing productivity of crop enterprises.

ABARE is currently investigating possible linkages between these trends in rainfall and productivity. It is clear that drought related decreases in agricultural output and associated changes in input use have affected measured productivity patterns. Therefore, it appears that the broadacre sector, and particularly the cropping industry, requires a new surge

map 1 Australian total rainfall deciles, 1 October 1996 to 31 May 2006



e Farmers terms of trade and the real net value of farm production



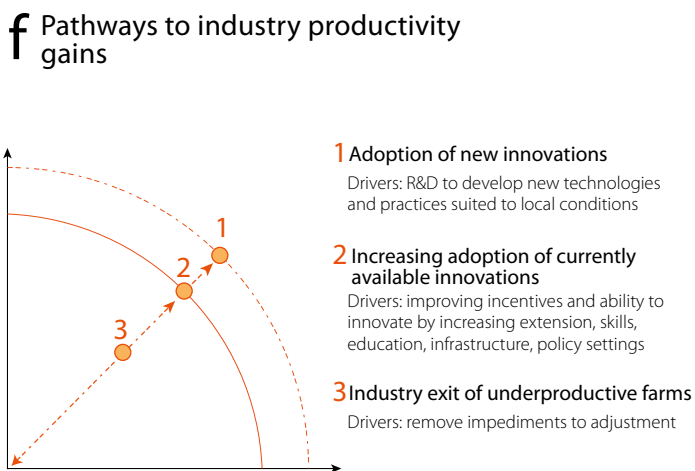
in productivity growth to get back to its long-term trend average. Moreover, it seems likely that productivity growth will need to exceed the long-term average to maintain the competitiveness and profitability of the sector in the face of ongoing challenges such as climate change, population ageing and reduced water availability (Productivity Commission 2008).

Another important trend that has relevance to productivity is the terms of trade, which is the ratio between the prices received and prices paid (figure e). It is widely believed that productivity gains in agriculture have offered Australian farmers an avenue to circumvent the effects on farm profitability of a falling terms of trade. Since the early 1990s, there appears to be a slowing of the rate of decline in the terms of trade. It has more or less stabilised in recent years with improvements in the value of farm production, reflecting higher global commodity prices. This means that recent productivity growth has contributed to real growth in the long-term profitability and competitiveness of the agricultural sector (Mullen and Crean 2007).

Productivity pathways

In economic analysis, productivity is considered within a framework that relates input-output combinations at a firm level. In the aggregate case, a production function represents possible levels of total output that can be produced with varying levels of inputs. In this framework, productivity growth may occur through a number of 'pathways', as shown in figure f.

Firstly, new technologies and practices generated through agricultural research induce outward shifts in production functions, enabling greater output with fewer inputs. Innovation thus creates the potential for higher real incomes and lower food costs. Innovation may make some practices obsolete, and may also induce some producers to exit an industry. Resources exiting an industry have potential to be used elsewhere in the economy (figure f).



R&D and its commercial uptake can have a wide variety of effects. Some of the main points are:

- expenditures on agricultural research generate new knowledge that can eventually lead to improved technology that is adopted by farmers
- technology adoption increases average productivity (the output of crop and livestock commodities per unit of land, labour, capital, and intermediate inputs employed in production)

- higher productivity of agricultural resources leads to lower costs, higher production, and the release of some resources (such as labour) from agriculture to other sectors of the economy
- higher agricultural production leads to lower commodity prices, passing some of the technology-induced cost reductions to the food industry and eventually to consumers.

Ongoing ABARE research aims to disaggregate historical productivity change in broadacre agriculture into these various components.

Productivity and profitability

It is important to briefly note the distinction between productivity and profitability. Productivity refers to the ratio of the quantity of outputs and inputs, whereas profitability is dependent both on quantities and prices (both output and input prices). Changes in the terms of trade (the ratio of output price to input price) therefore have significant implications for profitability. Profitability change over time can be viewed as the combination of productivity change and terms of trade change. Holding the terms of trade constant, improvements in productivity will lead to improvements in profitability (and vice versa).

It is widely acknowledged that Australian primary producers are generally price-takers, in that the actions of any individual farmer cannot independently influence the prices received for outputs or the prices paid for inputs. Given that the terms of trade is largely out of the farmer's control, the main driver of long-term profitability growth remains productivity growth. For example, in Australia it has been observed that over the past 40 years, consistent productivity gains in agriculture have allowed farmers to mitigate the effects on farm profitability of a relatively consistently falling terms of trade (see figure e).

Given variation in the terms of trade, productivity may not always be directly associated with corresponding changes in profitability, especially in the short run. For example, a short run decline in productivity could be associated with a gain in profitability if it is accompanied by a gain in the terms of trade. However, in the long run, productivity change remains farmers' key driver in achieving growth in (or maintenance of) profitability.

3 Rural R&D and agricultural productivity

One of the key drivers of long-term productivity growth is the development and adoption of new production technologies (innovation). Research and development (R&D) activities contribute to a range of technological advances and knowledge that may lead to improvements in agricultural productivity in the long run.

In addition, some new technologies may be developed through farmers own general experimentation and learning by doing. New technologies may also be developed indirectly on the back of research undertaken in other regions (domestic or international) or in other sectors. In any event, there is a growing agreement that formal agricultural research and development activities play a key role in increasing agricultural productivity through innovation (OECD 1995).

New technologies may induce changes in resource use, including the use of new inputs and new ways of combining inputs, as well as the development of new outputs. Research may also contribute to new, improved institutional arrangements that facilitate efficient resource use. New technologies may generate increased output per unit of input either from more efficient resource use (disembodied technological change), or through the development of better quality inputs (embodied technological change). Although growth in TFP is often interpreted as a measure of technological progress, it is only an imperfect indicator in that regard. TFP growth is computed by subtracting the growth of inputs from the growth of output, so it reflects anything that causes output to grow faster than input use.

Some examples of embodied technology include: more advanced farm equipment (e.g. harvesting, planting equipment), improved farm chemicals (e.g. selective herbicides, pesticides, fertilisers), improved plant and animal genetics (e.g. either through selective breeding or direct genetic modification), new information technologies (e.g. internet / GPS-related technology).

While there is general agreement that agricultural R&D contributes to productivity growth, quantifying the exact nature of the relationship between productivity growth and R&D expenditure remains difficult in practice. Some observations from the empirical research literature on this topic are presented later in the paper.

Gains in productivity have been a driving force for growth in agriculture across the world. The effects of these changes over the past 30 years for Australian agriculture have been dramatic: between 1979-80 and 2007-08, the average volume of milk produced per cow increased from 2950 litres to 5350 litres a year and the average yield of wheat rose from 1.03 tonnes to 1.30 tonnes a hectare. Also, on average, a farmer in 2005 produced three times as much farm output per week worked as a farmer did in 1985 (\$2800 compared with \$850, in 2008-09 dollars). The development of new technology that has allowed better ways of combining inputs in production has been a primary factor in these improvements. Changes in the quality and types of outputs, resulting from marketing and product development research have also contributed to these improvements.

The above statistics are only partial measures of productivity. However, they represent productivity gains achieved through different types of innovations including those generated outside the sector and include a number of broad categories: mechanical, chemical, biological, monitoring devices and information technology.

Factors influencing the demand for R&D

Value of information

The primary demand for R&D is related to the value of information. The value of information is essentially an outcome of choice in uncertain situations (Hirshleifer and Riley 1979, McCall 1982). Individuals may be willing to pay for information depending on how uncertain they are and on what is at stake. They may be willing to pay for additional information, or improved information, as long as the expected gain exceeds the cost of the information—inclusive of the distilling and processing of the information to render it useful (Macauley 2005). From an economic perspective, R&D is therefore a strategic investment to safeguard future benefits because new information clarifies the nature of constraints to economic activities while also informing the choice sets available for consumers and producers.

Moreover, as described in Macauley 2005, the value of information depends on the nature of uncertainty and the nature of choices surrounding a decision. When the choices are narrow in costs and benefits, information can add little value even if it virtually eliminates uncertainty. By contrast, if the costs of actions widely diverge, then additional information may be quite valuable even if it reduces uncertainty very little.

Thus, the value placed on information also depends on the value of output in the economy—that is, the aggregate value of the resources or activities that are managed, monitored or regulated. In other words, a willingness to pay for data about a new wheat variety is in part a function of the price of wheat. More formally, willingness to pay for information is derived demand—a market pull resulting from the value of services, products or other results that in part determine this worth. Where the value of information relates to non-market goods and services, output measures such as the value of environmental quality or the value of avoided damages because of actions that may be taken in light of the information provides a basis of comparison.

It is important to note that usually there are substitutes for information and there are costs involved in collecting, processing and interpreting data to make them usable. These will in turn affect the expected value of information in its final applications. Therefore, in attributing the value of information, the net benefits resulting from information needs to be considered.

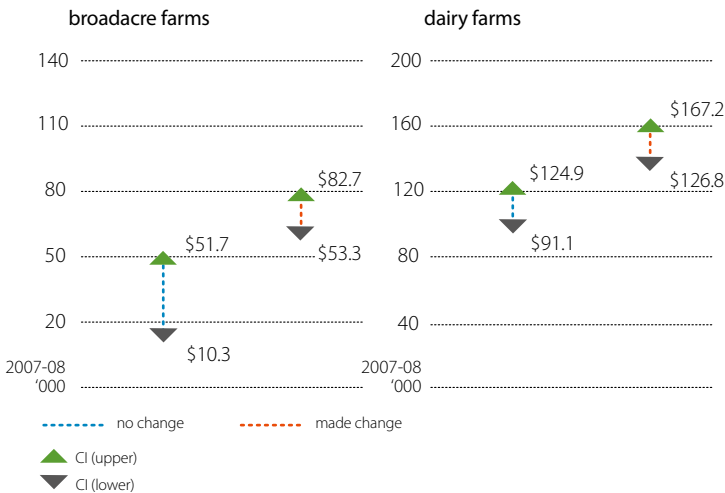
Generally, the larger the current level of uncertainty and greater the benefit of resolving the uncertainty, the larger the value of information. On the other hand, the greater the costs of adoption and larger the number of substitutes for the information created, the smaller the value. Therefore, these values can be incremental in nature and are dependent on the context of the information, such as the existing knowledge, personal beliefs and operating environment (such as policies) governing the ability to use the information being generated.

Innovation and adoption

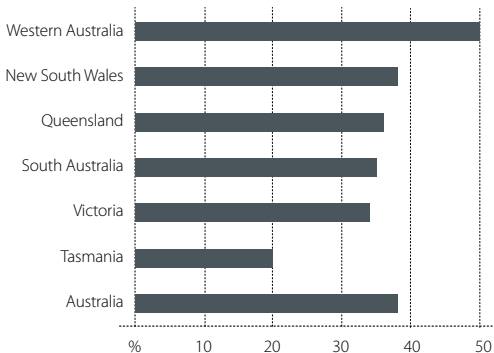
Recent ABARE analysis on innovation adoption offers insights on hurdles that need to be overcome to make the best use of available innovations to raise productivity (Liao and Martin 2009).

While productivity and profitability are two different concepts, profitability has an important bearing on the take-up of innovations (Arrow 1969, Hirsch 1969, Paris 2008), particularly where investment is involved. For a given innovation, the greater the ability to pay for investments the higher the potential take-up. For example, ABARE surveys in both broadacre and dairy industries during 2007-08 indicate that farms making a higher farm cash income were more likely to make changes (figure g).

g Farmers' innovation take-up in relation to farm cash income (CI), 2007-08



h Percentage of farms reporting new cropping equipment on Australian farms by state, 2007-08



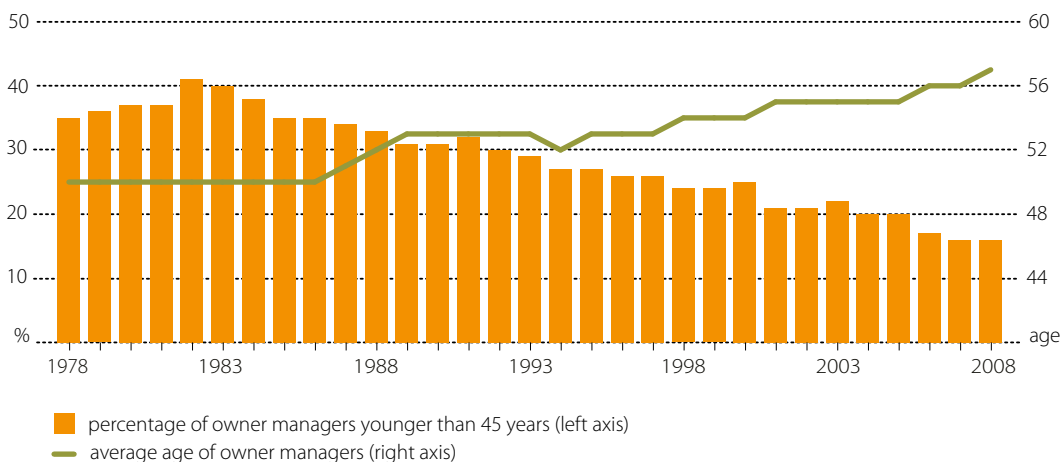
Agricultural production depends on a number of constraints that often act jointly. They represent attributes of natural resources and the environment, scientific and technical knowledge, and institutional setting (Ruttan 2002, Gunderson and Holling 2002). Therefore, agriculture performance can vary across regions as local ecological conditions and individual resource endowments influence agricultural potential. This is also reflected in farmers' uptake of new cropping equipment as presented in figure h using ABARE survey data for 2007-08.

It is notable that in Western Australia, where take up of new crop management technologies is high, the take-up of new cropping equipment is also high.

Relating to the Western Australian grains industry, Kingwell and Farre (2009) indicate that in the context of a changing climate, machinery investment decisions would be influenced by location specific factors and particularly by how climate changes alter the patterns of yield response to the time of sowing at a given location.

Among the socio-demographic factors that affect the take-up of innovation, operators' age is often important. Older operators may have difficulty in raising capital, and tend to be more risk averse. Farm survey data indicate that the Australian farming population is ageing (figure i). While that is similar to the general population, the difference is that the sector's ability to recruit younger farmers may be causing this trend (Barr 2005), leading to a growing skill shortage which could influence future productivity. ABARE is undertaking further research to determine whether there is a clearer link between operators' age and productivity.

i Changing demography of Australian farm managers



Economics of R&D policy

In this section, the role of public and private agricultural research in generating improved technologies and institutions is considered as well as the effect of those technologies on productivity and income growth.

Government involvement in agricultural research

Governments have played a key role in influencing the direction and performance of agricultural research through direct budgetary allocations and by determining agricultural research and development policies. In this section, the rationale for public and, rapidly evolving,

private roles in financing agricultural R&D are examined with an analysis of the economic characteristics of agricultural research.

In examining the case for attracting additional resources to enhance the productivity and profitability benefits of research, the public good characteristics of agricultural research is a focal point. In addressing efforts to improve the efficiency of agricultural research delivery, the management of existing funds for rural R&D in relation to the broader National Innovation System becomes important. This is particularly so in light of emerging cross-cutting issues, such as climate change, health and infrastructure, which have a bearing on productivity performance.

Justification for government involvement

Government involvement in agricultural research is typically justified on the basis of a divergence between the private and social benefits of research. For a number of reasons the social benefits of agricultural research may exceed the private benefits and, as a result, a market outcome may involve a less than ideal amount of expenditure on research. This offers the scope for governments to implement policies to increase the amount and the type of agricultural research undertaken (Alston et al. 1999).

Social benefits may exceed private benefits, primarily because research and development activities tend to produce outputs with public good characteristics. The public goods characteristic of the basic output of research activities—ideas and knowledge—implies that they are freely available to all and are not diminished by use. Notwithstanding the existence of patents and copyrights in various forms that have become more pervasive in capturing the full public benefit of research, scientific knowledge in its pure form is a classic public good (Dalrymple 2005).

Access to agricultural research may vary depending on barriers to dissemination and, therefore, scientific public goods are, like others, most often impure public goods and increasingly represent a mixture of public and private efforts. In the past, it was not uncommon for the government to sponsor more basic research and the private sector the more applied, particularly as knowledge was embodied in a process or product. In recent years, an increasing number of firms have delved into more basic areas of research, particularly as they relate to biological sciences (Dalrymple 2005).

The potential for many parties to obtain a benefit from research, outside of those directly involved in the research, is also often referred to as a positive spillover effect. The extent of positive spillover effects from agricultural research will depend on the nature of the research being undertaken. Some research may be highly specific and of value only to those organisations directly involved. Other research may be of value to whole industries (e.g. dairy, beef, wheat) or across the agricultural sector more generally. In some instances, agricultural research results may even have unforeseen applications in completely different sectors of the economy.

Research undertaken by the Consultative Group on International Agricultural Research (CGIAR) has long been driven by the motive to provide global, international and regional public goods by drawing on the spillover characteristics.

There is the potential for regional spillovers, where the results of agricultural research undertaken in the context of a specific region are also of benefit to other regions and contexts. Such effects may operate over small or large regional scales and can occur between countries: Australian agricultural research may be of benefit to other nations and Australia may benefit from agricultural research in other countries.

In practice, regional spillovers (especially at the national level) will be limited by variation in environmental (especially climatic) conditions. For example, a vast amount of experimental evidence and farm experience shows that the performance of plants and animals is altered by changes in soil, temperature, moisture and photoperiod characteristics of the producing environment. Accordingly, new technology embedded in plants and animals will be inhibited in performance, and its real economic value will be altered by these factors, for example water stress in certain geographic locations (Evenson 1989).

Another source of social benefit arising from agricultural research may be positive environmental externalities. Agricultural research may generate new technologies which provide adopters with productivity improvements while also generating general environmental benefits. Thus, potential environmental benefits arising from new agricultural technologies should be included in any assessment of the social returns to agricultural research. However, it should be noted that such environmental benefits are only realised in the event that the new technologies are actually adopted. Research into new technologies that have predominantly environmental benefits may be of no value if these technologies are not adopted because of lack of commercial viability.

Similarly, some agricultural technologies, such as some agrochemicals or biotechnologies, may have harmful external effects on other ecosystems and threaten the supply of other services. Public research on these issues focuses on developing ways, including policy frameworks, to minimise external impacts. The balance between public and private research in this area is important in achieving sustainable agricultural growth.

The returns from agricultural research

Successful agricultural research is expected to lead to improvements in agricultural productivity by providing new technologies, institutional innovations or knowledge which lowers the costs of production, or increases the volume of output. There exists a large body of literature reporting on attempts to empirically estimate the social returns on investment in agricultural research both in Australia and internationally. These studies have attempted to estimate returns from agricultural research by establishing a statistical link between research effort and agricultural productivity.

Alston et al. (2000) summarises the results of more than 290 international studies of returns to agricultural research. Overall, Alston et al. (1998) found that estimated rates of return to

agricultural research were very high, with a median rate of return of 25 per cent. Taken on face value, these high returns would suggest there has been significant under investment in agricultural research.

Mullen (2007) provides a summary of a number of Australian studies, undertaken between 1991 and 2006, that have estimated the rate of returns to agricultural research using a range of data and econometric techniques. Mullen (2007) concludes that, based on the available evidence, returns to agricultural research are likely to have remained between 15 and 40 per cent, as originally estimated by Mullen and Cox (1995). Importantly, Mullen (2007) found no evidence of a decline in rates of return to agricultural investment over time.

The existing econometric evidence has to be treated with a degree of caution given the presence of a range of methodological difficulties. For instance, it is generally recognised that there are significant time lags (potentially several decades) between the completion of R&D projects and the full realisation of productivity benefits. These time lags may be difficult to estimate in practice and may vary significantly over time, across regions and across different R&D programs and projects.

In addition, in practice there will be a range of factors influencing productivity that need to be controlled for in any study in order to accurately isolate the effect of domestic agricultural research. For example, knowledge is cumulative and positive spillover effects from various sources, including international agricultural research, may increase observed productivity, but such effects are difficult to account for. Not taking into account other causes of productivity growth may result in an overestimation of returns to domestic research. On the other hand, there may be a range of benefits from agricultural research that are not captured by traditional productivity measures (such as environmental benefits), which would result in underestimation of returns to research.

Alston et al. (1999) notes that, regarding agricultural R&D, 'informal impressions suggest that there has been rising scepticism about whether the estimated rates of return are accurate'. Despite concern over the accuracy of the econometric evidence, Alston et al. (1999) and Mullen (2007) both conclude that the evidence is sufficient to infer that a significant positive relationship between research and productivity exists and that returns to research are at least high enough to justify maintenance of current agricultural research expenditure. Moreover, the growing number of cross-cutting issues that influence productivity in the agriculture and food sector value chain means that there is a clear role for governments to better coordinate research expenditure to enhance its effectiveness

Forms of government involvement

Governments may adopt a range of strategies in attempting to increase the amount and effectiveness of agricultural research. Alston et al. (1999) consider four such approaches:

- improvements in intellectual property rights (e.g. patents)
- creation of new public or private research institutions (e.g. RDCs)
- incentives for private R&D (e.g. tax breaks, subsidies)
- provision of public funds for agricultural R&D.

The Australian context involves a combination of all of the above policy measures. The Australian Government supports a number of agricultural research institutions including Research and Development Corporations or companies (RDCs), Cooperative Research Centres (CRCs) and the CSIRO. Apart from CSIRO, the RDCs form the main platform for Australian Government involvement in domestic agricultural research. The RDCs are a form of public-private research partnerships, as they raise private funds through industry specific levies and receive matching government funds for research addressing both public good and collective private industry issues. Both state and federal governments provide funds for agricultural research, including matching funding to RDCs, other research grants and direct funding to public research providers (e.g. CSIRO). In addition, tax breaks exist for privately funded research activities. Systems of property rights protection for research results (e.g. patents) are also in place, although intellectual property relating to most agricultural research are not amenable to patent rights.

Effective intellectual property rights over agricultural research may encourage private involvement in research by ensuring investors can adequately capture the benefits of their investment (overcoming non-excludability). Intellectual property rights may be better suited to particular types of research, specifically that of a more applied nature, resulting in relatively excludable commercial products such as new plant varieties or chemical products.

However, such property rights have the potential to introduce economic inefficiency in the allocation of research results. That is, for the duration of the patent, patent holders are likely to charge a higher than socially optimal price for agricultural research results. While patents may encourage greater private investment in agricultural research, they may result in fewer farmers being able to reap the benefit from the research and therefore limit the social returns from investment.

In recent times, public research organisations have been increasingly encouraged to pursue commercialisation opportunities, by taking out patents and other controls over research outputs. One concern with such an approach is that by encouraging public institutions to undertake research with greater commercial potential, public policy could reduce welfare by crowding private research and directing resources away from research with more public good characteristics. The recent decision by the Australian Government to reinstate the public good focus of Cooperative Research Centres is an acknowledgement of this point. A greater public good focus for public research institutions is also consistent with the view that the basic research generated by the public sector may have limited commercial potential.

Another important consideration is the extent to which the beneficiaries of research bear the cost of research: the 'beneficiaries pays' principle. Alston et al. (1999) suggests there may be both equity (fairness) and efficiency motivations for maintaining a beneficiary pays principle. To some extent this principle is present in the Australian context. Industry specific RDCs leverage their industry sourced funds to undertake research that is of direct relevance or benefit to the industry. Research with broader cross industry or wider social benefits is largely undertaken or commissioned by institutions with a broader focus than the industry based RDCs.

However, in a number of occasions, the Productivity Commission has raised concerns about the extent to which, in public private partnerships (such as in RDCs), public funding may be

directed towards research with predominately private or direct industry benefits. The commission has generally maintained that public research should be directed more towards addressing market failure issues relating to externalities, public goods and other collective benefits (Productivity Commission 2007, 2005).

Finally, it is also important that in addressing any market failure, governments consider the costs of any intervention and only intervene where the expected benefits exceed the expected costs. For example, governments should consider the costs associated with raising additional funds for research and the potential for government intervention to crowd out or redirect private R&D or affect the degree of competition in the market for research provision. This is particularly important because the supply of research talent is limited and development of research capacity involves significant opportunity costs.

Allocation of research funding

The primary motivation for government intervention in research funding is to enhance social welfare; more specifically, by influencing the direction and pace of technological progress. Regardless of the extent or nature of government intervention, the allocation of funds to specific research projects is a challenging task. In this section, some of the overriding principles of research funding allocation are considered. In general, the same principles apply regardless of the type of institution involved be it public, private or some combination. The primary difference between public and private designation is the extent to which spillover benefits to other firms, industries, sectors or the environment are taken into account.

Maximising the social benefits of research

The research funding allocation problem may be defined as maximising the expected benefits from research given a fixed budget constraint. From a public perspective, any estimate of expected project benefits should incorporate all social benefits: increases in agricultural productivity, positive spillovers to other sectors as well as any environmental benefits or disbenefits. These benefits may accrue through new or improved technologies that are embodied in inputs, methods of production, or new or improved policy designs and institutional changes.

Marketing and pricing policies, resource access policies, land tenure and natural resource policies are examples of institutional arrangements that can be improved through research. Negative spillovers or externalities may include those that are ordinarily treated as environmental or social effects that are not accounted for in markets. Understanding and considering these costs and benefits in a comprehensive manner is important in R&D monitoring and evaluations, to accurately reflect the net social benefits of R&D investment. Moreover, such information may also provide useful triggers for further research and refinements that could minimise costs and thus enhance the potential net benefit.

The role of a research manager is to allocate funds to projects with the highest expected net social benefits, until the fixed budget constraint is reached (assuming that there exists

an excess of positive expected value research projects). In addition to taking account of the magnitude of the expected benefits of each project, a comprehensive approach would also include consideration of the likely distribution of potential outcomes (the level of uncertainty).

Even in the hypothetical case where research results are known with certainty, estimating the exact value of benefits flowing from any new knowledge and technology is a difficult task in practice. For example, uncertainty may surround the degree and time frame over which new technologies will be adopted, the specific productivity improvements they will provide, and the spatial scales at which the adoption is likely to take place. Further, estimating the environmental benefits of agricultural research is also a difficult task, given both the complexity of environmental relationships and the uncertainty over the social valuation of environmental benefits.

Given these complexities arising from the interaction between people and nature, the monitoring and evaluation of biophysical and socio-economic variables relating to research projects is likely to involve controversy and incur significant costs in gathering and interpreting information on expected social benefits and costs of research. Research funding institutions need to take into account these uncertainties and related costs when considering research program planning and allocation of research funds. As the rural R&D portfolio includes a growing number of cross-cutting issues with a high level of uncertainty and complexity, the need for a well-designed monitoring and evaluation framework and well articulated decision criteria becomes increasingly important. Other existing frameworks such as those of the Australian Research Council may provide a useful starting point in such developments.

The uncertain nature of research

The returns to agricultural research (or any research) are subject to significant uncertainty. The fundamental nature of research means that the ultimate outcome of research projects may be difficult to predict. Research projects may successfully develop new technologies as intended. Alternatively, research may prove that a particular technology is not viable (a result which still has value in terms of avoided costs), or research methods themselves prove unreliable or obsolete to the point where no new information is obtained. In contrast, research projects may result in highly positive outcomes beyond any reasonable prior expectations (windfall gains).

The degree of uncertainty relating to research projects is likely to vary, partly depending on the type of research. Some research projects may be highly reliable, for example projects with a narrow applied focus are likely to have a high likelihood of success, as the success is dependent on a small marginal gain in knowledge or application of an existing technology. Other projects may have a more strategic focus and be more speculative in nature, having a high likelihood of generating a small result but a small likelihood of generating a highly valuable outcome.

In determining the composition of research programs and portfolio makeup, it is important to incorporate projects with different likelihoods of success (or risk profiles) in order to maximise the expected value of the net portfolio outcome. This is particularly important for RDCs as the priorities may differ between the industry partners and the government. In particular, the industry may focus on immediate commercial outcomes, and a lower degree of risk, and therefore inadvertently forgo potentially significant benefits from more strategic research.

Information problems

Given the significant uncertainty surrounding the expected returns from agricultural research, it is important that research funders have access to as much relevant information as is cost effective. Setting priorities for research using economic criteria in addition to scientific criteria could help ensure resources are spent efficiently and equitably. The expected value of research, as reflected in ex-ante benefit-cost assessments, will vary depending on the interpretation of the research problem, time scales of the research focus, the risk perceptions of the evaluator and the measures available to mitigate risks.

One challenge is to design systems to overcome the problems of unequal access to information by the purchasers and the providers. This information asymmetry requires careful management to minimise social costs. For example, it may mean that research providers have knowledge on the relative merits of specific research techniques. At the same time, research institutions such as RDCs, through strong links with industry, may have greater understanding of the specific challenges facing industry and therefore the areas where new technologies would be of most practical use. Ideally, the information sets of both research providers and research institutions would be combined to provide the most comprehensive information set with which to evaluate suitable projects. However, existing incentive structures, particularly the competitive nature of research grants, may induce a level of reluctance on the part of the researcher to fully disclose information as it may weaken their competitiveness.

Research funding institutions may adopt a variety of approaches to address this information problem, including involving research provider representatives in the research allocation process, through consultation or through a direct appointment. Research funding institutions may also adopt variations within the competitive approach. These may include requirements for research providers to reveal risk information in proposals and a mechanism to reward them on the basis of the approaches they propose to address the identified risks or information gaps. Another option is to encourage 'blue-sky' research in areas of potentially high pay off that are also high risk.

Another information problem relates to the relative capability of research providers, whether individual researchers or research organisations. The common approach to this problem is to include criteria that take previous performance of researchers and organisations into account in making funding allocation decisions. The disadvantage of this track record based approach is that it may cap innovation by missing the opportunity to assist the emergence of new expertise outside existing 'units of excellence'. This could become a particular weakness in instances where out of the box solutions are not possible and the outcomes sought require genuine innovation or discovery, which in turn expands the body of scientific knowledge that underpins new technologies.

One important public policy lesson from the ambiguous results that academic investigations reveal about the distinction between science and technology is that there may be additional gains in public funding in certain cases to evaluate the feasibility of new technologies. The related market failure in this case concerns the possibilities that, in relatively new technological areas, the difficulties of translating new laboratory results into industrially viable technology may be too risky for private investors because of potentially high spillovers.

In many cases, as in the case of many biotechnology firms, established firms may find it an intolerable risk to nurture new technologies as their own research investments where the potential for rent capture is low. While there is a market for high risk activities, these are likely to be limited to areas where the rewards may come quickly and property rights could be secured. This is why the pooling of risk, and consequent benefits of portfolio diversification, have become so important in biotechnology where the developmental phase could be lengthy. These lessons can be extended to the management of RDC funds in the areas of cross-cutting interest.

Competition and accountability

The dominant approach to allocating research funds is through a competitive process, such as a competitive tender. Under this approach, research providers are required to submit proposals outlining the costs and potential benefits of specific research projects, and the funding institution selects the projects that are likely to deliver the greatest net social benefit.

Such an approach may be effective in ensuring an optimal allocation of research funding across predetermined priorities. It does this by giving research providers an incentive to reveal information and compete with fellow researchers on the basis of cost. The main problem with a competitive tender based approach is the potential for high transaction costs including the costs incurred by researchers in preparing proposals and the costs incurred by funders in evaluating proposals, particularly in the light of the information asymmetry and uncertainty issues discussed previously.

An alternative to the competitive approach, adopted in allocating Australian Government funds for agencies like CSIRO, is to provide block funding, on the basis of some established criteria. Providing block funding to research organisations is likely to involve lower transaction and administration costs, but may lead to a less efficient allocation of research funding. In determining an appropriate degree of competition Alston et al. (1999) suggests research institutions find an appropriate middle ground, combining a mix of competitive and non-competitive mechanisms in order to strike a balance between the benefits of improved resource allocation and the potential for higher transaction costs. CSIRO appears to be benefiting from such an arrangement, where block funding provides certainty and competitive funding provides flexibility.

While mixed funding models, in which research projects may receive funding from both competitive and non-competitive as well as public and private sources, may be of some benefit they are not without associated costs. As discussed previously, where projects are funded by multiple partners, especially where there are public private partnerships, issues arise as to the distribution of research benefits. An often stated issue is the extent to which public funds are used to leverage privately appropriable benefits versus leveraging private investment to achieve greater public good benefits from public good research.

Another issue is the complexity and administrative costs of having a potentially large number research funders. For example, there is the practice of 'leveraging partnerships' which is quite common among RDC sponsored research, where a research organisation may on top of block

funding seek research grants from a potentially large number of different funders (potentially many of them being different public institutions). Such an approach may significantly increase transaction costs, relative to securing funding from a small number of sources, while from a public standpoint the additional benefits of such an approach appears to be minimal.

Another important consideration when determining the appropriate funding mechanism will be the potential for rent seeking behaviour. Rent seeking behaviour refers to situations where research funders establish mutually beneficial relationships with research providers, resulting in funds diverted away from the most socially beneficial projects. Both competitive and non-competitive funding mechanisms may be subject to potential rent seeking behaviour, although non-competitive processes may be more open to such behaviour. Regardless of the mechanism used, it is important that research funding agencies are subjected to a degree of accountability and transparency to ensure that the incentives of decision-makers are aligned with those of the beneficiaries (and funding sources) of research—industry and the community.

Moreover, the quality of research and development is also dependent on the incentive to publish and disseminate findings, which varies across the rural R&D domain. These limitations mean there is a need to develop appropriate mechanisms for collecting the critical information to undertake ongoing monitoring and evaluation.

Regional spillovers

As information technology develops and communication and trade links expand, the opportunities for research spillovers grow. For example, electronic publishing has allowed faster dissemination of ideas and rapid intellectual exchange. Spillovers are unavoidable and mostly useful. What is required is a mechanism to share costs and benefits—an agreement on coordination of R&D effort across different regions, both state and international.

State-based research institutions may be expected to focus predominantly on the research benefits achieved within their state and less on the potential spillover benefits to other jurisdictions. While acknowledging the differences in the stage of development, where possible there should be a degree of coordination between compatible regions to ensure research effort is not duplicated. It may also be preferable for research which has wide applicability across Australia to be overseen by national research institutions so that national benefits are more fully taken into account.

At the national level, Australia should engage in research that generates the greatest benefits for Australia, such as those with the greatest potential for rapid adoption. This may often ignore any spillover effects passed on to other nations, except where those benefits are able to be appropriated through property rights protection. Moreover, collaborative partnerships, such as those with international research institutions, could be used to strategically participate in fundamental, cutting edge research with wider spillover benefits. Australia should be mindful of international research opportunities and attempt to gain positive spillovers to boost domestic research capacity through targeted international research projects.

4 Rural R&D in Australia

Scope of rural R&D in Australia

A strong tradition of innovation, characterised by the adoption of new farming practices and technologies, has played a key role in the development of Australia's agriculture and food sector as an efficient and competitive supplier in international markets. Equally, research, development and extension (RD&E) in primary industries has helped improve productivity and assisted sustainability.

As indicated earlier, rural R&D is defined in this report to include agriculture, fisheries, forestry and the food industry value chain. This encompasses the current DAFF portfolio responsibilities, as well as climate, health, water and food security issues. It excludes issues relating to public land such as parks and recreation areas. It is consistent with the rural R&D framework being developed by the Commonwealth-State Primary Industries Ministerial Council incorporating 14 sectoral and seven cross-sectoral industry strategies (DAFF 2009).

Specifically, it encompasses the activities undertaken by the RDCs, for example:

- dryland/broadacre, and intensive and irrigated agriculture
- fisheries and aquaculture
- forestry and land use change
- conservation (of the natural resource base)
- water availability and access
- biosecurity and biosafety
- improving industry productivity, including market access and trade
- diet, nutrition and food safety
- climate variability and climate change effects and implications for the above.

The agriculture and food sector operates in a dynamic and complex environment, and the issues listed above cross portfolio boundaries and involve broader economy-wide issues. To address the R&D needs identified in the Australian Agriculture and Food Sector Stocktake (2005) and subsequent deliberations of the Commonwealth-State Primary Industries Ministerial Council, the scope of R&D in the agriculture and food sector may need to be widened. This would certainly be necessary for rural R&D to:

‘develop evidence to inform and underpin food, fibre and rural resource policy and to foster research focussed on the collective needs of primary producers and the public to ensure sustainable and profitable production system and a value chain that enhances benefits to consumers’ (Australian Agriculture and Food Sector Stocktake (2005).

This focus will provide a sound basis to promote productivity in the agriculture and food sector value chain in the long run, while addressing ongoing challenges facing the sector.

Australia's rural R&D system

The Australian Government supports research and innovation in the rural sector with funding to CSIRO, Cooperative Research Centres (CRCs) and universities plus partial funding to Rural Research and Development Corporations (and companies). An estimated \$1.3 billion is invested in primary industry R&D in Australia each year by governments and the private sector. This support has helped Australia's agriculture sector productivity grow at an average annual rate of 2.2 per cent between 1974-75 and 2007-08.

From a policy perspective it is useful to examine R&D in terms of suppliers and users.

R&D providers

Australian universities

Australian universities are an important provider of research relevant to the agriculture and food sector. Most universities do this through partnerships with other agencies as well as the private sector and benevolent organisations in Australia and overseas. While university programs, in particular those attached to Cooperative Research Centres, focus more on applied research, the sector is largely responsible for providing the basic research that extends the sciences and contribute to the discovery process in the innovation continuum. In that sense, research conducted by universities in almost all scientific disciplines has the capacity to contribute to improvements in agricultural productivity from the point of reducing the costs of inputs or increasing the value of outputs being produced. An important contribution from universities in this regard is the training of scientists and technologists.

CSIRO

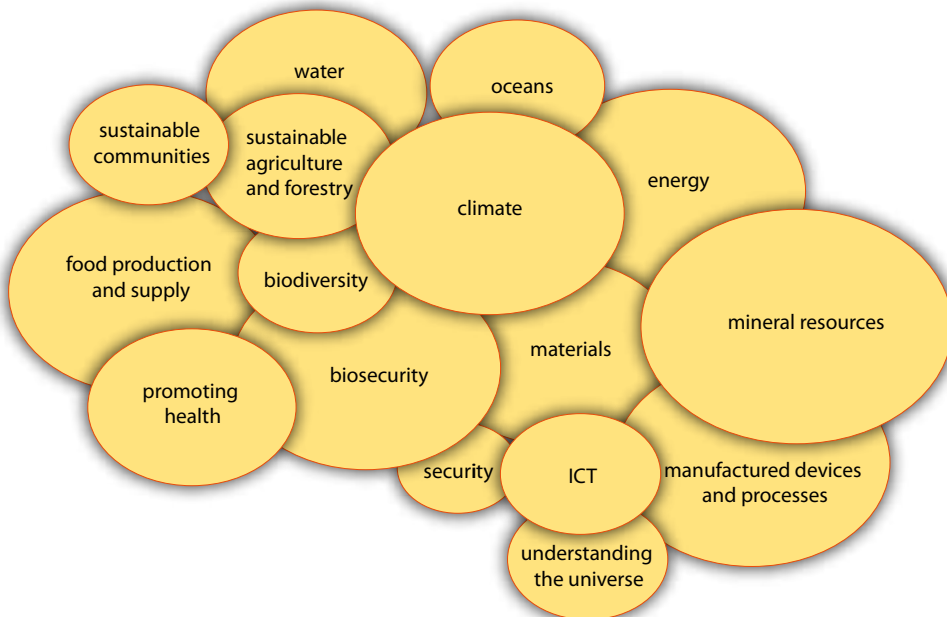
With an annual budget of around \$1 billion in 2008, CSIRO carries out scientific research in a number of areas relating to the rural sector, including energy, the environment, information technology, health, mining, manufacturing, agriculture and natural resources. Although CSIRO's focus is on the nation's big challenges and opportunities, major CSIRO projects of recent years such as the CSIRO-Bureau of Meteorology national climate assessment, Climate Change in Australia, and the Murray-Darling Basin Sustainable Yield study align closely with agriculture interests (CSIRO 2008). Moreover, a vast majority of CSIRO outcome domains represent close linkages to the agriculture and food sector (figure j).

Since 2003, CSIRO has drawn on its key strengths of scale, breadth and multidisciplinary science to develop the CSIRO National Research Flagships. Development of flagships was a concerted effort by CSIRO to pool national research resources to address identified key research issues requiring cross disciplinary collaboration. This was pursued at a time when a large number of disciplinary or industry based CSIRO divisions were amalgamated along broader themes representing national priorities.

A recent review of the flagship program chaired by Professor Robin Batterham concluded that the:

‘Flagship model has provided a compelling framework within which broad ranges of research capabilities (from both within CSIRO and externally through partnerships and collaborations) are assembled to focus on outcomes of national significance to Australia. The model has had a profound impact on the culture and practices of CSIRO’ (National Flagship Initiative Review Panel 2006).

j CSIRO outcome domains: broad areas in which science delivers benefits



Source: Reproduced from CSIRO Annual report 2007-08 (CSIRO 2008).

The National Flagship Initiative Panel outlined a number of significant advantages in the flagship model of dual delivery, where there is a clear focus on the dual importance of science and the route to impact together with an emphasis on collaboration and partnering. The panel concluded that the key elements of this model are more widely applicable, throughout CSIRO and beyond. A number of recommendations made by the panel have led to the continuation of the flagship program, which has now grown to include 10 national flagships that bring together 15 CSIRO divisions into a working partnership that includes a number of public and private sector partners as a way of catalysing collaboration to address a number of national research themes. The 20 flagship clusters operating in 2009 now have partnerships with more than 30 universities, two CRCs and several publicly-funded research agencies (CSIRO 2009).

A number of CSIRO national flagships focus on issues of direct relevance to the rural sector such as sustainable agriculture, climate adaptation, food, water, energy, and health and well

being. In searching for an effective model to strengthen the R&D effectiveness in the rural sector, some important lessons can be drawn from the successful CSIRO flagships program.

State governments

State governments' contribution to national rural R&D has been significant. Each of the states and the Northern Territory have provided funds and managed rural R&D and extension services in the past. The amounts of funding, especially the extension component, has been declining in recent years along with changing social priorities.

As the relative contribution of agriculture to the Australian economy and employment declines, the share of national R&D on agriculture has been falling, with some funds being diverted to issues such as the environment. Along with this trend, freestanding departments of agriculture have now been folded into larger entities. This has also been reflected in the realignment of rural portfolios across state governments. A number of previous state departments of agriculture have since been folded into broader entities:

- Department of Agriculture and Food, Western Australia
- Department of Primary Industries, Victoria
- Department of Primary Industries and Resources, South Australia
- Department of Primary Industries, Parks, Water and Environment, Tasmania
- Department of Employment, Economic Development and Innovation, Queensland
- Department of Industry and Development, New South Wales.

Cooperative Research Centres

The Cooperative Research Centres (CRCs) program, established in 1990 has encouraged academic-public-private collaboration in R&D, in particular in addressing public good research related to a number of industries or national priority issues. The model allows different parties to pool their resources to attain a combination of private and public good outcomes that may not be possible if each party was to act alone, and therefore assists coordination.

A fundamental aspect of the CRC program is that Australian Government funding is awarded through a competitive merit based selection process and the program does not provide recurrent funding. Since the commencement of the CRC program in 1991, the Australian Government has provided \$547.4 million to 39 CRCs in the agricultural sector.

A review of the CRC program in 2008 found that, since its inception, the program has delivered significant identifiable social and economic benefits, particularly through end use application of research (Australian Government 2008a). Large numbers of agricultural businesses have benefited from RDCs involvement with CRCs, partly because of a shift towards supporting end user driven research and research capable of producing commercial outcomes. These trends are consistent with the drive over the past 20 years to derive financial returns from commercialisation of intellectual property arising from publicly supported research. Although this has enabled the formation of a number of successful research collaborations, issues remain

about the equity considerations of using public monies to generate essentially private gains (Australian Government 2008a).

An important area of CRC contribution is in skill development, in particular producing postgraduates with industry knowledge. For example, 168 CRCs have produced more than 4650 industry-ready postgraduates, including more than 2460 graduates with PhDs (Australian Government 2008b). The recent changes to the CRC program, including the reinstatement of its focus on public benefits, offer considerable potential to strategically use the CRC program to develop the capacity to address emerging market failure and public good issues in the rural sector.

Private sector

Private sector contribution to R&D has been an important source of productivity growth around the world. This has been particularly evident in the areas of service delivery in input supply and output utilisation. Because of the economies of scale benefits attached to such activities, in general private sector research and development in agriculture has been linked to multinational corporations and other international groups associated with agricultural chemicals, seed and commodity trade. Local private sector activities relating to R&D largely resemble extension advice, farm planning and infrastructure development, where the focus is on customising knowledge and technology to suit local conditions. In recent times, some grower organisations and managed investment scheme operators have commenced operating in this space in order to gain economies of scale and scope benefits in providing complementary benefits to their members. However, to what extent these activities resemble R&D is not clear.

Most private sector investment in agricultural R&D falls within six subsectors: basic plant biological research; plant breeding and the production of seed and planting materials; agrochemicals, including chemicals for plant protection, fertilisers, and biotechnological applications; processing, storage, and transport of food; animal and livestock improvement; and agricultural equipment and machinery (Naseem et al. 2006). These sectors provide the greatest opportunity for appropriating benefits from private sector investment on agriculture R&D.

A number of private sector partners have engaged in joint research in collaboration with state, CSIRO and university sector providers to develop research with both social and privately appropriable benefits.

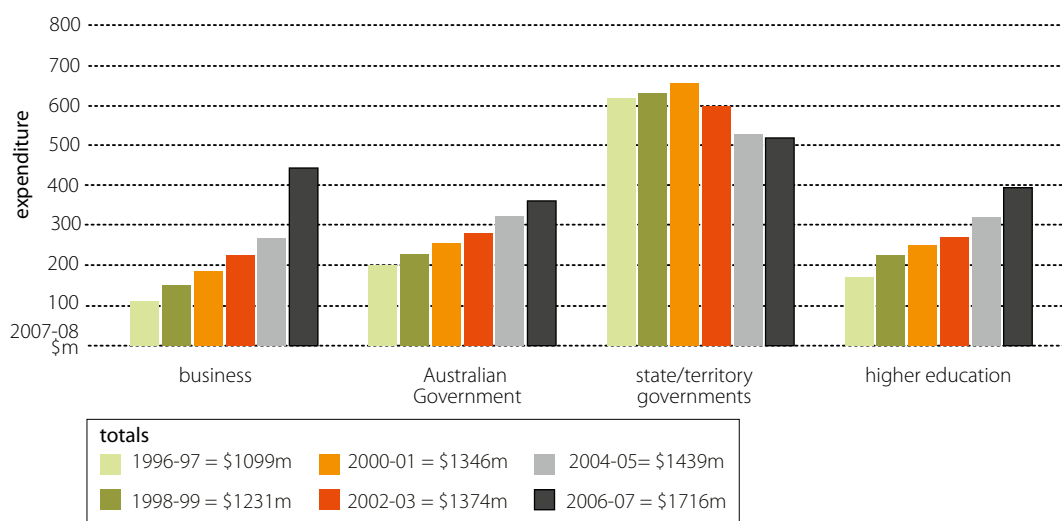
R&D purchasers

Australian and state governments

The public sector is the primary purchaser of research in Australia, and the purchases relate to various government programs ranging from those building up strategic knowledge and capability to those addressing immediate policy needs. In the rural sector, rural research and development corporations are the primary purchasers of rural research.

A breakdown of expenditure by source as a proportion of the total since 1996-97 as analysed in DAFF (J Austin 2009, pers. comm., November) indicates that total R&D expenditure for the key providers has increased over the period to 2006-07 (figure k). A notable trend is that the relative contribution by states and territories has fallen significantly over the same period, which has been offset by increases in R&D expenditure by business and higher education over that period.

k Agricultural, veterinary and environmental science R&D expenditure by sector



Sources: ABS (2008)

Research and development corporations and companies

Australia's 15 rural R&D corporations and companies (RDCs) are well-connected to the national research system that includes state and territory governments, CSIRO, universities and the private sector. The RDCs are the primary vehicle for funding rural innovation by the Department of Agriculture, Fisheries and Forestry (DAFF). In 2007-08, the total R&D expenditure by these RDCs was around \$500 million. Seven of the 15 rural RDCs fell within the DAFF portfolio responsibilities.

With a R&D mandate that extends over virtually all primary industries, the RDCs bring industry and researchers together to establish strategic directions, and fund projects that support innovation and productivity improvements to meet competitiveness, profitability and sustainability goals.

Other government programs

Various public programs that have contributed to rural R&D in Australia over the past 20 years include a number of Australian Government programs, administered through DAFF.

For example, the Australia's Farming Future initiative is providing funding over four years to help primary producers adapt and adjust to the effects of climate change. One component of the initiative, the Climate Change Research Program (\$46.2 million), will invest in research and development that is needed to reduce greenhouse gas pollution, improve soil management, and help farmers adapt to a changing climate.

The Caring for Our Country program, its predecessor program the Natural Heritage Trust, the National Action Plan for Salinity and Water Quality, and the National Environmental Research Facility program are other examples that included broader rural R&D components designed to meet program goals and often provide funds to RDCs through collaborative ventures. Although these programs were designed with an environmental focus, they have been included in rural R&D expenditure discussed later in this report because of their close links to land, water and vegetation management. These programs have been significant in raising national awareness of a number of cross-cutting issues affecting agriculture in the medium term.

Rural R&D also has forward and backward linkages to both private business and academic research activities, in particular with regard to the initial discovery process that leads to innovations later in the research value chain. The linkage between rural R&D and the national health and medical research system is significant in relation to rural health and living conditions, labour productivity, food quality and demand patterns for rural outputs.

The linkages and the complexity of the rural R&D system indicated above need to be fully considered in designing a monitoring and evaluation framework for rural R&D.

5 Rural R&D performance

A comprehensive review of Australia's innovation system, Mapping Australian Science and Innovation (2003), examined a range of R&D investment and performance issues including rural research. The review noted the role of science and innovation in providing tools to manage risks, solve complex problems and adapt to change.

The 2007 Productivity Commission review, Public Support for Science and Innovation, focussed on public investment in R&D across the innovation system. It stressed the importance of effective performance evaluation and benchmarking for the efficient allocation of funds. The commission noted that the governance design for RDCs was inherently sound, but observed that the current mixed quality may be improved through routine program evaluation employing rigorous and transparent methods.

The Cutler review, Venturous Australia: building strength in innovation (Cutler & Company 2008) concluded that the R&D system requires renewal. The Cutler Review noted that innovation is central to the transformation of the global economy. The report identified a need for reappraisal of Australia's national innovation system. It showed that the nature of innovation and our understanding of innovation are rapidly changing. While the focus of the 1980s policy framework sought to increase the supply and accelerate the commercialisation of research, less attention was paid to improving the capacity of firms to apply the products of science and research. One of the most important features of rural R&D investment has been the integration of R&D and extension, to promote faster and more effective adoption of technology.

Sources of performance information

Monitoring research performance is important to ensure that the research conducted meets social expectations in terms of its relevance and effectiveness as well as international reporting requirements that allow comparative assessments.

ABS research classifications

The Australian Bureau of Statistics follows the Australian Standard Research Classification (ASRC 1998) in line with its international reporting requirements. While the biennial data series provides a useful basis to compare international research performance and assists in national planning, it remains inadequate for the purposes of rural R&D monitoring and evaluation. The planned Australian New Zealand Standard Research Classification, ANZSRC 2008, will soon replace ASRC 1998. It is expected that the new system will maintain a high level of comparability to minimise discrepancy in the data collection.

In the ABS series, the socio-economic objective assigned to R&D is the purpose or outcome of the R&D as perceived by the data provider (researcher). It consists of discrete economic, social, technological or scientific domains for identifying the principal purposes of the R&D. The attributes applied to the design of the socio-economic objective classification represent a combination of processes, products, disciplines (e.g. health and education) and other

social and environmental aspects. The socio-economic objective is a four level hierarchical classification with sector at the broadest level; and divisions, groups and objectives are assigned unique two-digit, four-digit and six-digit codes, respectively. In this classification, agriculture R&D is most likely to fit under the ASRC 1998 division of:

62: Plant production and plant primary products

63: Animal production and animal primary products.

More detailed breakdown of research expenditure can be drawn from the ABS database through customisation, down to their six-digit code of socio-economic objective for the 1998 Australian Standard Research Classification.

An examination of ABS data indicates that the data are useful for the purpose of identifying broad areas of scientific effort. However, the data are of limited value for aggregating or scaling up this information to outcome categories as often required for assessing R&D effectiveness. In particular, it is difficult to derive the contribution of different scientific fields to an outcome such as those relating to yield improvement or reducing the application of an input because the result is derived from a number of fields contributing concurrently and often separately.

ABS notes that a number of non-sampling errors may contribute to the reliability of data. For example, statistics classified by the socio-economic objective, and the research fields, courses and disciplines are subjectively allocated by organisations at the time of reporting. Many organisations provide estimates because of a lack of separately recorded data on R&D activity. The estimation of overhead R&D expenditure varies across organisations. For these reasons, the ABS data remain inadequate for the purposes of the council. The discussions relating to ABS data on research expenditure provided in this report should only be treated as a guide.

It appears from the R&D expenditure analysis, although not directly related to agricultural productivity growth, that it would be desirable to clarify the appropriateness of including planning and policy analysis work conducted by R&D providers as R&D. Planning and policy analyses are largely administrative functions that could be more appropriately funded outside R&D budgets rather than through competitive funding. For example, a decision analysis framework developed by a government agency for a government program is regarded as research while a similar service provided by a consultant to a private business is not. Such anomalies can reduce the effectiveness of the ABS R&D classification data in planning and information management roles.

Research expenditures are also classified according to field of research (FOR), which addresses the nature of the R&D conducted. Agricultural R&D is most likely to be classified as:

- agricultural sciences (for years 1986-87 to 1998-99)
- agricultural, veterinary and environmental sciences (for years 2000-01 to 2006-07).

Although it was not possible to determine the correlation between expenditure on SOE and by FOR, we have assumed them to be approximately the same in this report.

R&D databases and information

Australian Agriculture and Natural Resources Online (AANRO) is an integrated database for agriculture and natural resources research. It provides access to complete and ongoing Australian research programs and projects, and their outputs. It was originally developed in 1996 by integrating three databases, Australian Agricultural Research in Progress (ARRIP), Australian Bibliography of Agriculture (ABOA) and Streamline (the national water research database). It is currently being redeveloped as a digital repository of full text resources by a group comprising AANRO research and development contributory agencies.

The AANRO is a joint initiative of the Primary Industries Standing Committee (PISC), the Natural Resource Management Standing Committee (NRMSC) and the RDCs. The audience is primarily the agricultural and natural resources research community, which includes all AANRO program partners plus some smaller groups such as the catchment management authorities.

A key value of AANRO is that it provides the opportunity to access research in progress and other unpublished research information that is difficult or impossible to find using internet search engines such as Google.

In addition, AANRO provides a list of all research being undertaken or that has been undertaken previously in each drainage division, agro-ecological region, catchment, state or territory and is the only service that provides a 'drill-down' mechanism to find this information.

The key drawback with the system, with regard to measuring R&D effectiveness, is that it is difficult to determine how well it captures current research activities and how the outputs are being used. However, these databases are useful sources to gauge research interest by users and may provide useful indications of the regional significance of particular activities, and provide a context for research planning and evaluation from a supply side perspective.

Survey data

ABARE farm surveys and ABS agricultural data collections are a key source of demand side information for R&D, which offer the potential to identify linkages between R&D adoption, productivity and profitability.

ABARE surveys are conducted annually and are administered through personal farm visits. Therefore, they have the capacity to incorporate cross references for activities and outcomes, and are amenable for stratification based on biophysical attributes such as climatic and soil characteristics to allow meaningful comparisons.

Careful planning and collaboration between the ABS, the Rural R&D Council, RDCs and ABARE will be needed to capture the full potential of the data collection in productivity analysis, and for monitoring and evaluation of rural R&D and productivity performance. For example, the ABS agricultural census collects detailed information on farm inputs and outputs but does not collect comprehensive farm financial information. Hence, ABS data collections based both on frequent sample surveys and the five-yearly Agricultural Census can be used with annual ABARE data and the Census of Population and Housing and other ABS sources to derive useful information on socio-economic and rural R&D issues.

In designing a monitoring and evaluation framework, the advantages and weaknesses of existing data sources and their relative costs need to be taken into account to improve the reliability and cost-effectiveness of meeting management objectives.

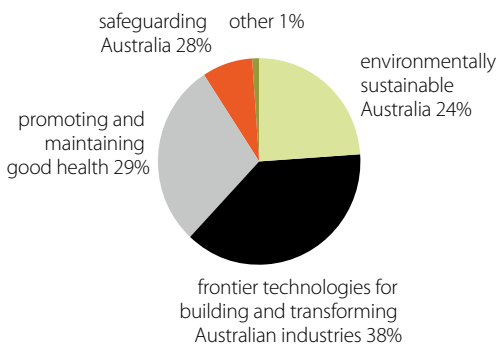
Difficulties will remain in quantifying the benefits of research. In particular, social and environmental outcomes are hard to quantify and, even when well-considered assessment approaches are used, data limitations may lead to understatement of their significance on some occasions and double counting on others. Reliable data derived from improved tools and techniques are needed to capture and value social and environmental outcomes in a consistent manner. This is important in a number of areas of priority to government business in both research management and policy development.

R&D priorities over the past decade

Ideally, R&D effectiveness may be examined in terms of effort, capacity and quality of outputs. Representing each of these objectives in evaluations is difficult because of issues of data availability and difficulties in benefit attribution.

Moreover, quantifying effort and capacity for rural R&D over generic national priorities is ambiguous because of a number of overlapping outcomes resulting from expenditure devoted to a particular objective within an industry. Examples of such attribution difficulties include the benefits of extension, and in kind research capacity contributions including spillovers from other sectors/industries to rural R&D discussed earlier. A further complexity lies in considering the benefits and costs of direct or indirect collaboration, knowledge transfer and sharing for collaborative ventures, which are often necessary for addressing cross-cutting issues. Moreover, benefits may be derived indirectly; for example, through effort and capacity in health and medical R&D, which might lead to improvements in animal health but cannot necessarily be measured as directly contributing to rural R&D outcomes.

Pattern of R&D expenditure by RDCs 2003-04 to 2007-08



Source: RDC annual reports.

For example, an examination of R&D expenditure across RDCs in real terms indicates that the growth in rural R&D expenditure in recent years has been consistent with agricultural industry incomes. However, it should be noted that since around 1990 the focus of R&D shifted in view of changing priorities to represent longer term goals such as 'an environmentally sustainable Australia' and 'frontier technologies for building and transforming Australian industries'. Recent RDC R&D expenditure reflects this shift (figure 1).

While it is difficult to generalise, in broad terms the focus on these objectives relates to sustainable agricultural production and environmental management and is consistent with changes in other western counties around

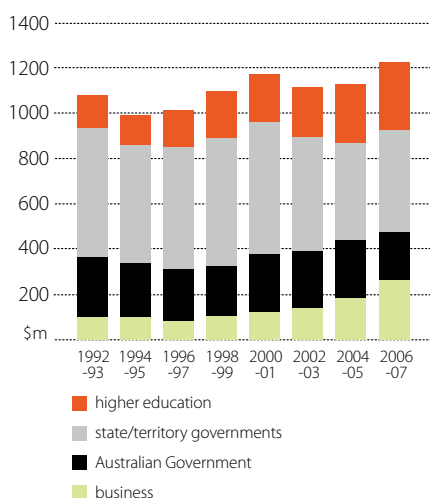
the same period. Studies now question whether this focus could have inadvertently imposed a drag on productivity growth in the short to medium term (Pardey 2009). This is because transition to sustainability objectives involves time lags in responding to associated changes in management practices, such as fertiliser rates, pesticide use and tillage practices in recognition of environmental pollution and related concerns. Realigning objectives and adjusting management practices to internalise the costs of these externalities involve costs to operators in terms of forgone yield, whereas the benefits may largely accrue to the public in terms of improved environmental services. As a consequence, expenditure increases immediately but outcomes are generally achieved only gradually.

In contrast, external factors such as climate variability and changes to water availability have had a large influence since the turn of the century. Past R&D has helped managed these influences and reduce their effect.

For policy purposes it is necessary to understand the length and shape of these lags (the duration of the effects of R&D on TFP), as both affect the rate of return. It is also important to know what percentage of the R&D is maintenance research that is necessary to maintain current performance and what proportion is actually productivity enhancing. This crucial question is usually overlooked by many analysts (Thirtle 2008).

For a given industry, gains in economies of scale, management practices that better address resource conditions and opportunities to increase the recovery rate of marketed output can all contribute to productivity improvements (Chavas 2008). These issues thus require further analysis to better understand the causes and gain insights for policy development.

m Trends in contribution to R&D expenditure by the four major provider sectors ^a



^a Based on contributions to plant and animal production SEO, in 2007-08 values.

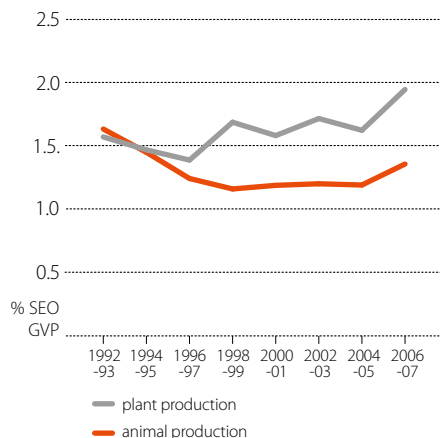
Source: ABS (2008).

Moreover, some authors argue that shifts in expenditure with a focus on environmentally-friendly R&D may have come at the expense of other R&D investment and could dampen the overall gains from induced technological change. Unfortunately, there has been little empirical work to assess the potential magnitude of such crowding out effects (Popp and Newel 2009).

R&D effort

R&D effort is usually measured as expenditure for particular socio-economic objectives, such as those defined by ASRC 1998 and ANZSRC 2008 (ABS 2009). The primary source is the biennial ABS data from 1992-93 to 2006-07 for R&D expenditure by business, government and private non-profit organisations and higher education sectors.

n Expenditure on plant and animal R&D 1992-93 to 2006-07, by major provider sectors



Source: ABS (2008).

The gross expenditure by these sectors (business, government and non-profit organisations and higher education) related to socio-economic objectives (SEO) for research and experimental development is plotted in figure m. These data represent expenditure in 2007-08 values for the total of two SEO categories, plant production and the total of plant primary products, and animal production and animal primary products.

The relative expenditures by different sectors on R&D for combined animal and plant production categories are also shown in figure m. This highlights the significance of the state contribution to rural R&D over the period despite a relative decline since around 2000-01. It appears that R&D expenditure by higher education and business sectors has increased slightly over the review period. The Australian Government contribution to rural R&D has declined somewhat, particularly over recent years. The contribution by the private non-profit sector is so small it was ignored in these analyses.

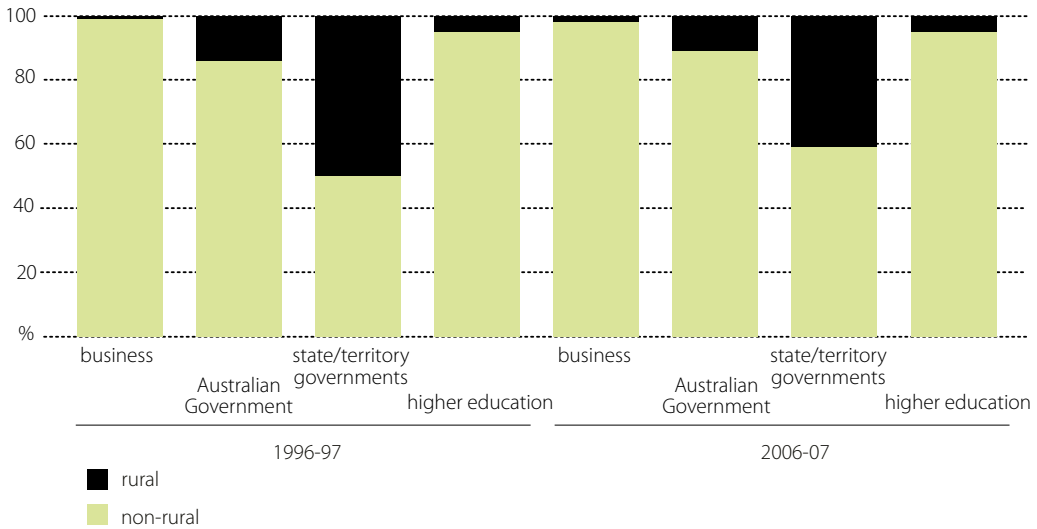
As noted by DAFF (2009), the bulk of the agricultural R&D that is supported through matching producer contributions is administered through RDCs. Data plotted in figure n indicate that broadly R&D expenditure on plant production has increased relative to the gross value of production (GVP) of plant based products, while R&D on animal production has declined over the same period. However, these data do not provide a basis to determine the composition of R&D outcomes or the likely effects on productivity of crop and livestock industries.

The emphasis placed by different provider sectors on rural R&D is illustrated in figure o. Overall, rural R&D expenditure as a proportion of total Australian R&D expenditure has declined from 8.6 per cent in 1996-97 to 5.6 per cent in 2006-07. This includes a slight decrease in the share of the Australian Government while the rural share of states' R&D has declined from around 50 per cent to 40 per cent over the same period.

The decline in state contribution to rural R&D is more pronounced over the 20 year period 1986-87 to 2006-07 (figure p). At the same time, the business expenditure on rural R&D has increased. This increase probably represents the increases in R&D through RDCs. It should be noted that the ABS data used in this analysis may not fully account for the private expenditure through RDCs within the category of 'business', as the grant recipients who report these expenditure figures may not be fully aware of the proportion of funds derived from the public and private sources that are delivered from RDCs.

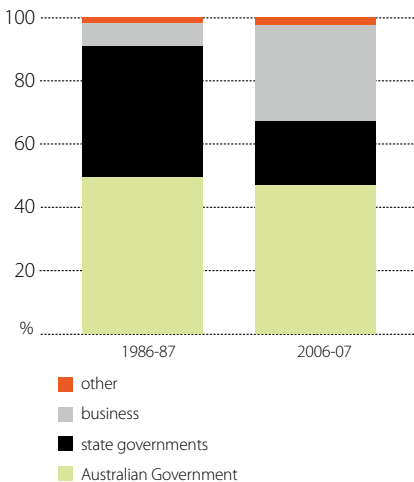
Moreover, data presented in figure q that attempt to distribute the R&D expenditure for agricultural sciences field of research in 2006-07 between the providers and purchasers are of particular interest. They clearly indicate the interconnectedness between different sectors. The

O Proportion of total research expenditure on rural R&D by the different sectors, 1996-97 and 2006-07



Source: ABS (2008).

p Proportion of research expenditure on agricultural science by the different sectors 1986-87 and 2006-07



Source: ABS (2008).

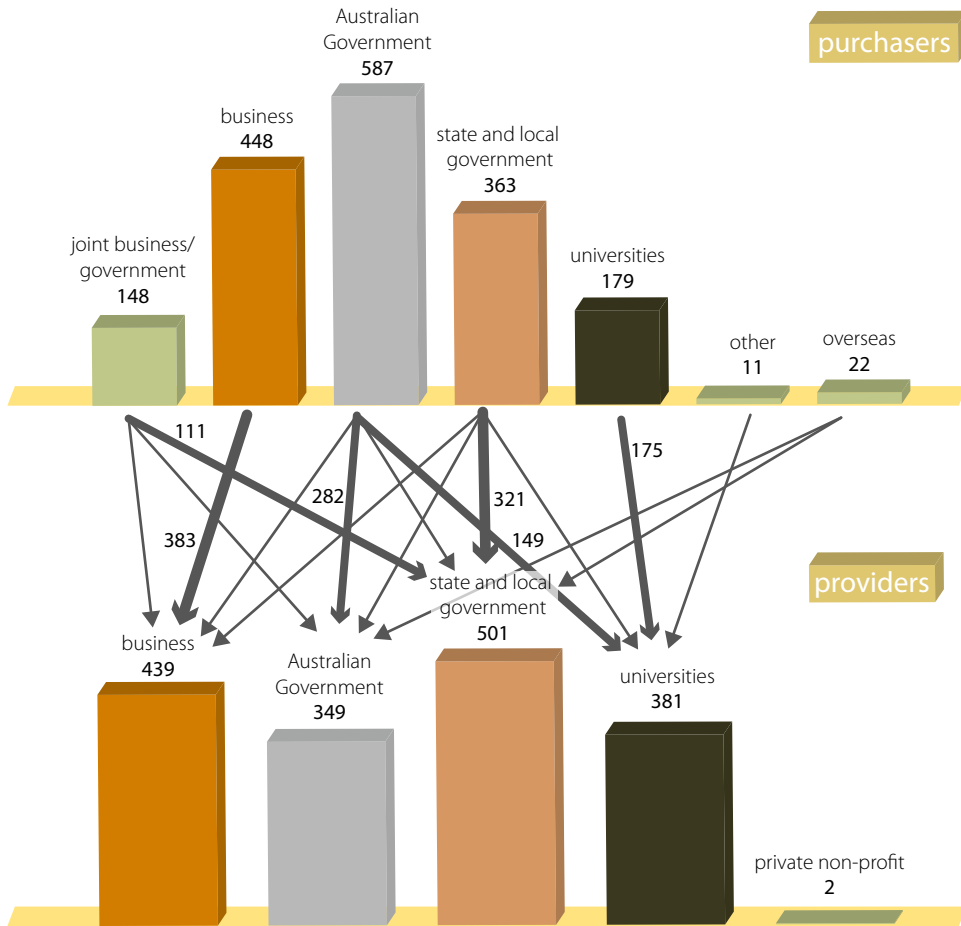
university sector as a provider group receives the highest proportion of funds outside their own. These are sourced mainly through the Australian Government. Within the limits of data, business support to agricultural R&D by universities appears non-existent. This suggests that, as stated earlier, business support through RDCs is captured within the joint business/government category. However, R&D performed by an organisation may be funded by more than one source. For example, funding provided to an organisation via an unincorporated Collaborative Research Centre may originally be sourced from the government, higher education and business sectors.

Nevertheless, given the dominant role higher education sector plays in the provision of basic research and opportunities for synergies with other research streams, their contribution to R&D-led innovation in agriculture and food value chain could be significant (figure q).

While the Australian Government is the dominant purchaser of agricultural R&D, states are the dominant provider group, with joint business and government support being a key contributor to state-led rural R&D effort.

q Agricultural R&D expenditure by source of funding, 2006-07

\$million



Source: Derived from ABS data.

Also of note is the level of intersectoral transactions including those between government providers and overseas purchasers. They may point to some of the international technological spill-ins to Australian agriculture.

R&D capacity

R&D capacity can be broadly expressed in terms of human resources and infrastructure. The human resources component is measured as person years of effort (PYE) in both scientific and technical staff categories. One person year of effort is equal to a full-time employee that is wholly devoted to R&D for an entire year. Information on person years of effort is not available from the ABS statistics at the level of socio-economic objective and is often inferred from other

data. The human resources that are focused primarily on rural R&D are best gathered from data relating to:

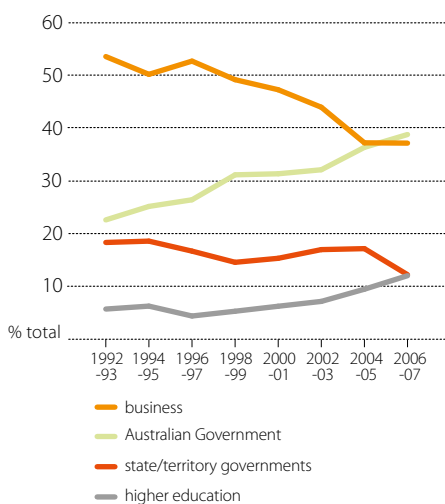
- agriculture, forestry and fishing (only available for the business sector at \$117.6 million in 2006-07)
- professional, scientific and technical services, which will include many other sectors (\$4025.6 million in 2006-07).

A crude estimate of the distribution of human resources devoted to rural R&D over the review period is illustrated in figure r. It follows the trend in rural R&D expenditure in figure q, which is not surprising given the high proportion of R&D expenditure that goes into salaries and wages.

Regardless of whether researchers are a part of organised groups or work in relative isolation within their own groups, the physical infrastructure for scientific and technological research is a key component of the ability to conduct R&D competently. It includes:

- research facilities and equipment and the buildings that house them
- libraries and mechanisms for accessing knowledge
- information and communications technology networks and equipment used for research purposes
- collections and archives
- large datasets.

r An indicative measure of the distribution of human resources in rural R&D



Note: Estimated as Person Year Equivalents derived from total PYE per sector multiplied by the ratio of expenditure on rural R&D to total R&D per sector (calculated from ABS 2008 data).

Ideally, an analysis of R&D effectiveness needs to consider an assessment of the infrastructure for meeting the requirements for discovery and innovation, as appropriate for the socio-economic objective and research field in question.

Data on these aspects of capacity are difficult to interpret as they are not reported at a sufficient level of disaggregation. For instance, availability of research support and information services is critical for research. However, it is difficult to get information on library use specific to the rural sector. Australia has 234 academic libraries that spent \$425 m in 2001, while CSIRO has 55 libraries.

The range of complexities and the possibilities for double counting is likely to mean that, in determining the architecture for a monitoring and evaluation framework, the council is likely to need to consider additional mechanisms for collecting the critical information to meet its ongoing needs.

6 Influencing future productivity performance in agriculture

Agricultural and food sector productivity will need to continue to improve to meet increased food demand and growing expectations for higher quality of life. However, as the literature on induced innovation highlights, productivity improvements that do not lead to increased profitability are of little interest and such productivity improvements cannot be sustained (Thirtle 2008).

Key insights

On the basis of the discussion presented in this report, supported by limited available data and underpinning economic principles, a number of points can be identified.

Links between productivity and R&D are strong, and they contribute to collective industry level outcomes and specific practices generating private economic benefits. However, the delays between innovation and adoption can be significant. The longer the duration of such lags, the lower the economic benefits and higher the chances of an innovation becoming obsolete.

The entire innovation system, from universities that undertake basic research through to private consultants providing advice to farmers and land managers, has a role to play in driving productivity growth. They can do so by identifying potential innovation opportunities, filtering out those innovations that are unlikely to be profitable and promoting the take-up of those that are both technically feasible and economically viable.

Given most agricultural innovations have benefited from spill-ins from international R&D, a better focus on understanding the heterogeneity of the resource base and identify emerging technologies to take advantage of local comparative advantage would likely to offer opportunities to improve productivity.

Understanding productivity drivers, and in particular the determinants that are within and beyond the control of rural businesses, will remain key issues requiring a concerted research effort.

It appears reasonable to conclude that, despite a notable contraction of R&D investment by state governments, the public sector in Australia (which includes both the government and most of the higher education sectors) is the key provider and purchaser of R&D. Given the small size of the Australian economy and the diversity of the Australian natural resource base and climate, this public sector dominance is expected as private sector investors have limited opportunities to capture the majority of the benefits from R&D investment.

While the level of business R&D investment is significant, expenditure is largely directed to meeting business needs relating to increasing direct economic output. In some areas, this expenditure relates to quality of life issues such as pollution, environmental quality and sustainability where they are addressed through various public-private partnerships.

While it is true that increasing the intensity of agriculture could also increase the risk of related externalities, and the private industry has a role in mitigating such externalities, a lack of clarity in the roles of public and private investment in addressing externalities and public good issues appears to be a source of ambiguity and high transaction costs in coordinating partnerships. It may have also created a degree of overcrowding, thus reducing the overall effectiveness of R&D.

In terms of output, it is difficult to ascertain the proportion of government spending that contributes to maintain and improve the productivity of rural resource use activities against those that contribute to meeting broader public good outcomes that relate to improving the quality of life of Australians.

Governments in Australia, as part of a global pattern, have in recent times placed an increasing emphasis on evidence-based policy making. However, because a significant proportion of rural R&D expenditure relates to public policy programs, a number of cross-cutting issues addressed as separate issues may undermine the effectiveness of program related R&D.

This leads to the conclusion that there needs to be a clearer definition of objectives, better coordination and more effective risk governance arrangements to better align R&D expenditure to increase overall effectiveness in promoting productivity growth and quality of life benefits from Australia's natural resources linked to the rural sector.

Another insight drawn from the R&D expenditure analysis, which is not directly related to agricultural productivity, is that it would be desirable to clarify the appropriateness of including planning and policy analysis work conducted by R&D providers as R&D. Planning and policy analyses are largely administrative functions that could be more appropriately funded outside R&D budgets rather than through competitive funding. For example, a decision analysis framework developed by a government research agency for a government program is regarded as research while a similar service provided by a consultant to a private business is not.

Driving productivity in a changing policy environment

There are likely to be many options for enhancing productivity in the sector. Since the beginning of the twentieth century, increases in land productivity has resulted in a transition from a natural resource based to a science based system of agricultural production (Ruttan 2002). Growing international trade and the resultant market competition has also played an important catalytic role. A number of attendant problems relating to land degradation and downstream environmental effects suggests that the most appropriate means to foster farming system development and market competition will vary between countries, regions and sites. The underlying resource endowments and institutional settings such as climate, soil and access to water, markets and infrastructure will determine enterprise choice, yields and relative profitability. Therefore, productivity potential will also depend on social and economic conditions across the value chain and the continued investment in research, education and technology transfer.

Broader technology options

A range of technical options are available to increase productivity for a particular combination of agro-ecological and socio-economic conditions. The main pathways for enhancing productivity are to be found in the combination of resources that provide the greatest value of output at least cost. To be sustainable, these costs must include all direct and indirect costs including social externalities. To reduce disparities and to direct resources to higher priority uses, it is important that policies do not distort prices and other incentives. Investment in resource-saving technology and promotion of unimpeded trade will increase agricultural productivity and facilitate structural adjustment in agriculture.

The leading resource and environmental constraints faced by farmers worldwide highlighted in the literature include:

- land degradation – including soil erosion, salinity and waterlogging
- pests and diseases, including resistance to management controls
- the effects of climate change, which will intensify the above two issues
- food safety and supply security emanating from all the above.

Given water scarcity and increasing global temperature are likely to be the greatest concerns for biological productivity of agricultural systems, combining biological water-saving measures (drought tolerance by genetic improvement and physiological regulation) with soil and agronomic manipulation may help address these constraints at a conceptual level. The challenge is to better understand these constraints at the farm level and throughout the value chain. Historical experience suggests that productivity improvements beyond the farm gate are likely to involve engineering solutions for infrastructure bottlenecks and social technologies and practices to minimise transaction costs in trade and commerce. R&D will likely play an important role in addressing the scientific and technical constraints and determining likely solutions for addressing any institutional impediments.

Improve returns to research

Overall, innovation in the Australian agriculture and food sector, whether generated through domestic or international research and knowledge diffusion, is a key factor in driving productivity growth. The Productivity Commission (2007) reported that the marginal rates of return to R&D elicited through public support could easily be as high as 65 per cent, and that the returns are influenced by other factors contributing to TFP growth, such as international spillovers, innovation more broadly and the effects of intensifying competition.

Moreover, the commission argued that, even though the social rates of return to publicly supported R&D may be high, the actual implications for long-run productivity growth are relatively modest compared with other factors. Given the international market exposure of the sector, it is important to better understand how markets drive innovation through the application of knowledge, technology and skills to develop new products, services and business processes that increase sector competitiveness.

Seek high value outputs

Traditionally, cost efficiencies gained through technological innovations have played an important role in improving competitiveness. As resource constraints tighten and addressing such constraints comes at an increasing cost, as is typical of any maturing industry, being able to influence returns, for example by producing high value commodities at a competitive price, would be an advantage.

In unveiling the recent Lord Sainsbury Review of the UK innovation system, HM Treasury noted that ‘strategies based solely on low costs will end in a downward spiral, each year bringing a new low-cost competitor. The best way ... to make the most of globalisation is to support the restructuring of ... companies into high-value goods, services and industries’ (HM Treasury 2007).

HM Treasury further remarked that, to take advantage of the new markets opened up by globalisation, businesses should seek to compete with emerging economies in a ‘race to the top’ rather than in a ‘race to the bottom’. The challenge, as noted by Lord Sainsbury, to win the ‘race to the top’ is to invest in the future in areas such as knowledge generation, innovation, education, re-training and technological infrastructure. The challenges identified for the UK are not unique and apply equally or perhaps more strongly to Australia because of relative geographic isolation, the greater variability in natural conditions and the relatively small domestic market, which makes global trade more compelling for economic growth.

In the past, Australian agricultural industries have adopted innovations that reduced input use, contained costs and changed the output mix to compete in global markets. Similar to the sentiment echoed in the Sainsbury Report, in an era of globalisation, a number of factors external to the immediate farming environment could influence future business performance. They include:

- development and access to new global technologies
- domestic and global economic conditions
- climate change, drought and related global environmental disturbances
- a more complex regulatory environment that links global issues to the local operating context.

This will mean that the conventional opportunities that were available for the sector to increase performance by reducing costs will narrow, and future increases in productivity may come at an increasing cost. Moreover, as discussed previously, the competition for resources used in the sector such as land, water, labour and capital are likely to intensify, thus adding further pressure for the sector to increase its rates of return to be able to remain competitive. This may mean that the sector will need to move more into high-value goods, services and industries, at a faster pace to mitigate any drag in productivity that may result from factors beyond operators’ direct control. As individual operators do not have the capacity or the incentive to invest directly in addressing these cross-cutting issues and enhance the sectors comparative advantage, a more effective and well-coordinated science and innovation system is vital to help achieve this objective.

Address broader issues more efficiently

The relationship between rural R&D and productivity growth in agriculture are linked to other issues outside the sector such as health, education and social policy. These linkages need to be examined in order to interpret the role of R&D in driving productivity growth and business performance in the agriculture sector.

Maximising the social benefits of government R&D support

On a number of occasions, the Productivity Commission has raised concerns about the present levy-matching scheme through RDCs, involving dollar for dollar contributions by the Australian Government up to 0.5 per cent of the GVP. While the commission supports the case for continuing compulsory levy arrangements, it has not been convinced that the level of community benefits associated with aspects of rural R&D justifies the extent of public support collectively provided to the sector (Productivity Commission 2007).

The basis behind the commission's concerns is not the public support per se, but the social outcome of that support. The commission's longstanding preference, as alluded to in Alston et al. (1999), is to encourage:

- rural industries to take greater financial and managerial responsibility for research that provides direct industry benefits
- governments to take full responsibility for, and confine its activities to, research with predominantly public good characteristics.

This functional separation could increase the effectiveness of publicly funded R&D through RDCs and help achieve an appropriate balance between the public good and private benefits research being delivered through the RDC model.

This separation is important and timely because, as reiterated by the commission in 2007, the current arrangement may not provide the best mechanism to coordinate a research portfolio that addresses a number of cross-cutting issues with high public good and industry strategic benefits:

'Australia's rural research corporations are one model of industry-based collectives. In this case, producers vote on whether there should be a levy (and, if so, its size), have a say in selecting the members of the Board for each RRDC and contribute to setting research priorities. Funding issues aside, this serves to align the interests of the producers with both the level and type of research undertaken. But as producer groups dominate the representation on RRDC boards, there is a risk that research priority setting will focus disproportionately on benefits that are appropriable by that group' (Productivity Commission 2007, p 431).

The self assessment of the role of RDCs contained in the Chair of Rural Research and Development Corporations Council (CRRDCC 2008) also highlights this inadequacy, and indicates opportunities for realignment of objectives to better deliver social benefits:

‘The RDCs were formed first and foremost to manage and administer the levies contributed by the industries they were created to serve. That said, individual rural industries do not have scientific disciplines that are unique to them – there are common areas of interest across industries, resulting in common interests across RDCs and their stakeholders. Consequently, the RDCs seek to collaborate where such actions improve the returns to the levy payers they are accountable to. In doing so, RDCs are aiding the effectiveness and efficiency of the entire RDCs R&D investment portfolio. Collaboration by the RDCs is a means by which the net returns from an R&D investment can be increased over and above what would have been achieved if only one RDC was acting alone’ (CRDCC 2008, p. 20).

Whether this self assessment reflects broader public objectives of setting up RDCs is a matter of judgement. What the above assessment clearly indicates is that there are significant transaction costs in coordinating outcomes between RDCs.

Moreover, a recent evaluation of the Cooperative Venture for Capacity Building (CVCB) program, an initiative of RDCs to collectively address capacity building issues, also highlighted some difficulties contributing to suboptimal outcomes. For example, while the CVCB program was successful in defining capacity building and setting a strategic agenda, the evaluation noted that the CVCB did not fully achieve its outcomes and potential because of five factors. ‘A logical rather than strategic portfolio of research due to the need to balance investor/ researcher interests and the wide range of potential capacity building research against the divergent needs of the various stakeholders’ was one of those factors identified (Hassall & Associates 2008).

Partnerships and collaboration are features of how the RDCs operate. Their investment has a significant influence on where other research and extension organisations (including CSIRO, universities and state departments) invest. As highlighted by some commentators, this strength also has the potential to endanger benefits to society, particularly because of the highly leveraged approach to funding R&D through these partnerships. As ability to leverage funds is used as a performance criterion to maximise the amount of cash and in-kind effort attracted through brokering, there is a risk that preference is given to projects with the best leveraging capacity rather than the greatest research merit. This could particularly affect the investments in long-term sustainability issues that are of high social, economic and environmental interest (Atkinson 2009), but are of low immediate priority for industry partners.

Such partnerships, strategic collaborations and corporate restructuring are evident across governments, private businesses and even the non-profit sector. These administrative innovations can address issues of focus and effectiveness which are key challenges facing the rural R&D sector.

The social benefits of government support through RDCs may thus be improved through governance reform that reflects emerging circumstances and would involve objective setting, R&D governance and coordination as discussed below.

Objective setting

Addressing future challenges for rural industries with limited R&D budgets raises questions regarding the optimal research and innovation strategies to achieve desirable outcomes from more than 60 per cent of Australia's landscape that is managed by agricultural industries. Innovation and technical change, such as that involved in the adoption of minimum tillage, involves the integration of technical and managerial expertise and the expectations of a range of stakeholders.

The House of Representatives Standing Committee on Science and Innovation inquiry into Business Commitment to Research and Development in Australia (2003) reported that the economic benefit to Australia from a greater business expenditure on R&D (BERD) is considerable. Though amounts of BERD that businesses will outlay will vary reflecting many factors including business cycles, the principal determinant is the perceived returns in the marketplace.

On the other hand, public R&D needs are communicated through national research priorities (NRP). As Nix (1985) noted, R&D strategies and priorities emphasise the priority areas for research rather than the modalities for achieving specific objectives. In translating national research priorities in the rural sector, the challenge is to find a better balance in order to satisfy the individual producer's requirements as well as goals set by the wider community at a region, state and national scale. In other words, it would involve a combination of R&D between that which is specific to an industry and that which relates to managing resources of climate, soil and genetics in particular regions.

More broadly they represent the two categories:

- a research of interest to private industries being capable of improving profits
- b public good research contributing to broader social benefits.

Often there are a number of research issues pertinent to the rural sector where private and public benefits will overlap.

As discussed earlier, research spillovers provide a strong *a priori* rationale for public support for rural R&D. However, this support needs to be viewed against the incentive for private businesses to support R&D where the outputs can be appropriated for private benefit. While the current RDC system has encouraged strong partnerships and a collaborative spirit amongst research groups and between providers and purchasers, in view of enhancing effectiveness it would be desirable to set clearer objectives for R&D procurement with a view to functionally separate the purchasing arrangements for the provision of:

- privately appropriable R&D
- R&D that has a greater public good focus such as those relating to cross-cutting issues such as the water, climate and the environmental issues affecting the rural sector.

Besides this, the objective setting would include identifying the comparative advantage for RDCs across different cross-cutting themes. For example, for areas such as research related to human health and nutritional benefits of food, there is a broader question of why such research needs to be sponsored through RDCs as opposed to a dedicated health research funding body such as the NHMRC (Productivity Commission 2007).

Improving R&D governance

Because RDCs are the key R&D purchasers in the rural sector, improving their effectiveness is a key to enhancing rural R&D for productivity gains. A number of criticisms relating to RDCs may be addressed through improved governance arrangements. While it is beyond the scope of this report to examine such arrangements, it is important that such examination would focus on reducing administrative, transaction and coordination costs. It may involve a process of joint priority setting for RDCs coordinated through the Rural R&D Council to help enhance synergies and address potential duplication of research effort.

Alston et al. (1999) identifies four main factors that research institutions need to consider when designing efficient funding allocation mechanisms. They are:

- allocative efficiency
- information costs
- transaction costs
- rent seeking costs.

These offer useful principles in considering governance arrangements including monitoring and evaluation approaches. In practice, the challenge is to devise mechanisms that strike a balance between these considerations.

Coordination

Coordination between discovery and innovation

The sector's R&D contributes strongly to innovation as its body of knowledge grows through the discovery and adoption of technologies and practices. While experience is an important factor in the discovery process, science is the essential catalyst. There is considerable debate over the 'R' and 'D' components of research and development. According to the traditional view, research is comprised of two components: basic research and applied research. Basic research provided the means to expand the scientific principles, providing a foundation for applied research to investigate ways to enhance social benefits. With the stock of knowledge improving rapidly, in recent times the focus on basic research has faded, and so has the distinction between 'R' and 'D'.

In Australia, basic open science research is largely confined to academic institutions and funded predominantly by the public directly or indirectly through tax incentives. In contrast, rural R&D activities, which predominantly include applied research and experimental development, are often triggered by pure and strategic basic research conducted elsewhere.

As highlighted by the Productivity Commission (2007), the benefits of the open science system are magnified by links across countries and disciplines, and between applied and basic research.

Moreover, in the current context, delineating the 'R' and 'D' components or the distinction between basic and applied science is difficult and of no practical benefit. What is required is to provide for a clear linkage between the discovery and adoption phases of innovation and to ensure a healthy balance and strong connectivity between them to allow the best use of R&D resources. Given the bulk of R&D administered through RDCs has a focus on applied research, but draws on linkages to the rest of the innovation system, these issues require careful consideration.

Enhancing international research linkages and knowledge sharing

Globally, available land and water resources may be used more efficiently when production systems can match the agronomic needs of the crops and animals and the resource endowments of farmers.

With the increasing integration of the world economy, and a greater appreciation of the productivity mitigating potential of global externalities, such as climate change, there is an increasing need to better utilise the international research system to find adaptable solutions.

Technologies have allowed greater control of natural variability and substitution of purchased inputs to supplement the natural system. With concern about environmental externalities, food safety and supply security gaining importance, it is important to find ways to exploit regional variability in agro-ecological conditions through new technologies to find adaptable and resilient food production and land use systems. Technologies and policies that create economic opportunities in food production, and trade in goods and services may expand the range of future land use choices. The opportunities for this in Australia seem relatively large as land is abundant and agro-ecological variability is high.

Foreign knowledge flows

Foreign knowledge flows, both technological and non-technological, are very important for a small open economy like Australia, and their diffusion and adoption is likely to be a major source of productivity gains (Productivity Commission 2007). Policies and mechanisms that allow better use of international research resources through strategic collaborations, such as improving access and designing domestic R&D to assist in absorbing such foreign technological knowledge flows, will help in the acquisition and domestication of imported knowledge.

In understanding future land use options in Australia, new and innovative scientific information and monitoring systems from overseas may be important in a number of areas. For example, in adapting to increased climate variability, overseas experience could provide useful insights. While technology is crucial for the continued economic performance of the sector, future improvement in productivity seems to be limited more by economic factors rather than a lack of technological means (Ali and Talukder 2008).

Building adaptive capacity

Adaptive capacity in agriculture is achieved by substituting the direct reliance on the local natural endowment with human capital, institutional support and technology that may often come from national and global sources. This substitution improves productivity and profitability, thus improving resilience. However, as discussed earlier, the regional comparative advantage of a given technology set can be affected by factors such as rates of resource depletion, environmental pollution or demographic change.

While local environmental conditions will influence adaptation options, the growing diversity in preferences for food, environmental concerns and food safety regulations may mean that, for future productivity growth, some broadening of the range of technologies would be particularly useful. This could provide opportunities to explore synergies between different technologies that could provide farmers with greater flexibility to match a changing production environment (Chavas 2008).

Enhancing spillovers may provide technologies desirable for local conditions, but it would also require local research capacity to comprehensively address local adoption issues (Alison and Hobbs 2004), which cut across different scales of the agriculture and food sector value chain. It would entail greater coordination among research providers and additional effort in identifying the emerging and future needs.

The drought induced social pressure across both dryland and irrigated sectors has been a catalyst for accelerated government action across the rural landscape. The widespread awareness of climate change, its effects and the potential effect of climate change policy responses have also provided an additional incentive to address broader adaptation issues. Increases in global food prices in 2008 and continuing uncertainty about global food supplies and national food security for a number of countries has brought about another wave of change, both in the direction of urgent research needs and policies to facilitate global food supply and demand imbalances.

Solutions to these issues require new knowledge and a capacity to use that knowledge in designing solution pathways to adapt. Radical sectoral changes can occur over long periods and are often characterised by continuing numerous and mostly gradual organisational, structural and institutional adjustments. Incremental technical change, facilitated by demand-pull, technology-push and government-led incentives has assisted agriculture to varying degrees in the past (Nemet 2009). While the nature of these influences will vary as conditions change, they will continue to influence the performance of the sector. In trying to accelerate this change, a balance between bottom up strategies that assist primary producers with knowledge and capacity and top down strategies that appropriately modify the operating environment (including R&D) is likely to be required.

A case for an expanded rural R&D scope

Productivity Commission (2007) noted that 'total funding of science and innovation by the Australian Government has actually fallen slightly as a share of GDP between 1981-82 and

2005-06. But science and innovation funding as a share of total outlays by the Australian Government, which is a better measure of government priorities, is now significantly higher than it was in the early 1980s, and has increased strongly since 1997-98 with a series of major funding initiatives’.

What the above assessment suggests is that governments are under pressure to allocate tax earnings across a range of activities to meet differing social objectives. Science and innovation still command a relative high priority but broadening government priorities may make funds scarcer and achieving more value out of the R&D dollar across the economy is becoming increasingly important. One approach to ensuring higher returns is to expand opportunities for intersectoral collaboration, particularly in studies across cross-cutting issues that enhance spillover benefits of research investments.

The recent drought further highlights the need for broadening the R&D scope in addressing rural issues. Droughts are complex bio-physical events that have significant socio-economic effects depending on the severity and timing of the event. Addressing the causes and effects of droughts involve almost all scientific disciplines.

Moreover, the recent drought experience, and the scientific consensus that agricultural regions will experience increased temperatures and, for some, more frequent periods of very low rainfall, also suggest that drought management will become an ongoing issue for governments and the community.

Rural R&D strategy

The purposes of R&D in the agriculture and food sector include: collating evidence to inform and underpin food, fibre and rural resource policy; meeting the needs of primary producers for profitable production systems; ensuring sustainable practices in areas of public concern; and creating a value chain that enhances benefits to consumers. In meeting these objectives, with limited funds obtained from individual producers and the government, it is crucial to strengthen R&D accountability within and between RDCs and other research providers.

The RDCs already work across functional boundaries to effectively identify and (consistent with their contractual obligations) prioritise emerging research opportunities (both from their own R&D activities and from external sources), and develop them to meet market and social needs to maximise potential benefits. However, given the increasing community focus on cross-cutting issues that confer widespread strategic and operational benefits, more consideration to research governance, including priority setting, monitoring and evaluation, will be required.

Governance arrangements may provide for additional collaboration and cooperation between the different RDCs where there is significant overlap or greater opportunities to gain joint benefits in addressing critical public good issues. They may also provide for greater specialisation, particularly where particular industry groups or commodity lines have common private industry issues to address and pooling of resources would allow economies to be gained.

The Rural R&D Council's consideration of a National Australian Strategic Rural R&D Investment Plan and the development of the R&D strategy involves consideration of factors such as emerging needs, market opportunities and emerging science. To ensure adequate returns to the private-public partnership that contribute funds, a number of accountability mechanisms may be considered. They may include strategies to ensure the optimal delivery of joint research objectives, scope for working with other relevant public research providers, and establishing processes to ensure resource prioritisation and delivery falls in line with emerging needs.

Scope for an assessment framework for rural R&D

The science–technology–innovation system is one that is continuously and rapidly evolving. The dramatic growth over the past 20 years in the use of science, technology and innovation has been the result of a combination of the ease of access to inexpensive computers and the collective influence of a growing number of public policies that enabled public and private business investments in innovation. These activities have provided society with a growing range of economic opportunities, and they reflect increased use of organised science and technology to achieve a variety of social and economic objectives and greater business competition based on innovation (Freeman and Soete 2009).

This R&D effectiveness in business innovation has been largely supported through information and communication technologies to create a well-organised innovation continuum. While technology-led innovation has spread relatively easily across industry and business, in agriculture extension has played an important role in advancing technological change.

In determining the balance among R,D&E, and in exploring ways to improve monitoring and evaluation as a tool for enhancing effectiveness, it is important to develop a clearer definition of each of these activities as well as ways to effectively treat available data on R&D expenditure in aggregating the various types of activities into fields of research and socio-economic objectives.

Given the above considerations, a monitoring and evaluation framework suitable for ongoing monitoring of rural R&D activities and identifying emerging gaps in the R&D effort at a broad sectoral level that focus particularly on productivity, would involve a range of considerations:

- ability to identify broad priority needs
- monitoring of emerging issues and strategic directions, including emerging needs, markets and technologies
- development of short to long-term priorities for investment to drive change
- identification of near, mid and long-term rural R&D priorities and investment directions to drive change in Australia's rural sector.

Addressing these needs is beyond the scope of this discussion paper and requires further work to:

- analyse potential sources of future productivity and business performance
- examine drivers of productivity change outside the rural sector (e.g. demographic change)
- assess industry capacity to innovate including adaptive capacity
- identify barriers for enhancing productivity and profitability
- examine the case for increased investment to achieve productivity gains required to mitigate negative impacts arising from trends identified in the analysis.

7 Concluding comments

The Australian agriculture and food sector has long been served by a complex web of rural R&D links spanning from local research stations to international research consortia that have supported a culture of innovation and technological change. A number of these links have been supported through a number of rural research and development corporations that have addressed a range of production and environmental issues specific to the Australian rural sector.

Australia's rural R&D system has effectively promoted innovations in production, processing and marketing and induced significant change in natural resource management and environmental best practice. The R&D system has facilitated a distinct pattern of technology-based sectoral change.

In recent years, both the scope of rural R&D and the issues faced by the sector has broadened to the extent that a number of cross-cutting issues that confront the future ability of the sector to remain competitive are largely in common with the rest of the economy. Moreover, climate change, the key issue that confronts the agriculture sector globally, will influence the way in which future agriculture and land use systems will evolve. The role of R&D in guiding that evolution is critical. In particular, the ability of the sector to adapt to a changing climate and positively respond in the emerging climate policy environment will require activities across the value chain to be economically efficient and environmentally responsible.

Uncertainties that surround water availability, likely climate variability and the nature of policy responses to mitigate greenhouse emissions and adapt to a changing climate will intensify the traditional risks faced by farmers in managing seasonality and fluctuations in commodity markets.

Recent observations on the volatility in agricultural productivity and the apparent link to climate variability may mean that future productivity improvements need to come from diversification of activities to better suit changing climatic conditions as well as developing new outputs that can capture higher returns and pay for the new technologies. The industry is well placed to benefit from new opportunities presented by the growing income levels and associated diversity in tastes and preferences in the new growth markets of Asia. A key to meeting these challenges will be the ability to harness new knowledge and technologies to increase productivity, market intelligence and hence the profitability and resilience of businesses.

The growing trend in global knowledge generation and rapid spillovers means assessing suitable technologies and adapting them to local circumstances to address industry specific issues will become a priority for individual industries and producer groups. At the same time, the sector will be called on to deliver solutions and outcomes to broader environmental, health, food security and land use issues that have a sector wide strategic focus but are of no specific interest to individual producers. These challenges present an important opportunity

for the Rural R&D Council to address a number of concerns relating to the functional effectiveness of RDCs and to build stronger links with the national innovation system to gain synergies in capacities to address complex issues. Valuable lessons can be learned from the CSIRO Flagships Program to enhance the effectiveness of rural R&D in supporting the next wave of productivity growth in Australian agriculture and the food sector.

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