International drivers of rural R&D

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Executive Summary

The drivers of rural R&D reflect the interrelationship between the objectives governments have sought through R&D and the economic incentives that drive activity in the rural sector. These incentives reflect institutional factors, such as the development of intellectual property rights. They also reflect questions of market structure, such as whether activities are organised on a small, localised scale, or, at the opposite extreme, through multinationals trading in globalized agricultural markets.

From an economic perspective, a central question surrounding policy is whether it encourages the right amount and types of R&D from the point of view of society as a whole. There will always be private incentives to undertake some R&D because the individuals or businesses undertaking R&D stand to benefit from the results of their R&D. However, they are not likely to be the only beneficiaries of R&D. Depending on the type of R&D, other parties stand to benefit from investments in R&D. This reflects the concept of "spillovers". Spillovers are one reason why R&D has important benefits that extend beyond the party undertaking R&D. But by the same token, if parties undertaking R&D cannot capture these spillover benefits, then not enough R&D (or not enough of the right type of R&D) will be undertaken, in the absence of any further action by government.

In the immediate post-war period, increasing productivity was they key aim of policy towards R&D. Investment in R&D was primarily a publicly funded exercise, both within countries, and internationally through mechanisms such as the Consultative Group on International Agriculture Research (CGIAR). The results of R&D were generally freely accessible, and the diffusion of these drove the "Green Revolution" in Asia and Latin America. That R&D was predominantly funded and shaped by governments correlated with the low level of intellectual property protection for R&D, which in turn reduced incentives for private investment in R&D.

The first major shift in the drivers for R&D occurred through the 1980's and early 1990's. A strengthening of intellectual property protection, particularly through international treaty arrangements, increased the scope for private incentives in R&D. At the same time governments reappraised their approach towards rural R&D. Increased intellectual property protection, combined with a greater degree of liberalisation in the trade of agricultural products, sharpened the incentives for private investment in R&D in productivity, and a host of other issues (such as near market and consumer oriented research). In this context, governments sought to focus on issues less amenable to intellectual property protection, such as environmental and land management issues. The logic behind this was to make sure that R&D was funded efficiently: if there were incentives for private R&D because the returns could be privately appropriated, it made sense not to subsidise those activities but rather to focus on types of R&D that would not be undertaken because (in the absence of mechanisms such as intellectual property protection) appropriability was weaker.

These developments were largely confined to developed countries. In developing countries, of which China and India account for the bulk of R&D, public funds remained (and remain) the pre-eminent source of R&D spending. This has been supplemented by investments through the CGIAR, and those made by multilateral and bilateral donors.

International support for R&D in developing countries has reflected two sets of policy developments. One is an extension of trends in developed (i.e. donor) countries towards non-productivity-related R&D. This has been evident in the expansion of the priorities set for the CGIAR. The second set of developments reflects trends in aid and development cooperation policy. In particular, this refers to the need to articulate policy towards rural R&D within the context of poverty reduction strategies, and the delivery of global public goods (such as greenhouse gas emissions abatement, and a reduction in conflicts by ensuring greater food security).

The emergence of food security and climate change as two crucial issues on the international agenda has brought about a renewed focus on R&D policy. A particular question is the appropriate mix of public and private investments in R&D. To some extent, the developments of the 1980's and 1990s – strengthened intellectual property protection and trade reforms – should stimulate investments in R&D geared towards productivity. However, outstanding issues remain as to: the affordability of privately undertaken R&D, particularly for developing countries with a low ability to pay; and whether intellectual property protection affords sufficient scope for diversity and adaptation of varieties. These issues point to the need for targeted public investment, in making the results of R&D more affordable (for example, through a global fund for agriculture R&D and through public-private partnerships) and for supporting localised breeding activities.

In regard to climate change, and environmental concerns more generally, there is a basic requirement to address the wider policy issue of pricing (or finding some mechanisms to reflect) the impact of agriculture. An example would be valuing and rewarding reductions in emissions from rural sources. We would expect such policy action to create some incentives for R&D, given the rewards from environmentally friendly practices that result from the R&D. Having said that, there is likely to be scope for substantial government intervention. This is because even if there are rewards from reducing environmental impacts, the R&D to support this will often relate to and use management practices, that is, types of R&D that are usually not subject to intellectual property protection.

The international policy agenda for food security and climate policy provides many opportunities for Australia, particularly through institutions such as the Australian Centre for International Agricultural Research (ACIAR), to meet R&D needs. Australia has a comparative advantage in R&D geared towards agriculture in difficult environments with variable climates, a description that also fits many of the more vulnerable developing countries. Support could focus on the direct and indirect mechanisms linking rural R&D to poverty, notably: (i) impacts on hunger, as measured by the availability of food calories and the impact this has on health (ii) impacts on economic growth through expansion of the agricultural sector, particularly by stimulating technical change; and (iii) impacts on food prices and incomes.

1 Introduction

1.1 Context and objectives

Frontier has been retained by the Department of Agriculture, Fisheries and Forestry on behalf of the Rural R&D Council to review international drivers of rural R&D. Frontier recognises that the wider context for the report is the preparation by the R&D Council of its investment plan, and consequently the approach taken to this report and the key messages that emanate from it have been prepared with this objective in mind.

Approaches towards R&D, at country and international levels, have undergone various phases of change in the post WWII period. And arguably, a new phase is under way as individual countries and the international community grapple with the confluence of two priorities. These are the need to achieve food security in order to meet poverty alleviation goals, and the need to address climate change and other environmental issues. In addition to these global goals, there are also several issues–such as nutrition and health, evolving consumer tastes – that have emerged as policy concerns in developed nations such as Australia. These challenges come at a time when the appropriate role for government in the delivery of policy is under discussion, and when fiscal imperatives have resulted in increased scrutiny of public investment decisions.

This paper surveys developments past and current, and in doing so, attempts to draw out principles that can help to inform the discussion surrounding the design of current policy towards R&D.

1.2 Structure of the paper

The paper is structured in the following manner.

- Section 2 provides an analysis of the factors underpinning approaches to rural R&D, at the country level, and in terms of international collaborative approaches to R&D.
- Section 3 provides an overview of developments in R&D, including available country data on R&D investments and on productivity. It also surveys approaches to evaluating R&D and the results that are derived from these.
- Section 4 begins by synthesizing the findings of the first two sections into an economic framework, which is then applied to understanding key current and emerging issues of policy relevance.
- Section 5 concludes with a summary of key messages.

2 Understanding the factors influencing developments in rural R&D

2.1 Overview of developments in the policy context

2.1.1 Overview of changes to the policy context

In broad terms, rural R&D at an international level has gone through several distinct phases. We briefly summarise the main phases here.

In the 30 years following the second world-war, R&D was mainly funded by the state and undertaken by state-owned institutions. The focus was primarily on increasing productivity. This dovetailed with the need for reconstruction in those countries affected by the depredations of war, and the need to meet the nutritional requirements of developing countries. Many of the latter group were newly independent, with underdeveloped agricultural systems, and with rapidly growing populations due to their position in the demographic transition.

Rural R&D was dominated by developed countries. Developed country funds also supported R&D carried out through multilateral agencies and institutions, including the CGIAR network of research centres. To a lesser extent, aid from developed nations supported developing country R&D. These international efforts spearheaded the Green Revolution of the 60's and the 70's.

It is generally acknowledged that a first major shift in R&D patterns and policy began in developed countries in the early 1980s, the outworking of which continued over the next two decades. In particular, the respective roles of the public sector and private industry in agricultural research have undergone significant changes due to developments in science, policy, and markets. This is true in terms of the aggregate levels of investment in R&D by private and public institutions, the research focus, and the objectives sought.

In terms of aggregate expenditure levels, the public sector was the primary investor in agricultural research prior to the 1980s. Since then, growth in public R&D spending has been small or stagnant in most developed countries, while privately financed R&D has grown rapidly, to the point that it has achieved parity with public spending in some countries or exceeded it in others (see section 3 for more data). The focus of R&D spending also shifted in developed countries from a dominant focus on farm-based productivity research, to address a number of other issues, including, notably: market access and product quality/ attributes; and linkages between rural activities and wider issues of public policy (notably environmental policy and the management of natural resources).

Reforms were also made in most jurisdictions to the National Agricultural Research System (NARS - shorthand for the network of research institutions, including universities, that undertake R&D). The main thrust of reforms has been to create a contestable market for R&D service provision. To this end, a number of initiatives have been implemented (to varying degrees across different jurisdictions), including: competition for grants-based funding; the privatisation of research and advisory institutions, or their corporatization, by which is meant that agencies remained publicly owned but that their budget needed to be at least in part financed through the sale of services and products on a commercial basis; and the use of short term contracts both to commission research and to employ researchers.

Alongside these trends were developments at an international level. These included an internationalisation of private R&D conducted by the private sector, notably multinationals. In addition, various legal frameworks that related to the conduct of rural R&D were extended or developed, notably in the area of intellectual property. There was also a deepening of collaborative relationships between countries through research institutions. In particular, whereas for much of the post-war period international R&D collaboration was primarily undertaken through the prism of development and international support, the period since the 1980's saw an increase in the role of trade in R&D services i.e. contractual commercial relationships between research institutions and overseas users (whether private or public).

A third phase in international R&D, which in fact partly ran in parallel to the developments above, has consisted in the increased importance of developing country R&D investment as a proportion of the global R&D (see section 3 for further details). This has been driven primarily by increased investments in R&D and India and China. Mainly by virtue of the sheer scale of these countries, their public investments in R&D are a large share of the total for developing countries. However, as observed in section 3, when adjusted for the size of their respective agricultural sectors, neither China nor India are particular outliers in terms of their spending on rural R&D.

Finally a fourth phase in global R&D is currently emerging. While the specific features of this phase are, by necessity, still unclear, some of the broad factors that will shape the development of R&D are already apparent. These include the need to respond to increased concerns for food security, as a result of demographic trends and the consequent pressures on land use and other factors, notably climate change.

Indeed climate change is a factor in its own right for the following reasons: the projected impact of climate change on agricultural output, and the need for adaptation; the environmental impact of the rural sectors because of rural sector emissions and the impact of the rural sector on natural resources affected by climate change; and the need to manage land use and land use change as part of mitigation strategies.

From an international perspective, an overarching goal that brings together issues of poverty and climate change is the need to meet the millennium development goals set by the international community, and more specifically the goal to halve the number of people living in extreme poverty by the year 2015.

We will examine these emerging issues in greater detail in section 4. At this juncture it is useful to examine in greater detail some of the developments of the last two decades given that these provide the backdrop against which current issues will need to be addressed. In particular, we focus on the shifting roles of private and public R&D since the 1980's, and on the issue of internationally conducted R&D.

2.1.2 Factors affecting the shift in policy context

Changing policy attitudes and the quest for efficiencies

Allocative efficiency and market failure

A key driver of economic policy towards R&D is the issue of allocative efficiency. By allocative efficiency, we mean a situation in which the resources of society are put to the uses that will generate the most value to society. Market failure occurs when private entities (individuals, firms) left to their own devices do not provide goods in quantities that reflect their value to society. The reassessment of the appropriate role of public funding and support to R&D reflected a concern that policy needed to be targeted towards correcting for market failure, with a view to maximising efficiency.

In regard to R&D, market failure is primarily driven by issues of appropriability, that is the extent to which the benefits of R&D can be captured by the agents that undertake them. There are two elements to appropriability:

- Excludability – the extent to which parties that do not undertake the investment can be prevented from enjoying its benefits
- Rivalry – the extent to which the consumption of the good by one party diminishes the scope for other parties to consume that good

A pure public good (like defence or clean air) is neither excludable nor rival. The key question is to what extent R&D has these public good elements. As it happens, the answer to this question turns on the issue of spillovers.

By spillovers, in an R&D context, we mean the extent to which a party (a firm, an industry or a country) benefits from the stock of R&D in another party ("outside

R&D").[1] Empirical evidence suggests that spillovers in R&D (generally, and more specifically for agriculture) occur at regional and international levels, and that a variety of factors intervene, notably openness to trade.[2] A survey of studies for Australia suggests that spillover returns for private R&D have an average gross rate of around 50%, though the exact contribution of private R&D to long run growth are much more difficult to quantify with precision.[3] International studies report spillover rates of between 50 and 130%.[4]

In the presence of spillover effects, some institutional response is required so that investors in R&D take into account the wider benefits of their actions. These responses can involve mechanisms for contract enforcement, the enforcement of intellectual property rights, or the development of collaborative networks. These responses have been shown to be influential in private R&D research.[5] Indeed, some estimates for European R&D in agriculture show that private spending on R&D responds positively to spillovers when these spillovers are associated with the presence of patent protection and contract enforcement mechanisms.[6]

The importance of institutional responses based on contract enforcement and intellectual property rights is a relatively recent phenomenon, in particular in relation to international spillovers in agricultural R&D. They have been largely the product of increased economic integration at a regional and global level (for instance, the estimates cited for European R&D in agriculture cover a period from the mid 1980s to the mid 1990s which was marked by increased regional integration). But for much of the 20th century the situation was different:

"Until recently, agricultural technologies (including new plant varieties and the processes and parent material required to develop them) ha[d] been unencumbered by proprietary claims and freely available to all".[7]

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1 See for example Zvi Grilliches (1979). "Issues in assessing the contribution of research and development to productivity growth: in *Bell Journal of Economics, 10. No.*1. A standard test of the impact of "outside R&D" is to estimate, through regression techniques, how total factor productivity (TFP) responds to outside R&D. TFP is itself the residual item explaining growth rates in output once increases in the stock of labour and capital have been accounted for.

2 See for example, David Coe and Elhanan Helpman, (1995) "International R&D spillovers", *European Economic Review*, 39, pp859-887; and Julian M. Alston (2002), "Spillovers" in the *Australian Journal of Agricultural and Resource Economics,* 46:3 pp315-346.

3 See Productivity Commission (200&, *op.cit* pp109-140 and Sid Shanks and S. Zheng (2006), *Econometric Modelling of R&D and Australia's Productivity*, Staff Working Paper.

4 See Productivity Commission (200&, *op.cit.* pp 128-129.

5 See for example Oscar Alfranca and Wallace Hiffman (2001), "Impact of institutions and public research on private agricultural research" *Agricultural Economics* 25, pp 191-198.

6 Oscar Alfranca (2005) "Private R&D and spillovers in European Agriculture", *International Advances in Economic Research* 11, pp 201-213.

7 Philip Pardey and Nienke Beintema (2001), *Slow Magic Agricultural R&D a Century After Mendel*, International Food Policy Research Institute, p 20.

Under these circumstances, much of agricultural R&D was publicly funded. The association between publicly funded R&D and freely accessible technologies makes sense, since left to their own devices, private agents would under-invest in the absence of any mechanism to appropriate the spillover benefits reaped by other parties.

The implications of this discussion are that:

- Various institutional responses (IPRS, contacts, collaborative networks) are required to address the issue of spillovers. (We survey these in greater detail in sections 2.1.3 and 2.1.4)

- When these responses have been unavailable, there has been a case, on efficiency grounds, for public funding. By the same token, the case for public funding needs to be re-examined when other types of institutional responses are possible.

In Australia, these arguments were largely embodied in the findings of the Industries Commission report of 1994.[8] This line of argument has been strengthened over time. For example, in its assessment of support to Science and Innovation, the Productivity Commission emphasised that spillovers were the prime justification for policy intervention. It also emphasised that spillovers per se were not a basis for intervention, but rather that it had to be demonstrated that such spillovers were great enough to make a socially beneficial project unprofitable on a private basis.[9]

These arguments also broadly reflected the thrust of policy reforms in the UK, initiated by the government in the early to mid 1980s (and thus which pre-dated the Australian reforms), and in other jurisdictions in continental Europe (e.g. the Netherlands) and in New Zealand. [10]

Productive efficiency

Aside from allocative efficiency, another objective sought through the reform process was productive efficiency. By this we mean the delivery of goods and services at the lowest cost. The quest for productive efficiency reflected concerns that the NARS as they existed in developed countries was overly bureaucratic and driven by the interests of the suppliers of research rather than the users. As noted, reforms to achieve productive efficiency involved contestable funding,

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8 Referenced in Julian M.Alston, Michael Harris, John Mullen and Philip Pardey "Agricultural policy in Australia" in Julian Alston, Philip Pardey and Vincent Smith (eds) (1999) *Paying for Agricultural Productivity,* pp 126-128.

9 Productivity Commission (2007), op.cit, pp 73-77.

10 See Colin Thirtle, Jenifer Piesse and Vincent Smith "Agricultural R&D policy in the United Kingdom" in Alston et al (eds) (1999) *Paying for Agricultural Productivity.*

privatisation/corporatization, and short-term research contracts. The quest for productive efficiency also made logical sense given the increased reliance on private funding – private funders would be expected to have an interest in the lowest cost delivery of outputs – but also reflected the increased emphasis on the need for the government sector to deliver value for money (particularly given the conditions of fiscal austerity that prevailed in the early 1980s).

Dynamic efficiency

There is a third aspect of efficiency that is also worth emphasising at this point – and that is dynamic efficiency. The concept is somewhat harder to define than the other aspects of efficiency, but essentially involves the question as to whether a society's resources are used optimally over time (rather than, say, in a static allocative sense). While dynamic efficiency is not expressly articulated as a policy principle, it does underpin one of the fundamental aspects of rural R&D policy to emerge over the last 30 years – the role of intellectual property rights (IPRs). One of the standard defences of IPRs is that they preserve dynamic efficiency by preserving incentives to invest over time, by granting exclusivity of use (i.e. a monopoly) over the results of R&D. We thus turn to an overview of IPR issues in the context of rural R&D.

2.1.3 Intellectual property

As already observed, an important determinant of how far governments should finance R&D is the question of appropriability i.e. to what extent does the party investing in R&D capture the benefits of its investments. The more appropriable are the results of R&D, the less case there is (all else being equal) for government intervention. An important factor behind appropriability is the protection of intellectual property involved in the conduct of R&D.

The strengthening of protection for plant varieties in the 1980s is often cited as a catalyst of the increased private investment in rural R&D.[11] Of particular note was the conclusion reached by US Courts and the US Patent and Trademark Office that plant breeders could seek protection both in the form of breeders' rights but also as general utility patents. This is important because while the eligibility requirements for breeders' rights are relatively easy to satisfy, the exclusivity provisions that accompany them are relatively limited. Patent protection, on the other hand, sets much higher eligibility hurdles but also provides much broader rights in excluding third parties from exploiting the patented invention.

As a matter of practice, patents have been granted on all aspects of innovation relating to plant science, both biological and microbiological processes: seeds,

[11] See for example Julian Alston, Jason Christian, and Philip Pardey "Agricultural R&D Investments and Institutions in the United States" in Alston et al. (eds) (1999), *Paying for Agricultural Productivity,* p 76.

breeding methods and plant biotechnology, including gene transfer technologies that enable researchers to tailor crops for specific uses, such as crops resistant to disease, pests, herbicides, or harsh environmental conditions; and crops with increased nutrition or improved food processing traits.[12]

The developments in the United States were a precursor to developments worldwide. One of these was the renegotiation, in 1991, of the UPOV agreement on plant varieties initially negotiated in 1978. The new agreement repealed a prohibition on dual protection under breeders' rights and plant protection, and tightened exceptions relating to the use of protected varieties by other breeders and by farmers for research purposes.[13]

The other major development was the entry into force of the Agreement on Trade-related aspects of Intellectual Property (the TRIPS agreement), under the auspices of the World Trade Organisation. The TRIPs agreement also provided for the possibility of patent protection (indeed, there have been steps under the implementation of the agreement to make this mandatory) and also set out national implementation rules, and enforceability and dispute mechanisms. The fact that the TRIPS agreement is associated with the WTO dispute settlement process – and the consequent possibility of retaliatory trade measures in the event of non-compliance – made it a powerful (and much criticised) instrument. Because the TRIPs agreement relates to all aspects of intellectual property (and not just plants) it has implications for all aspects of innovation that impacts on agriculture including pharmaceuticals, chemicals, machinery, software and so forth.

2.1.4 Other institutional developments

Besides intellectual property, various other institutional developments have facilitated private sector R&D. The progressive reform of agricultural markets has also created scope for private investment in R&D through various channels. This has been the case in both developed and selected developing countries.[14] One of these is the creation of contestable markets for inputs. Another has been the confluence of a reduction in traditional barriers to trade (tariffs and quotas) and the increased importance of standards as a means of regulation, which has increased the potential rewards for near-market R&D.

The development of collaborative arrangements between the state and the private sector has also facilitated private investment in R&D. This has occurred

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12 M. Janis and J. Kesam (2001), "Designing an optimal intellectual property regime for plants: A US Supreme Court debate", *Nature/ Biotechnology*, Vol. 19, October, p 981.

13 Laurence R. Helfer, (2004) "Intellectual property rights in plant varieties – international legal regimes and policy options for national governments", *FAO Legislative Study*, 85, pp 50-51.

14 See Nienke Beintema and Gert-Jan Stads (2008), *Diversity in Agricultural Research Resources in the Asia –Pacific Region*, Agricultural Science and Technology Indicators Initiative Background paper.

through two channels. First, these partnerships have acted as a mechanism for coordinating the decisions for large numbers of produce. Secondly, such partnerships feature institutional arrangements that facilitate the implementation of cost recovery mechanisms. The allocation of funds on a contestable basis has also helped, by sharpening the focus of private purchasers of R&D on the delivery of results, to orient investment towards projects where the benefits were more visible and tangible (for the most part, because they could be measured through market outcomes).

In sum, these developments in the environment for R&D have increased the scope for private funding of R&D, while at the same time sharpening the focus on what should be the appropriate role for publicly funded R&D. One implication that has been drawn by policymakers is that public support should switch to those activities – mainly in the pure sciences – where intellectual property protection is less readily available (if at all). It is also easier to obtain intellectual property protection where technologies are embodied (as in agricultural inputs on processed farm products), rather than where they are disembodied as is the case, for example, of technical knowledge regarding crop management.[15] Other issues of emerging concern have been the interface between agriculture and environmental management, notably on account of the externalities imposed by the former on the latter. All these issues are developed in greater detail in sections below.

The strengthening of intellectual property regimes has also brought attention to the nature of the interaction between public and private expenditure on R&D. This has been reinforced by some evidence of a negative correlation between public expenditure on R&D and private expenditure, suggesting that there might be crowding out effects. In particular, the suggestion is that public expenditure on applied R&D has been crowding out private expenditure.[16] A variant on this thesis is the fact that co-financing arrangements can give rise to subsidies that have the potential to direct public resources to funding private gains, with the effect of displacing publicly beneficial forms of R&D.[17]

While developments in intellectual property have been an important factor in shaping R&D, it is important not to overstate the case. Quite aside from inherent limitations to patentability and protection in relation to some types of R&D, other issues include the fact that:

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15 See for example Ruben G. Echeverria and Nienke M. Beintema (2009), *Mobilizing Financial Resources for Agricultural Research in Developing Countries, Trends and Mechanisms*, Global Forum on Agricultural Research.

16 See Alfranca (2005), op.cit

17 See Frontier Economics (2006) *National Framework for Primary Industries Research, Development and Extension – Economic Considerations*, Department of Primary Industries, Discussion Paper.

- Intellectual property protection alone does not explain the particular mix of private R&D and the relative weight attached to one type over another.

- In many developing countries, provisions for intellectual property protection (and the governance conditions for private sector investment more generally) are lacking leaves an important role for publicly supported R&D.

- Issues related to the concentration of R&D and innovation in certain countries, and within these, certain firms or organisations, and the challenges this creates for the conduct of R&D to meet the policy requirements, notably of developing countries with low ability to pay for innovation done outside and whose needs may differ from the objectives of privately conducted R&D.

- The appropriate trade off between dynamic efficiency and allocative efficiency that stems from IPRs. As already observed, IPRs attempt to safeguard dynamic efficiency by providing exclusivity over the results of R&D – in effect a form of monopoly. This has implications for allocative efficiency insofar as prices are higher and quantities lower compared to a situation where the results of R&D were immediately accessible to competitors. In the context of rural R&D, particular issues are the extent to and cost at which growers can have access to seed varieties, and are able to experiment with these with a view to adapting them or developing alternative varieties.

These different debates surrounding IPRs have placed the topic firmly on the current policy agenda. We shall discuss them in greater detail in the context of the specific issues discussed in section 4.

Summing up: policy trends and substantive R&D objectives

The main message that emerges from our survey of developments is that the respective roles of the state and the private sector have been an important focus of policy debate. The nature and extent of these relative roles have been shaped by a number of factors: objectives sought from R&D; institutional developments (notably relating to intellectual property); and wider policy trends dealing with the appropriate scope for government intervention.

We attempt to summarise the implications of these various observations for substantive types of R&D in Figure 1 below. [18] The figure relates types of R&D to the extent to which they have been the object of policy action on account of market failure.

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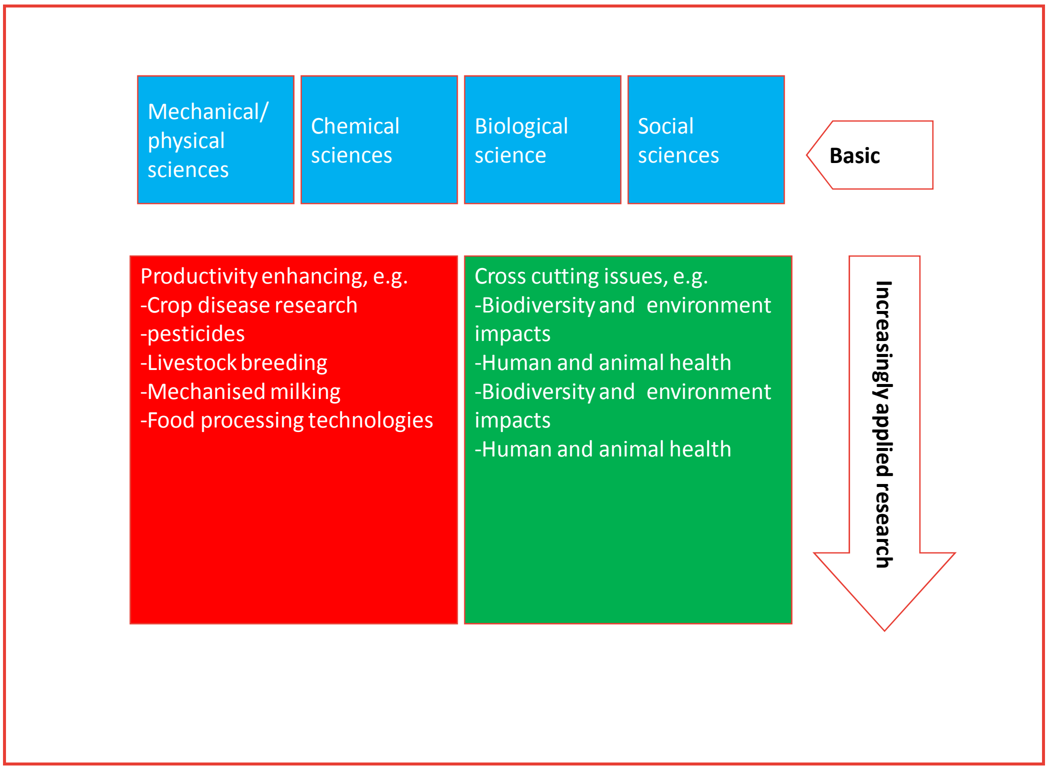
[18] Taken and.

Our observations suggest that private R&D focused primarily on the left section that is shaded in red. This is relatively intuitive: the activities in this section lend themselves well to private appropriation of the results of R&D, through the use of IPRs, and because of the existence of markets for the acquisition of the goods and services that are the product of these types of R&D activity.

This has been accompanied by a tendency, in developed countries, for publicly supported R&D to focus on the blue row of this table (basic research), and the green shaded right hand side of the table. The latter represents activities geared at non-productivity and cross cutting issues. Here, appropriability is weaker because protection through IPRs is more problematic, and because markets for the outputs of R&D, or the activities that would make use of these outputs, tend not to exist.

Figure 1: Typology of rural R&D types



Source: adapted from Andrew Barnes (2001), "Towards a framework for justifying public agricultural R&D: the example of UK agricultural research policy", *Research Policy* 30, p 667

If we consider, for example, the United States "Science Road Map for Agriculture" we note that the top two priorities are food safety and health, and "environmental stewardship". Objectives related to an economic return for producers, and competitiveness in crop production and livestock also figure in the list of 7 priorities, which also include strengthening communities and families, and lessening the risk of global warming. Overall, the general mix of priorities and the ordering given to them is fairly representative of the changes in policy stances and priorities towards R&D.

Of course, one needs to be careful about generalisations. First there is clearly a degree of divergence between countries (as observed in the data presented in section 3) as to the strength of private investment even in activities of the "red side" in this table. Co-financing arrangements are not uncommon. Secondly, there is also some concern as to the extent to which private R&D, driven by intellectual property, is able to address in a socially efficient way concerns regarding productivity. This issue was already flagged above and is addressed in section 4.2.1 below.

Conversely, it would be wrong to view the entire green side of the table above as being riddled with insuperable market failures. For example, there are means through which pricing externalities can increase the private reward from undertaking socially beneficial R&D. Moreover, some approaches to environmental management may require investments in information technology, which may be afforded patent protection.

In sum, the policy stance towards R&D can be characterised in terms of an intention to:

- Reduce public support where returns are privately appropriable. This includes cases were there are substantial spillovers, but where private returns are sufficiently strong to incentivize private R&D

- Reorient public support into areas where appropriability is a greater issue, because protection of intellectual property is more problematic. This includes areas that complement private R&D, but also "cross-cutting issues" particularly those involving linkages between rural activities and other issues (such as environmental and natural resource management)

- Re-appraise the interaction between private and public R&D expenditure, in the context of public policy goals that are sought through R&D, and the types of governance arrangements that are appropriate to managing this interaction.

2.2 Developments in international collaboration

The internationalisation of rural R&D is by no means a new phenomenon. In particular, we noted that it was part and parcel of the postwar expansion of publicly funded R&D. In this section we focus on developments since the 1980's, and the particular forms R&D has taken at the international level.

2.2.1 Multilateral initiatives

CGIAR

The best known multilateral initiative in rural R&D is the network of research centres that comprise the Consultative Group on International Agricultural Research (CGIAR). The basic rationale for CGIAR is to provide a mechanism for conducting rural R&D to support agriculture in developing countries, on the grounds that such R&D would not otherwise occur because of market failures, the lack of resources of many developing countries to support R&D, and the economies of scale and scope that exist in coordinating R&D for multiple countries through designated centres.

Total spending by the CGIAR centres increased steadily through the 1980's before levelling off, in real terms, at between 350 million and 400 million dollars per annum since the early 1990s.[19] This is mainly a reflection of trends in funding, particularly from the OECD member countries of CGIAR that account for about 80% of funding. At the same time, the scope of activities covered by the CGIAR network has moved beyond specific crop focus to include a range of cross-cutting issues including: biodiversity, genetic improvements, agricultural diversification, natural resources management and the support for the development of national policies and institutions in developing countries.

Access to genetic material has become a particular issue of importance to the CGIAR. This is due to the fact that such access is a pre-condition for maintaining crop diversity (for example, through adaptive breeding experiments), and the fact that access to genetic material, and experimentation with crop varieties, has become more complex as a consequence of the implementation of IPRs. In response to these issues, the International Treaty on Plant Genetic Resources for Food and Agriculture was adopted in 2001, following seven years of negotiation, and ratified in 2004. The aim of the treaty is the creation of a multilateral system that will enable signatories to gain access to selected genetic resources from all other signatories. The centres of CGIAR have started using the treaty's Standard Material Transfer Agreement (SMTA) to distribute crop samples as well as the products of its own research. [20]

In addition to the developments relating to the focus of its work, the CGIAR's operations have also had to take into account trends in development policy, notably the need to integrate support for rural R&D within wider development strategy frameworks geared towards poverty alleviation. In practice, this means alignment with Millennium Development Goals (MDGs), and the frameworks

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[19] Philip Pardey and Nienke Beintema (2001), *Slow Magic Agricultural R&D a Century After Mendel*, International Food Policy Research Institute, p 19. The figures used here are in 2000 PPP dollars.

[20] See CGIAR (2008), *Safeguarding the World's Agricultural Legacy*.

agreed by the development community to achieve these, notably the Paris Declaration on Aid Effectiveness (agreed in 2005)[21].

The five key elements are:

- Ownership - Developing countries set their own strategies for poverty reduction, improve their institutions and tackle corruption.
- Alignment - Donor countries align behind these objectives and use local systems.
- Harmonisation - Donor countries coordinate, simplify procedures and share information to avoid duplication.
- Results - Developing countries and donors shift focus to development results and results get measured.
- Mutual Accountability - Donors and partners are accountable for development results.

The principles set out here respond, to a certain extent, to the aid effectiveness literature that developed since 1998, which has emphasised the importance of governance systems, accountability, and a partnership approach. This in practice means a shift away from donor directed priority setting largely based on conditionality, to a process of joint priority setting between donor and developing partner country, and more emphasis on the overall coherence of programmes that are adopted.[22]

The main challenges for the CGIAR appear to lie in reconciling accountability and ownership, and results with alignment of country objectives.[23] These tensions have surfaced because:

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21 See OECD "Paris Declaration of Aid Effectiveness" (available at http://www.oecd.org/document/18/0,3343,en_2649_3236398_35401554_1_1_1_1,00.html). The Paris Declaration was followed up by the Accra Agenda for Action (AAA) which agreed to further principles regarding the implementation of the Paris Declaration.

22 The literature in aid effectiveness is quite vast, reflecting a variety of perspectives. Work by David Dollar and Craig Burnside ("Aid, policies and growth", *American Economic Review*, September 2000, 90 (4), pp 847-868 first raised the issue of linkages between governance and policies in developing countries, on one hand, and results on the other. Their methodology and findings were extensively critiqued notably by Easterly (see in particular W. Easterly, Easterly W 2002 *The Elusive Quest for Growth*, MIT Press, Cambridge, Mass; Easterly, W., Levine, R. and Roodman D 2004 "Aid, Policies, and Growth: Comment" *American Economic Review*, Vol. 94, No. 3, June, pp. 774-780) who emphasised the weaknesses of centralised approaches to aid (including the concepts of the MDGS) and the need for locally designed and accountable schemes.

23 See CGIAR (2008), *Bringing Together the Best of Science and the Best of Development – Independent review of the CGIAR system, synthesis report.*

- The relatively loose structure of the CGIAR has been conducive to fragmented donor support, in that individual donor countries have tended to earmark support for specific areas.

- Developing country participation in CGIAR processes, though it has increased, is still weak.

- The weaknesses of many developing country NARS means in practice that partnerships (especially within a results oriented framework in which donor organisations need to show value for money) are problematic, and there are questions as to whether CGIAR activities are capacity building or capacity substituting in relation to developing country NARS.

- Results and evaluation, though improved, still pose a challenge. This is partly a reflection of the nature of R&D, where the long-lived and diffuse nature of the activities make attribution difficult. Moreover, even where returns on projects can be estimated, understanding these within the context of overarching priorities (such as poverty alleviation) is difficult.

In response, a number of proposals for reforming the CGIAR system have been made. The main proposals involve:

- The creation of a Consortium to bring the different CGIAR centres under one umbrella, in order to increase the coherence of their activities and manage funding optimally across the centres.

- The creation of a CGIAR fund, to act as a centralised instrument for collecting and coordinating funding. [24]

The proposed model, in particular the creation of a fund, mirrors approaches taken in other areas associated with the delivery of development and public goods within development, such as the Global Fund to fight AIDS, Tuberculosis and Malaria. Indeed, there are certain obvious affinities between the human health and rural development fields, insofar as both face issues connected to the question of creating sufficient incentives for R&D and the issue of maintaining accessibility to the results of this R&D.

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[24] The fund would comprise 4 windows allowing for different financing "modalities". The notion of "modalities" is commonly used in the development community. It is derived from the French "modalites" and essentially refers to the mechanisms and procedures through which something (in this case, financing) will be executed. These modalities involve, respectively: long term funding (e.g. to support genebanks); multi-year finding for programmes administered by the Consortium of centres; bilateral donor funding directed at specific windows; and lastly a window for contributions by non-CGIAR members.

Multilateral development agencies

The World Bank has had a long-standing involvement in agriculture and rural development (ARD), through policy support and lending through its concessional lending facilities. Support for R&D by the World Bank falls within this wider context of support for ARD. The World Bank's policy template for agriculture is governed by the imperative of poverty reduction and the millennium development goals. The projected level of funding for all ARD activities for the World Bank's next funding cycle (2010-2012) is estimated between US$ 6.2 billion and 8.3 billion, up from 4.1 billion in 2006-08 and 3.0 in 2003-05.[25] The World Bank's flagship report, the World Development Report for 2008, was devoted to agriculture, indicating the priority attached by the institution (in the wake of increased food prices) to ARD.

The World Bank implements its support to R&D on three levels: nationally, regionally, and through the CGIAR. It estimates that it has committed over US$ 2.5 billion in funding to rural R&D over the last 20 years, in addition to its involvement with CGIAR. About 7% of current spending is estimated to be allocated to the category "Research and extension", while 74% of all spending has been allocated to productivity enhancing activities (the single largest component of these categories is irrigation at 22% of all spending). [26]

In terms of approach and execution, the World Bank faces many of the requirements discussed in relation to the CGIAR – namely, the need to integrate R&D assistance within wider development frameworks geared towards poverty reduction, the need to build effective partnerships with beneficiary countries, and the need to strengthen coherence in the delivery of assistance.

The major multilateral development banks with a regional focus (notably the Asian Development Bank, the Inter-American Development Bank, the African Development Bank, and the European Bank for Reconstruction and Development) also provide programme support for agriculture and rural R&D, and with the advent of the food crisis are likely to play an increasing role.

Within the United Nations and its specialised agencies, key players include the Food and Agriculture Organisation (FAO) and the International Fund for Agriculture Development (IFAD). The FAO's remit is much broader than development assistance (let alone development assistance specifically for R&D). Key functions include the coordination of important treaties relating to agriculture, notably the Codex Alimentarius and the International Plant Protection Convention. While neither are directly connected to R&D, they do set

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[25] World Bank (2009), *Implementing Agriculture for Development – World Bank Group Agriculture Action Plan*: FY 2010-12, p21.

[26] World Bank (2009), *Implementing Agriculture for Development – World Bank Group Agriculture Action Plan*: FY 2010-12, p19

important elements of the overall framework within which R&D is conducted, in particular the objectives that R&D might seek to achieve (e.g. meeting biosecurity and market access requirements). Other key functions that relate to R&D include capacity building initiatives for developing agriculture policy (which can provide the overall context within which R&D policies are articulated and implemented). IFAD also plays a role in this domain, and in disseminating the results of research.

Other global initiatives

Other global initiatives include the Global Forum on Agricultural Research (GFAR). The aim of this organisation is to facilitate the integration of science with local practices within the framework of hunger and poverty alleviation strategies. It aims to do so by, amongst other things, creating networks and partnerships between research institutions, and by providing mechanisms through which civil society (mainly through representative groups such as farmers associations and non-governmental organisations) can influence the policy and practical agenda relating to rural R&D. The influence is less on funding and executing R&D, than in contributing towards ensuring that the appropriate frameworks are set in place to ensure that R&D contributes effectively to solving policy issues surrounding hunger and poverty.

A more recent initiative is the formation of a Global Plant Council in June 2009, following a meeting of representatives of 13 plant science societies worldwide. The aim of the GPC is to harness scientific research toward alleviating hunger and poverty. The initiative is still in its infancy and it is not clear how this will relate to existing global and regional initiatives, nor how funding will operate. The main aim, as with the GFAR, appears to be coordination and ensuring the responsiveness of R&D to the policy agenda in developing countries. In many ways, the emergence of such mechanisms for coordination at the global level can be said to reflect the proliferation of regional and sub-regional initiatives (which themselves are geared towards coordinating activities of national NARS).

The notion of "global public goods"

Assistance to agriculture, and development assistance more generally, is increasingly couched in terms of the delivery of "global public goods". For example, manageable levels of atmospheric carbon dioxide is a global public good. In that case, supporting R&D initiatives that encourage agricultural and land use practices that are consistent with emissions abatement efforts can be characterised as delivering public goods.

Food security is not strictly speaking a public good (in the technical sense of the word) since it does not meet either of the two defining characteristics of public goods (non-excludability and non-rivalry, see section 2.1.2) . However, a number of other goods that are contingent on productivity are more obvious types of public good. These include for example, social stability and security (within countries and across regions). The idea is that promoting food security helps to deliver these wider goods.[27]

None of this is to deny the need to address hunger and poverty in their own right; nor does it detract from the distributional imperatives that underpin assistance to agriculture and development assistance more broadly. Rather, it serves to highlight the increased emphasis by the donor community on efficiency based concepts as well – that is the notion that the global community as a whole would be better off through these forms of support, and that the important matter is to find ways in which support can deliver these gains.

2.2.2 Regional initiatives

Collaborative efforts between NARS

We can distinguish between different types of regional initiatives. One type consists, essentially, of networks and arrangements between the NARS of different countries. Important ones in the developing world include: The Forum for Agricultural Research in Africa (FARA) in Sub-Saharan Africa; The Asia-Pacific Association of Agricultural Research Institutions (APAARI); the Regional Fund for Agricultural Technology (FONTAGRO), for Latin America and the Caribbean; and the Forum for the Americas on Agricultural Research and Technology Development (FORAGRO), also for Latin America and the Caribbean. Overlapping with these are sub-regional associations such as the Association for Strengthening Agricultural Research (ASARECA) in Eastern and Central Africa and the Cooperative Programme for the Technological Development of the Agro-food and Agro-industry in the Southern Cone (PROCISUR).[28]

These regional organisations were established largely through the initiative of representatives of member country NARS. The rationale was to develop synergies between the research conducted in different countries by pooling resources and capacity, and internalising the spillovers that occur between

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[27] In this context, it is worth noting the increased emphasis placed by the development community on the issue of fragile states. Fragile states impose costs on their own citizens, but also often the region (and sometimes indeed the wider world) through the disruption caused to trade and by the fact that these stats may end up as breeding grounds for terrorism. While the fragility of a state clearly makes hunger and food insecurity more likely, it is also the case that the causality will operate in the other direction as well. See for example, Paul Collier and Lisa Chauvet, (2005) *Development Effectiveness in Fragile States: Spillovers and Turnarounds*, Center for the Study of African Economies.

[28] See for example Ruben G. Echeverria and Nienke M. Beintema (2009), *Mobilizing Financial Resources for Agricultural Research in Developing Countries, Trends and Mechanisms*, Global Forum on Agricultural Research, pp 20-21

different types of research (i.e. to develop mechanisms by which the potential benefits of research conducted in country A for country B could be captured). The regional structure of these initiatives is also a function of the fact that the conditions for the successful application of R&D can vary considerably across regions, owing to agro-ecological differences, but also because of the policy and organisational frameworks surrounding agriculture. For example, there are likely to be substantive differences in both the practical R&D requirements, and the methods through which R&D could be applied, between, say, large scale livestock farming in the southern cone of South America and small scale agriculture in Africa.

The multiplicity of regional organisations does raise issues, however, as to how the interaction between these organisations, and between these organisations and international initiatives can be handled. There has not been, to date, a systematic overview or appraisal of this issue, though the coordination mechanisms that have emerged (such as GFAR or the GPC, discussed above) might provide avenues through which this may be addressed. Amongst the concerns that can be advanced are the fact that because many of the regions supporting these institutions are resource poor, their operation is likely to rely on donor funding, with the effect that several institutions (regional or global) end up competing for the same research dollar. There has been to date no review of the additionality in activity that has arisen out of the multiplicity of these organisations. Similarly, while the existence of regional and sub-regional networks can enhance efficiencies through the pooling of scarce resources, where there is a multiplicity of such institutions, the costs of coordination are likely to increase, as does the risk that managerial capacity is diverted away from addressing issues on the ground.

Regional economic arrangements

A second type of regional initiative that is relevant to rural R&D can be found in regional economic arrangements, including free trade agreements as well as other forms of arrangements that do not necessarily involve formal trade liberalisation (e.g. economic cooperation agreements). These arrangements go well beyond agriculture, let alone rural R&D, but are relevant insofar as they can play an important role in influencing the policy framework within which R&D is conducted. This could be directly (e.g. through decisions on the priorities sought by rural policy in general or R&D in particular) or indirectly, for example, by influencing the policy framework for agriculture.

APEC (Asia-Pacific Economic Cooperation) provides an example of an arrangement that operates through both these direct and indirect routes. The latter has tended to dominate, in that trade liberalisation and trade facilitation issues play a preponderant part of the APEC's work programme. These have an impact on the framework within which R&D is conducted given that trade integration involves a harmonisation of standards relating to issues such as biosecurity and product standards, which has knock-on effects in terms of the objectives R&D might seek to achieve. Moreover, increased market access can also increase the returns from investment in certain types of R&D, notably near-market research. At the more direct level, the APEC has working groups on, respectively, biotechnology and on technical cooperation in agriculture (the latter is essentially aimed at developing policy making capacity in developing member economies). The focus is thus somewhat restricted, compared to the range of issues that are involved in rural R&D. There are some references to the need for public-private partnerships in respect of food technology transfer and training, but these are at a relatively high level.[29]

Other examples of regional frameworks include the New Economic Partnership for African Development (NEPAD) which involves both regional cooperation and development assistance from donor partner countries. The NEPAD has formulated a Comprehensive African Agricultural Development Programme (CAADP), though this has yet to be implemented.

2.2.3 Bilateral donor initiatives

The United States and the UK

There has been a long history of bilateral contact and exchange between developed and developing countries, the role of US based research centres and land colleges in the initiation of the green revolution being a significant example. A more recent trend has been for countries to develop overarching strategies for cooperation on matters relating to agriculture, including R&D, within the general framework of development cooperation. Two examples include the US' "Linking Producers to Markets"[30], managed by USAID (United States Agency for International Development) and the UK's "Strategy for Research on Sustainable Agriculture", run by the Department for International Development (DFID).[31] The latter strategy is arguably more focused on R&D per se, while the former also addresses issues related to rural infrastructure. Moreover, the UK's paper focuses more heavily on issues of public goods, particularly the relationship between agriculture and the environment and natural resource management, including issues of water management. The regional focus of DFID's activities is more concentrated –it has identified four regional research programmes, three of which are in Africa and one in South East Asia.

Both the US and the UK have in common the fact that they rely on multiple delivery mechanisms to promote rural R&D with a view to achieving

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[29] See for example, APEC (2006*), Food System Report to the Ministers*, pp4-7

[30] USAID (2004), *Linking producers to markets*

[31] DFID (2008), " DFID Research Strategy 2008-2013", *Sustainable Agriculture Working Paper Series.*

development objectives. These include: funding the activities of developing country NARS; developing partnerships between donor country research institutions and partner country NARS; and supporting the CGIAR network.

Both the United States and the UK have sought to integrate their cooperative arrangements for development with wider policy mechanisms. In the United States this has involved collaboration between USDA, USAID and The State Department. In the UK, the DFID houses the Resarch4Development programme and coordinates linkages with other government agencies.

DFID has also helped develop and financially support two public-private partnerships: the Global Alliance for Livestock Veterinary Medicines (GALVmed) and African Agricultural Technology Foundation (AATF). DFID has also developed a programme, "Research into Use" which is aimed at facilitating the dissemination of research funded by DFID and other donors.

In many ways, the approach pursued by DFID represents an advance on the way bilateral support for international rural R&D has been conducted. The approach towards agriculture is articulated within the wider framework of a general approach to research geared towards poverty reduction. Agriculture is thus one of several topics that have been identified as core research topics. A common feature across all of these topics is that efforts at supporting research are geared towards supporting the delivery of public goods, which is in keeping with the way in which approaches towards R&D issues has developed locally within the UK. Within the specific subject area of agriculture, care has also been taken to spell out the public good aspects that rural R&D will support; namely, basic research that supports productivity, and the linkages between agriculture, the environment and natural resource management.

Australia

The conduit for Australia's support for international efforts at R&D is the Australian Centre for International Agricultural Research (ACIAR). The development of ACIAR's activities since its foundation in 1982 largely reflects the way in which policy and practices in relation to R&D support, and development cooperation more generally, have evolved. As noted before, this has involved:

- Integration into wider policy frameworks relating to poverty reduction. This is reflected by the emphasis given in ACIAR's corporate plan and underlying strategy to the linkages between its activities and the Millennium Development Goals.[32]

[3232] ACIAR (2008), Corporate Plan 2008-2012.

- The emphasis on effective partnerships with beneficiary countries. The need to invest in capacity building initiatives, notably the capacity of partner countries to identify priorities and to help integrate them into concrete strategies was one of the important recommendations of the last review of ACIAR activities. [33]

- The broadening of the scope of research beyond productivity issues to include climate change, market access (including dealing with standards and biosecurity issues), aspects of natural resource management (particularly water); fisheries, forestry, rural development, policy reform and institutional capacity building, and post conflict and natural disaster responses.

ACIAR's regional focus, dominated by the Asia-Pacific, and South and South East Asia, is largely in keeping with the focus of its overall development cooperation efforts. At the same time, given Australia's comparative advantage in dealing with issues related to climatic conditions and relatively poor soil conditions, there would be scope to expand ACIAR's influence to parts of the world (notably Sub-Saharan Africa, where ACIAR's activities are limited to South Africa) that are characterised by similar conditions.

The main delivery mechanisms for ACIAR's support are bilateral programmes (which account for 80% of funding) and support to multilateral initiatives (20%). ACIAR does not appear to have engaged with global private public partnerships in the manner, say, of DFID.

In addition to support for R&D, another aspect of Australia's international involvement in research lies in its participation in its linkages to global science activities. These are primarily conducted under the auspices of the International Council for Science (ICSU) and its subsidiary bodies, and science bodies under the United Nations. The research supported through these organisations is often pure science research, which if properly leveraged, such research helps to support the more applied forms of R&D that are delivered by institutions such ACIAR.

The main benefits from international collaboration through these organisations lie in the pooling of expertise. This in turn provides access to the fruit of scientific research, and also increase the influence of Australian researchers. One rough measure of the extent of international collaboration is the proportion of Australian publications that feature international collaboration. A Bibliometric analysis of publications between 1997 and 2004 reveal that, in the area of plant and animal science, 46% of publications featured international collaboration,

[33] Malcolm Nairn, Gelia Castillo and Rob Dun (1998), *Staying Ahead – Report of a Review of the Australian Centre for International Agricultural Research (ACIAR).*

which is slightly above the average for all disciplines. [34] It is not clear to what extent or how effectively the fruit of such collaboration translates into the operational activities of organisations such as ACIAR. The report that contained the evidence just discussed suggested there was scope for better integrating Australia's engagement with the global science community, on one hand, with the work of government agencies on the other.

2.2.4 Summing up

The main messages to emerge from our review of international developments are that:

- Approaches towards international R&D have reflected two sets of policy influences: approaches to R&D within developed countries themselves; and trends in policy and practice in relation to development cooperation and financing.

- The linkages between approaches to R&D in developed countries and international approaches is illustrated both by:
  - the Green Revolution episodes of the 1960s and 1970, which largely drew on the experiences of developed countries (and particularly the US) in increasing productivity through publicly funded research.
  - Through the shift, since the 1980's towards a widening research agenda, with an increased emphasis on the delivery of public goods, particularly the relationship between agriculture, the environment and natural resource management.

- The trends in policy and practice in the realm of development cooperation that have been most relevant to R&D have been:
  - The emphasis on poverty reduction, and the need to articulate R&D policy , and measure its impact, in those terms. This in turn has required engaging with the various ways in which agriculture impacts on poverty outcomes including: the links between agriculture and food security; agriculture and international trade (and particularly market access issues); and the linkages between agriculture and environmental issues (including climate change).
  - The emphasis on partnership approaches, accountability and results, and developing country ownership – a combination of requirements

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[34] See Chris Warris (2005), *Maximising the Benefits From Australia's Formal Linkages to Global Scientific Activities*, Australian Research Council Linkage-Leaned Academies Special Projects, Australian Academny of Science, p 32.

that in practice poses significant challenges for the delivery of R&D, particularly in the context of weak policy and institutional capability in developing country partners.

- The increasing emphasis on the delivery of "global public goods" as a rationale for assistance to R&D, alongside more traditional distributional objectives.

- There are multiple types of mechanisms and initiatives for the delivery of R&D at an international level. All face the challenge of adapting to the policy influences set out above. In addition, there are important issues relating to the coherence of these initiatives.

- Many of the challenges that face ACIAR are reflective of the challenges enumerated above that confront the development community globally. ACIAR has made efforts to relate its assistance efforts to the attainment of broader poverty reduction goals. A further step would be to assess what specific R&D activities, or groups of activities, have the highest payoff in terms of poverty reduction.

- Australia collaborates with international science and research initiatives through its participation in relevant international science organisations. There is scope for the results of such collaboration to be better integrated into the operation work of agencies such as ACIAR.

3 Trends in R&D

3.1 Investments in R&D

Having considered the factors that have shaped policy towards rural R&D, we now consider some of the trends in R&D expenditures. The aim is to provide some rough comparisons of trends across countries. We also consider data on changes to productivity.

3.1.1 Overview

The standard way of comparing expenditures on R&D is to convert data from different countries into a standard unit of account, usually the US Dollar. Because the exchange rate between countries can vary, often significantly, it is useful to perform currency conversions using a measure of the long run exchange rate between countries. Purchasing Power Parity (PPP) exchange rates are such a measure – they are the exchange rate that equalizes the cost of living between any two countries. It is also standard practice to adjust for inflation by standardising values with reference to a benchmark year. The year adopted for the data presented below is 2005.[35]

The data in Table 1 incorporate revised estimates for R&D, following revisions made by the World Bank to cost of living data and GDP deflators. As such, the numbers differ from previous studies on the subject.[36] In particular, previous findings that developing (low income) countries had overtaken developed (high income) countries in terms of public investment in agricultural R&D have been shown to be incorrect – developed countries accounted for over 57% of public R&D expenditures in 2000, which was only slightly lower than their share in 1980. The United States remains the largest investor of public funds in R&D, with 3,796 million invested in 2000 and 4,313 million in 2005. By 2005, China had taken over (from Japan) as the second largest investor of public funds in R&D in total dollar terms.[37] Data for 2005 for selected countries (ones for which the data are reliable) are provided in Table 2 below.

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[35] The choice of this particular year was made by the organisations (i.e. the World Bank and ASTI) that are the source of this data.

[36] Notably Philip Pardey, Nienke Beintema, Steven Dehmer and Stanley Wood (2006), *Agricultural Research – A Growing Global Divide*, Agricultural Science and Technology Indicator's Initiative, IFPRI.

[37] Amounts are in US dollars at 2005 PPP levels, unless otherwise stated.

Table 1 Public R&D investments 1981 and 2000 in selected countries

Country category	Investments (million 2005 PPP dollars)		Share of global total (%)	
	1981	2000	1981	2000
Low income	1,410	2,564	9	11
Middle income	4,639	7,555	29	32
High income	9,774	13,313	62	57
Total	**15,823**	**23,432**	**100**	**100**
Sub-Saharan Africa	1,084	1,239	7	5
Asia-Pacific	1,971	4,758	12	20
Latin America and the Caribbean	2,274	2,710	14	12
West Asia and North Africa	720	1,412	5	6
Sub Total	**6,049**	**10,119**	**38**	**43**

Source: Nienke Beintema and Gert-Jan Stads (2008), Measuring Agricultural Research Investments – A Revised Global Picture, ASTI Background Note, October, p2, NB: data for Asia –Pacific are for low income and middle income countries, and exclude OECD countries of the region (Australia, New Zealand, South Korea and French Polynesia).

Public investment in R&D as a share of agricultural GDP has varied over time. In Australia, some estimates suggest that it has declined from a high of nearly 6% in 1987 to close to 4% by 2003.[38] In the United States, the share of public investment in R&D has remained broadly constant, between 3% and 4% of agricultural GDP, over the last two decades.

[38] John Mullen and Jason Crean (2007), *Productivity Growth in Australian Agriculture: Trends, Sources, Performance,* Research Report prepared for the Australian Farm Institute, p. 25

Table 2 Public agricultural investment in 2005, selected countries

Country	Public investment in R&D, million 2005 PPP dollars
Australia	431
Brazil	727
China	2,268
India	1,075
Japan	1,195
USA	4,313

One of the most notable features emerging from the data is the growth of R&D spending in the Asia Pacific, driven largely by increases in China and India. Public R&D investments in China increased from 713 million dollars in 1981 to 1,684 million and 2000. As reported in Table 3 below, this increased to 2,268 million by 2005. Public R&D investments in India increased from 400 million dollars in 1981 to 1,152 million in 2000, before tapering off somewhat to 1,075 million. South East Asia, notably Thailand, the Philippines, Indonesia and Malaysia, has been another growth area of R&D investments (with total public investment in R&D estimated at 1,355 million)[39].

3.1.2 Differentiation, rather than a global divide

While trends in global R&D are sometimes spoken of as showing a growing divide, it is more appropriate to speak of several divides, and within these, various layers of differentiation. At a basic level there is a distinction between the countries that dominate R&D, and the others. The former include: the United States, Japan, selected European Union countries (the UK, France, and Germany), and OECD countries of the Asia-Pacific (Australia, South Korea and New Zealand) amongst developed countries, and China, India, Brazil and select South East Asian countries (Indonesia, Malaysia, the Philippines and Thailand).

There are also disparities between developed countries and developing countries, and within these groups. A glimpse of these differences can be given by consulting Table 3 below, which gives shares of public and private R&D spending as a percentage of agricultural GDP (i.e. the proportion of GDP accounted for by agricultural activities).

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[39] N.Beintema and Gert-Jan Stads (2006), Agricultural R&D Capacity and Investments in the Asia-Pacific Region, IFPRI, p 3. The figure quoted here was estimated prior to the revision by the World Bank to its cost of living indices and GDP deflator, hence it is likely to have overstated the actual position.

Table 3 R&D expenditures (public and private) as share of agricultural GDP

Country	Public R&D (2000)	Private R&D (2000)
Australia	3.1%	0.4%
Brazil	1.8%	n/a…
China	0.4%	0.02%
France	0.2%	0.6%
Germany	0.2%	0.3%
India	0.3%	n/a…
Japan	2.9%	0.1%
UK	0.6%	1.5%
USA	3.9%	4.5%

. *Sources*: ASTI and OECD. n/a means "not available"

We note that for the main developing countries, the share of R&D as a proportion of agricultural GDP (known as "R&D intensity") is significantly lower than for developed countries, notwithstanding the high rates of growth in R&D investment in developing countries. There are many factors that can affect R&D intensity, so one cannot automatically draw inferences about the adequacy of R&D policy on this basis. For example, the progressive reform of the policy framework in many developing countries allowed them to move from a situation in which agriculture was heavily taxed (often indirectly, through exchange rate controls, administered product prices and the higher rates of protection for manufactures) to a more favourable policy environment. This is likely to have increased the agricultural output independently of R&D spending, and therefore to have caused a drop in intensity measures.

The second observation is that private investment in R&D is much more important in developed countries than in developing countries. Virtually all of the 12.9 billion dollars of private R&D expenditures in 2000 were undertaken in the developed world. There are a number of explanations for this including more favourable institutional conditions (such as the enforcement of intellectual property rights), more established markets for the outputs of R&D including seeds and other inputs, and a greater degree of commercialisation in agriculture in developed countries.

It should be noted that in two South East Asian countries, Indonesia and the Philippines, private expenditure on R&D has increased, to account for nearly 20% of total R&D. This is to a large extent the reflection of investment in export oriented products, such as plantation products, forestry, food-processing and fishing – and thus in all likelihood a reflection of the need to meet product standards in export markets.[40]

3.1.3 Mix between private and public R&D

While private R&D is concentrated in the hands of developed countries, the trends across developed countries are far from uniform. Private R&D in the United States and the UK accounts for the majority of R&D in agriculture, with private R&D in the UK exceeding public R&D by a factor of nearly 2 to 1 in 2000. (France and Germany also have levels of private R&D higher than public R&D, though at considerably lower levels than the UK). By contrast, public R&D dominates in Japan and Australia.

The economic explanations behind these trends are not always obvious. As discussed below, reforms in the UK led to a reduction in government spending on all forms of R&D. The role of public R&D in Japan is not surprising, given the large measures of support afforded to the sector – total government support for agriculture amounted to 1.1% of GDP in 2006, whereas agriculture accounted for 1.6% of GDP (as against 5.2% of employment, belying very low productivity).[41] The backward nature of the agriculture sector in Japan and its small share in Japan's total exports signify that the scope and incentives to sustain private agriculture are missing.

There is some indication that the share for private R&D spending in Australia increased in the five years since 2000, from roughly 10% of total R&D expenditure to nearly 25% by 2005 (according to OECD data). This may however be a blip, with current data from the Australian Bureau of Statistics putting total business spending on R&D at just under 120 million, which would be more to the tune of 15% of total R&D. These findings are corroborated by other studies, which have generally placed the private sector's share of total agriculture R&D in a range of 10% to 14% of total R&D.[42]

The relative weights of private and public sector R&D in Australia invite comment, given the history of reforms in Australia (see below), and also given the more commercialised nature of agriculture than, say, in Japan. Moreover, in

[40] Nienke M. Beintema and Gert-Jan Stads, *Diversity in Agricultural Research Resources in the Asia-Pacific Region*, ASTI., pp 32-36.

[41] WTO (2009), *Trade Policies Review of Japan, Report by the Secretariat*, p 71.

[42] See for example John Mullen and Jason Crean (2007), *Productivity Growth in Australian Agriculture: Trends, Sources, Performance,* Research Report prepared for the Australian Farm Institute, p. 44

Australia, Agriculture accounts for 15.8% of merchandise exports and 2.8% of GDP, compared to 9.8% and 1%, respectively in the case of the United States. Yet private R&D spending was nearly 10 times lower, even though the importance of trade to agriculture might suggest that there are strong commercial incentives. Even if one were to suppose that some spending actually recorded as government spending was in fact private spending (more specifically, industry levies to which the government provided co-financing), the disparity between government and privately funded research would still be notable.

The issue in contention is the degree of public support for industry based providers of R&D (as opposed to, say, RDCs that focus on cross-cutting issues). One possibility is that tariff protection and direct payments to producers is significantly higher in the United States, which could serve to artificially boost perceived returns to R&D. It might also point to different political economy arrangements between the two countries – a reduction in more distorting forms of assistance in Australia in exchange for relatively high levels of support through public R&D.

Indeed, this argument is sometimes advanced as a justification for public support for R&D,[43] though this is more a political economy argument (i.e. trying to placate certain constituencies that face a cut in support) than an economic one. From a global point of view, subsidies to R&D are generally preferable to using producer subsidies as a means of responding to product market distortions, given the efficiency costs of R&D subsidies are likely to be lower, on account of the effect of R&D spending on product quality, coupled with the fact there may be spillover gains to other parties.

Other arguments are less convincing. For example, it is alleged the benefits of R&D are often captured by third parties, such as consumers benefiting from higher product quality or lower prices. But this is not in and of itself a disincentive for private investment in R&D. In relation to prices, if the assumption is that markets are imperfectly competitive (and they would need to be if prices were to be responsive to output changes as a consequence of R&D spending), then increased R&D spending and increased output is likely to increase market share and profitability, if the responses of rivals are held constant. Indeed, the "political economy" argument referred to in the preceding paragraph (namely, that characterised R&D spending as a substitute for producer subsidies) is dependent on such an effect. One cannot argue simultaneously that there is a disincentive to invest because of the impact of R&D on prices and maintain that publicly financed R&D is a suitable response to overseas producer support.

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[43] See for example, Rural R&D Corporations (2007), Response to the Productivity Commission Draft Science and Innovation Report, pp 17-18

Moreover, recent research on public R&D in broadacre agriculture suggests that the productivity growth attributable to public R&D has been instrumental in avoiding sharp declines in the terms of trade for Australian farmers.[44] Since this is a privately beneficial outcome, it does highlight the incentives for private investments in R&D related to productivity. Finally, as discussed further below, the development of instruments such as End Point Royalties has played a role in contribution to the development of domestic breeding activities, in conjunction with public funds.

Relationships and partnerships between private and public investments

The United States is the world's single largest investor in R&D, in total, and in the private and public components. Moreover, both public and private R&D investments have grown together. Figure 2 depicts the particularly rapid growth in the number of biotechnology patents, one of key drivers of private R&D growth. Two phenomena are interesting – the growth in R&D undertaken by non-profit institutions, and the high share of non-US firms (the latter statistic reflecting foreign investment in US R&D).

The latter is illustrative of a wider phenomenon, namely the fact that R&D is increasingly undertaken by multinational corporations. Multinationals are able to manage international spillovers in technology because, by definition, they are present in many countries (indeed, one of the rationales for their emergence is to manage such cross-border linkages). This, combined with patent protection, further sharpens the focus on the rationale for public support, particularly for productivity issues. As mentioned before, the question of spillovers historically provided a basis for public support. To the extent that these can now be better managed, public support needs to find a different rationale (for example, the cost of accessing privately funded and patented R&D).

[44] John Mullen (2007), "Productivity growth and the returns from public investment in R&D in Australian broadacre agriculture", Australian Journal of Agricultural and Resource Economics, Vol 51, pp359-384

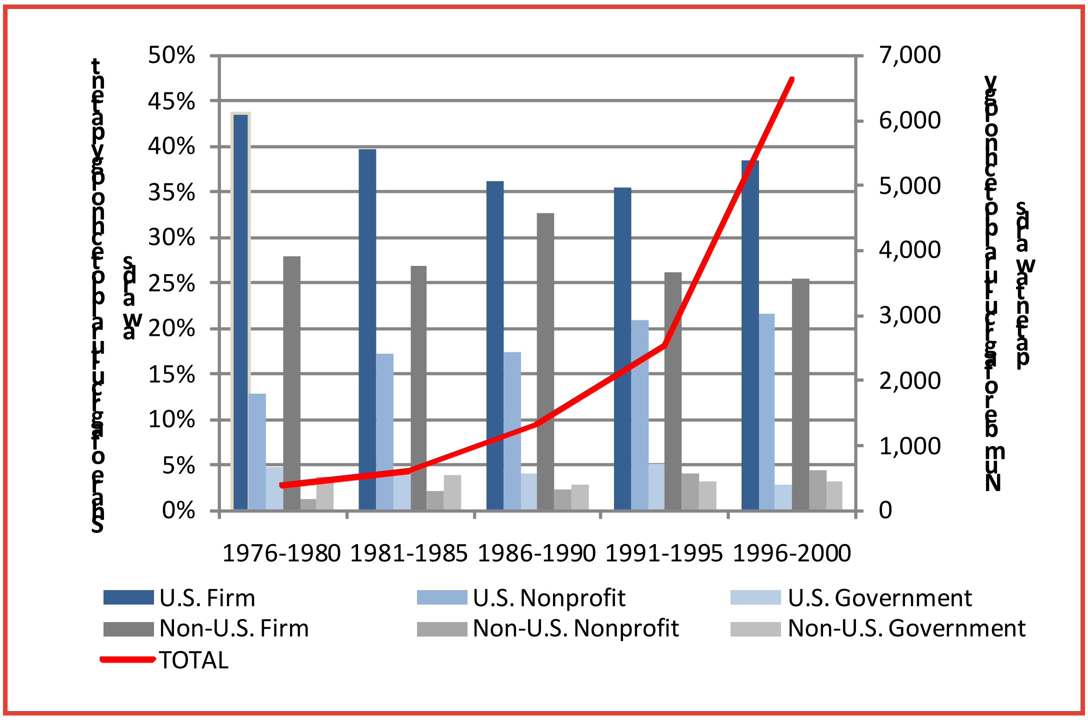

Figure 2: Agricultural biotechnology patent awards (patents awarded in the U.S.)

Note: For ease of presentation, the share of patent awards for the following categories are not presented: U.S. Independent, Non-U.S. Independent, and Unknown/Other. The cumulative share for the three categories in each time period is around five percent of the total. The three categories are represented in the total patent awards (i.e., right y-axis). NB use right hand vertical axis for red line, left hand vertical axis for bar charts.
Source: USDA using records from the U.S. Patent Office.

The data for the United States suggest some degree of complementarity between private and public R&D – or at the very least, do not point to a crowding out effect. This could be explained by changes in the environment for private R&D, including the strengthening of protection accorded to intellectual property for plant varieties. Changes in collaborative arrangements have also facilitated joint public and private investment, by allowing the private sector to retain intellectual property rights rather than cause them to automatically revert to the state.

Data for the US point to a very rapid increase in private investment in plant breeding since 1970 (and the introduction of plant breeding rights), from about 100 million to nearly 600 million by 2000.[45] The extent of actual cropping accounted for by private and publicly bred varieties differs by crop type and country.

Comparing across countries, privately bred varieties have, historically, accounted for a higher share of crops in the US and Western Europe compared to Australia.

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[45] See Paul Heisey, C.S. Srinivasan, and Colin Thirtle, "Privatisation of plant breeding in industrialised countries: Causes, consequences, and public sector responses:, in Derek Byerlee and Ruben Echeverria (eds), *Agriculture Research in an Era of Privatisation*, p 183.

A probable explanation is that IPR protection for privately bred varieties was introduced much earlier in US and Western Europe.

In addition to the introduction of IPR protection, Australia has taken other steps to increase the returns to private investments in seed breeding. One way rural RDCs have sought to achieve this is through the implementation of End Point Royalty (EPR) schemes. These schemes essentially provide contractual mechanisms (such as an agreement or a licence) allowing growers to access varieties and plants covered by some form of intellectual property protection (whether in the form of plant breeders' rights or patents). Whereas, traditionally, the way of paying for access has been at the point of sale (e.g. of seeds to growers), EPRs involve the payment of levies calculated as a function of the gross value of production. Because growers are liable on the basis of actual output, the shift to EPRs from payments at the point of seed purchase reduces their risks and thus has (from a grower perspective) desirable consequences. Rural RDCs involved in this process play a role in the coordination and the administration of this process.

The use of EPRs has played an increasingly important role in developing and sustaining local plant breeding efforts, in order to increase diversity and to reduce reliance on externally developed varieties. As things stand, EPRs are used in conjunction with public funds to support breeding programmes. Existing evaluations of wheat breeding programmes suggest that there are both private and public benefits from these programmes. For example, improved resistance to disease and pests confers a private benefit to growers, but also reduces the need for large-scale use of fungicides. By and large the private benefits dominate the public benefits, and hence there is scope for EPRs to become the main source of funding for breeding programmes, particularly for crops such as wheat.[46]

More generally, RDCs play a role in managing the intellectual property under their control with a view to ensuring that research outcomes are disseminated rapidly, through commercialisation or dissemination.[47] Together with the efforts outlined above in relation to EPRs, this points to the role that public-private partnerships can potentially play in enhancing efficient policy by (i) developing mechanisms that can increase the level of private sector funding in R&D and help to re-orient public funds towards wider (e.g. environmental) issues and (ii) managing the trade offs between dynamic and allocative aspects of efficiency (iii) and addressing distributional issues, such as the level of risk borne by growers.

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46 See for example John Brennan, Peter Martin, and John Mullen (2004), "An assessment of the economic, environmental and social impacts of NSW Agriculture's wheat breeding programme", *Economic Research Report No. 17*, NSW Agriculture, pp23-26.

47 See for example *GRDC (2008)*, Annual Report, p 87

3.1.4 Productivity trends

In economic terms, productivity is a measure of how much output can be generated by a given set of inputs. If, for example, a given hectare of land produces twice as much output as another hectare of land, then the former is twice as productive as the latter. This may be because of other inputs into production e.g. more fertilizer, better crop management, better machinery and so forth. The question of interest is to see what role R&D plays in improving productivity, in particular whether, for any given stock of inputs, R&D can increase output either by improving the quality of these inputs (e.g. better fertilisers or pest resistant varieties), or the interaction between these (e.g. better farming techniques to manage the use of fertilisers and irrigation).

There are three challenges: measuring productivity, linking productivity to R&D, and then drawing implications about the appropriate type of R&D and R&D policy.

Yields

Yields offer one way, albeit very crude, of measuring productivity. Figures 3-5 below depict some trends for selected key crops.

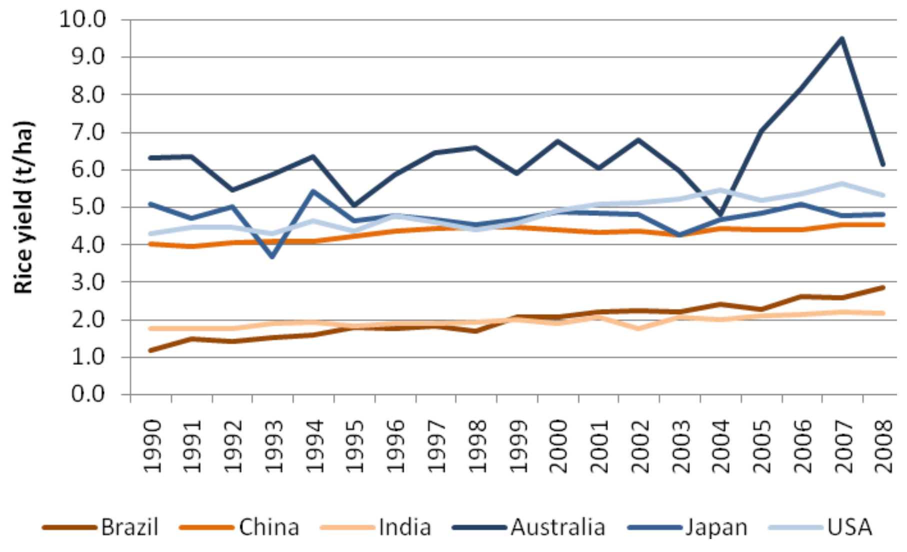

Figure 3: Rice yields, 1990-2008

Source: OECD.

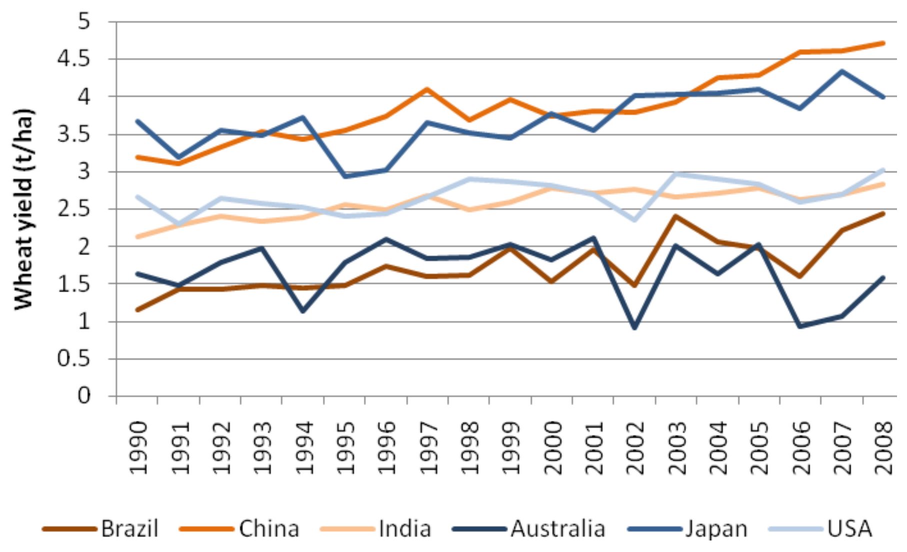

Figure 4: Wheat yields, 1990-2008

Source: OECD.

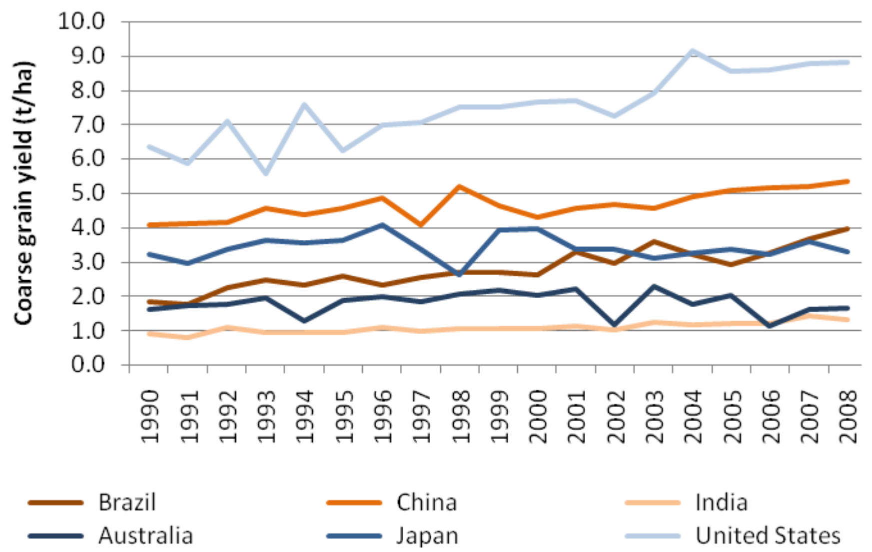

Figure 5: Coarse grain yields, 1990-2008

Source: OECD.

It is very difficult to draw any precise inferences between trends in R&D and the yield data. What is observable is the relative "flatness" of trends in yields in a number of economies, notably the major developing countries. For example, in China, yields for rice and coarse grains have remained relatively flat (though wheat yields have shown an increase) over a period when R&D spending was increasing. Indian productivity remains low and flat, probably pointing to the existence of a host of other factors besides R&D impinging on productivity growth, notably the existence of many small, barely viable farms or subsistence farming, missing markets for credit and inputs, and poorly developed transport linkages.

In terms of policy inferences, yield trends are of limited use in and of themselves since there is no causal attribution to underlying drivers for these trends.

Total factor productivity trends

Total factor productivity (TFP) is measured as the residual component of output growth once growth in factors of production (e.g. labour and capital) has been accounted for. The concept amounts to asking, first, how much growth is left unexplained once we have measured how much inputs have grown; and then attributing this unexplained element to changes in productivity.

The advantage of TFP measurements is that they offer a more complete picture of productivity by controlling for the effect of various factors of production on output. Moreover, it is possible to try and estimate the determinants of TFP, such as R&D (this is discussed in greater detail in section 3.2 below). Difficulties with TFP measures include the fact that they tend to be sensitive to the econometric methodology used (particularly the functional form of the output growth equation used to estimate them) which reduces the reliability of estimates. With these factors in mind we turn to broad findings.

Data for the period 1960-2000 suggest that annual TFP growth for agriculture has averaged between 1% and 2% in developed countries, being relatively stable around 2% as of the late 1980s. For developing countries as a whole, starting from a very low base of just above 0% in the 1960s, there was a progressive increase in annual TFP growth, reaching 2% in the early 1980s. Following a drop in the 1980s, annual TFP growth increased to an average nearly 2.5% in the mid 1990s, before dropping back to 2%, roughly the same level as developed countries.[48]

Developed countries

Comparisons between productivity growth rates across countries are not straightforward, given the sensitivity of results to estimation techniques. Surveying the results from a cross-section of estimates, one study concluded that

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[48] Data from Keith Fuglie (2009), *US Agricultural Productivity and International Comparisons*, Presentation made to the ABARE 2009 Outlook Conference, Canberra March 2009.

growth in TFP in Australia (at just over 2.16% per annum on average) was comparable to results for the United States and the UK, and at (or slightly above) the results for OECD countries as a whole.[49] The same study concluded that, on balance, there was an acceleration in productivity growth in the period 1980-2000 (and particularly through the 1990s) in Australia.

In regards to Australia, specifically, the fact that real public investment in R&D has remained relatively constant over the last few decades does not appear to have affected productivity growth rates; indeed there are some signs that this may be increasing. The public policy implications of this are unclear: it may be that current growth rates still reflect the lagged effects of past investments, or that there are some productivity spillovers from investments directed at public goods R&D (such as R&D relating to environmental outcomes). [50] Institutional arrangements that have facilitated private investment may have also played a role.

The sources of productivity growth in developed countries are mainly attributed to changes in farm size (larger farms leading to greater economies of scale) and to R&D effects. The latter comprise both domestic R&D and the spillover benefits of R&D undertaken overseas. The precise attribution of productivity growth to R&D is complicated, partly on account of lengthy lag times involved before R&D is incorporated into on-farm practices, and because of difficulties in controlling for other factors, including spillovers of foreign R&D. There is also some suggestion that the relationship between R&D and productivity (in Australia at least) may not be stable over time. [51] Bearing all these caveats in mind, the general consensus across findings is that there is a significant positive relationship between R&D and agricultural productivity, and that this is captured in estimated rates of return to R&D in the order of 10-30%. [52]

It is difficult to draw any strong conclusions about approaches towards R&D based on productivity data alone. For example, there are differences between, respectively, Australia, Canada, the United Kingdom and the United States in terms of approaches to R&D, even though most estimates of productivity place them roughly on equal footing. That they are on this same footing is not surprising, given that we would expect convergence in growth rates (of output and productivity) amongst countries of similar income levels.

[49] John Mullen and Jason Crean (2007), *Productivity Growth in Australian Agriculture: Trends, Sources, Performance,* Research Report prepared for the Australian Farm Institute, p. 25

[50] John Mullen and Jason Cream (2006), "Strong agricultural productivity growth despite weaker public R&D investment: Does this make sense?", *Farm Policy Journal*, Vol 3., No.1, pp 11-23

[51] John Mullen and Loris Stappazzon (1996), *The Relationship Between Research Investment and Productivity Growth: Australian Broadacre Agriculture 1953-1994*, Global Agricultural Science Policy for the Twenty First Century Conference.

[52] John Mullen and Jason Crean (2007), *Productivity Growth in Australian Agriculture: Trends, Sources, Performance,* Research Report prepared for the Australian Farm Institute, p. 41

Moreover, because productivity measures do not, by definition, capture non market effects (such as the value of improved environmental quality) they will not be suited to measuring the welfare impacts that are achieved, for example, by focusing public support for R&D on the delivery of these goods.

Developing countries

The broad trends for developing countries mask significant variation across countries and over time. Over the last four decades, productivity growth in China, South Asia and Latin America has out-stripped growth in Sub Saharan Africa, which benefited less directly from the effects of the green revolution. In the last two decades, however, productivity growth in Africa has picked up, moving from minus 0.77% on an annual average basis for the period between the mid 1960s and the mid 1980s, to nearly 1.83% per annum on average. [53]

Analyses of productivity growth typically attempt to break down the TFP estimates into various sources, of which there could be several. One way of classifying these factors is to divide them between effects that are efficiency related, and others that are related to technical change. The latter effects are ones that we would expect to be most reflective of the impacts of R&D, while the former are likely to include policy variables such as the extent of state intervention, trade policy and so forth.

Some estimates suggest that, since the early 1980's, technical change has been an important source of productivity improvements in Latin America and Asia (excluding India and China), a modest source of productivity improvements in India, and a moderate but increasing source of productivity growth for China. In Sub-Saharan Africa, technical change has been a very weak source of productivity improvements, the bulk of the turnaround in productivity having been accounted for by efficiency gains (as a consequence, notably, of macro-economic reform, the liberalisation of marketing arrangements and input supply arrangements and trade policy reform).[54]

The results for Sub-Saharan Africa (especially) suggest that productivity growth may be at risk in the near to medium term. This is because the incremental efficiency effects of reforms tend to diminish over time. In turn, this reinforces the need for stimulating technical change in Africa through R&D.

The results for India also bear some discussion, given its large share of public R&D (globally, and amongst developing countries). One explanation might be that, in relative terms, technical change effects were strongest in the period up to

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[53] Alejandro Nin Pratt and Bingxin Yu (2008), "An updated look at the recovery of agricultural productivity in Sub-Saharan Africa", *IFPRI Discussion Paper 00787*, p 11. The figures exclude Nigeria, which is a persistent (and negative) outlier.

[54] Alejandro Nin Pratt and Bingxin Yu (2008), *op.cit* pp13-14.

1980, as a consequence of public and (largely foreign) private R&D. Because India only initiated substantial economic reforms in the early 1990s (which involved a liberalisation of input and marketing arrangements, and tariff and exchange rate reform), it is possible that the results reflect the relatively strong impacts these reforms had through the 1990s. The contribution of R&D and extension to productivity growth is still estimated as significant, which is likely to stand India in better stead than Africa once the efficiency effects of reforms wear out. An interesting finding of one study is that the contribution of foreign private R&D to productivity growth is close, and at has times has exceeded, the contribution of public research. [55]

Finally, some observations are necessary regarding the issue of the concentration of R&D in a few countries. This does not in and of itself suggest that the world is divided into a few "R&D" rich countries and many "R&D" poor countries. It is unsurprising that rich countries and large developing countries with significant rural populations and/or trade orientation in agriculture jointly account for a large proportion of R&D. Neither does this automatically suggest that countries that are not part of this group are comparatively under-investing in R&D. Indeed, in a number of these "other" countries, R&D as a proportion of agricultural GDP is in line with larger developing countries. To the extent that practically all developing countries fall short of the 1% intensity benchmark recommended by the World Bank, the issue may be less about the distribution of R&D than about raising overall levels of R&D across the developing world.

3.1.5 Summing up

In this section, we have reviewed the data on various trends relating to the levels and composition of R&D funding, as well as data on productivity. We have observed that:

- A number of different R&D contexts have emerged over the last few decades, and there is considerable differentiation between developed countries as a group, between developing countries as a group, and across these two groups.

- Amongst developed countries we have identified countries where the mix of public and private has switched to the latter. These include the UK (particularly), the United States, France and Germany. Australia departs from this group in terms of its relatively high share of public R&D spending.

[55] Mark W. Rosengrant and Robert Evenson (1995), "Total factor productivity and sources of long-term growth in Indian agriculture", *International Food Policy Research Institute Environment and Production Technology Division Discussion Paper No. 7*, April, pp19-26. .

- Productivity trends across a range of developed countries are broadly similar, notwithstanding differences in their approaches to R&D policy. At the same time, because productivity measures do not capture non-market effects, they may not capture the welfare gains of public R&D on the delivery of certain public goods.

- The data from the US bear out the effects of strengthening IP rights on growth in private investment in on-farm R&D as a whole. The Australian experience with EPRs suggests that there are mechanisms, such as End Point Royalties, which, in combination with IPRs, can improve the returns to private investments in R&D. This in turn suggests that there is scope for more carefully targeting public R&D sending to the delivery of public goods (including in the context of investments made by industry based RDCs).

- There is a group of developing countries that have experienced rapid growth in R&D, though overall R&D "intensities" have remained low, mainly on account of the fact that other factors are likely to have contributed to growth in agricultural GDP. R&D in these countries has primarily been driven by public investments, though private R&D has made some progress in countries with export oriented agriculture.

- Productivity growth in Sub-Saharan Africa has been lower than trends observed in other parts of the developing world, notably in Asia. There has been however, an increase in productivity in Sub-Saharan Africa in the last two decades, mainly on account of policy reforms other than R&D.

- Based on the relative contributions of technical change compared to other efficiencies on productivity growth, it appears that the impact of R&D on productivity has been stronger in Latin America and Asia (apart from India in recent years) relative to Sub-Saharan Africa. This in turn suggests that there may be a slowing down in productivity growth in Sub-Saharan Africa (and perhaps in India) if R&D dos not lead to enhanced technical change.

3.2 Evaluation of R&D spending

There are essentially two broad ways of examining rates of return to R&D spending, in agriculture or in general. The first involves macro-econometric estimation, usually of the contribution of R&D spending on productivity growth. This is usually done by means of estimating total factor productivity as a function of the stock of R&D, as well as other variables (such as measures of openness to trade). R&D itself can be broken down by sector, or between home and foreign R&D, in an attempt to capture spillover effects.

Two results are usually sought from such estimations. The first is to see how important R&D is, relative to other factors, in explaining changes to productivity. Ideally, we would like to estimate what percentage change in productivity would result from increasing R&D by a specified percentage (a concept that is usually referred to as the elasticity of productivity with respect to R&D). The second step is to see how much GDP will change as a consequence of a change in R&D (because of the productivity effects of R&D). If we compare the change in GDP over time with spending on R&D, we can then arrive at an estimate of the rate of return to spending on R&D.

There are only a limited results under this approach that are specific to agriculture, as much of the work focuses on R&D in total. Where there are results, they point to a modest contribution to productivity growth, and high social rates of return (in a range of 35%-100%). According to a review of various models, the best models surveyed estimated that increasing R&D stocks generally would increase long run growth by 0.25 percentage points a year, with average gross spillover rates of 50%. Rates of return for agriculture were reported as 24% on average.[56]

Macro-econometric techniques suffer from non-robustness issues related to functional specification, and missing data. Moreover, fine grained data for agriculture, sub-sectors within agriculture, or particular project types are difficult to obtain consistently for this type of estimation project. Finally, because GDP captures the market value of goods and services, the impacts of R&D on non-market factors that contribute to economic well being will not be captured properly. Such impacts can be quite substantial in the case of R&D in agriculture.

Consequently, an alternative is to consider partial equilibrium estimates by looking at selected projects or types of R&D and to measure social rates of return. Here again, the results vary considerably. One survey of studies of rates of return suggested a median rate of return of 48% per year for studies that estimated returns to research, 62.9% for extension studies, and 44.3% for all studies.[57]

While many of these findings substantiate the value of undertaking R&D, they are less helpful for public policy decisions, such as the allocation of funding between competing types of research. This depends on marginal rates of return, while studies report average rates of return. In terms of the implications for policy, the following points are relevant:

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56 Productivity Commission, op.cit, p 121.

57 See Julian Alston, Connie Chan-Kang, Miclele Marra, Philip Pardey and TJ Watt (2000) " A meta-analysis of rates of return to agricultural R&D" *IFPRI Research Report 113.*

- Quantitative evaluation of returns to R&D investment are a useful, but often incomplete guide to the design of R&D policy. The modest impacts on productivity growth suggest that R&D is one of many policy instruments that should be considered when seeking improved productivity.

- Most R&D, including investments undertaken by industry based RDCS, will involve a mixture of privately appropriable benefits and wider public benefits. Because of the limitations of quantitative analyses, it is not easy to draw a particularly clear demarcation between the magnitude of these relative effects and hence to make decisions about the appropriate mix of funding, and the implementation and governance frameworks to go with this.

- While there is likely to be some inherent degree of subjectivity in the judgements surrounding these decisions, it helps to have a public policy framework that can:
  - Articulate the objectives that are sought by R&D policy and funding decisions
  - Assess how these decisions may be implemented to deliver the most efficient use of resources
  - Understand what institutional arrangements, if any, need to be developed.

In the following section, we develop a public policy framework, which we then apply to the understanding of current policies confronting R&D, and the best way to address these.

4 R&D Trends and developments in public policy

4.1 The economics of public policy towards rural R&D

The purpose of this section is to consolidate our findings on key trends in public policy approaches towards R&D within an economic framework. The aim is to develop a template that will serve as a basis for understanding the emerging issues that confront R&D policies, and how these might be handled given our observations on trends to date. Moreover, as we have already seen, a number of these emerging issues are being addressed by existing initiatives, or initiatives under development. The framework will help us to understand how well current approaches have addressed the issues they purport to address, and what opportunities might exist for change.

4.1.1 R&D and market failures

As discussed extensively in section 2.1.2, a recurring question in policy towards R&D has been the extent to which the results of R&D are appropriable i.e. can be captured by the investor. Where there are problems with appropriability, we have a situation of market failure – left to their own devices the private sector will not invest enough in R&D.

The solutions to this market failure can come through public investment, or some other institutional response to address the issue of appropriability (such as IPRs). Our observations in section 2 suggest that until the 1980s, public investment was the dominant response. From the 1980's onwards, the strengthening of intellectual property, and other institutional innovations such as contractual arrangements between producers and users of R&D, led to an increase in the role of private R&D. This in turn has raised further questions regarding the trade off between dynamic efficiency and allocative efficiency (see section 2.1.2) and equity issues relating to the cost of accessing the results of R&D (see below). Public spending was also recalibrated towards the delivery of public goods and cross-cutting issues such as the linkages between agriculture and the environment, where intellectual property provisions are weaker.

Consequently, in considering the appropriate policy response to R&D in the context of current issues (e.g. productivity and climate change), we need to ask:

- what is the extent of market failure associated with the type(s) of R&D that will be required (recalling our discussion in section 2.1.2, and particularly

Figure 1, that pointed to differences in the strength of intellectual property protection afforded to different types of R&D).

- When do market failures arise that require public financing?
- What other factors besides efficiency reasons justify public financing for R&D in response to spillovers? This is largely tied in with issues surrounding the distribution of rents that underlie different solutions to the spillover question.

Other types of market failure

While the issue of spillovers looms large in the discussion of market failure in R&D, spillovers are not the only possible source of market failure.

The returns to private investments R&D are contingent on the profitability of the industry the R&D relates to (such as the markets for fertilisers and seeds) which are in turn derivative on the profitability of farmers. Even a monopolist supplier of R&D generated products will be constrained by the willingness to pay of farmers. The issue is particularly applicable in relation to developing countries, where there would be real benefits from investments in R&D (say, in certain staples) but which would not be privately profitable.[58] The suggestion here is that such R&D would need some form of public support in order to be undertaken. The basis for such a subsidy would be the need to pursue hunger and poverty alleviation goals, which, as we already observed, can be couched both in distributional terms but also in efficiency terms insofar as they are tied into the notion of delivering global public goods.

Not all externalities relate to spillover effects in R&D. In some cases, the channel for externalities is the impact agriculture can have on other activities or areas of concern (notably natural resource and environmental management). In that case, the issue is the likely lack of incentives agriculturalists have to invest in R&D to address these impacts. Two possible examples include:

- The impact of irrigation on environmental assets, including ground water stocks
- The impact of greenhouse gas emissions from agricultural activities, notably livestock.

Here the problem is less with R&D policy but more with the fact that the impacts, in terms of water usage and emissions, of the decisions made by agriculturalists are not fully costed in the decision making process. This is

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[58] See for example, Persley, G. J. (1989), "The application of biotechnology in developing countries", Agbiotech News and Information Vo. 1, pp23-26. Persley described such crops as "orphan crops".

because of, respectively, over-allocation of water rights and a lack of a price on emissions. In both instances, there is a policy case for addressing the underlying market failure.[59]

The implications for R&D policy are that: in the absence of policies to correct the underlying market failure, it is quite possible that the types of R&D undertaken might worsen externalities (e.g. by stimulating activities that increase water usage or that increase emissions), or that R&D that has wider benefits in addition to productivity benefits may not be undertaken (e.g. investments in reducing the use of pesticides, and managing weeds).[60]

The development of a policy towards R&D to handle the type of externalities will then need to take into account:

- If there are policies to address the underlying source of market failure, to what extent this creates sufficient incentives for investment in R&D, and to what extent, if any, further policy intervention is needed

- If it is not possible to implement policies to correct for the underlying sources of market failure (for example, because the transaction costs of doing so are too great), to what extent this creates a case for public policy towards R&D as a means of addressing the underlying externality.

Equity issues

Arguments surrounding market failure are efficiency based arguments – the idea is that appropriate public policy directed at the sources of these failures can make society better off. Indeed, as we already observed in relation to the delivery of public goods internationally, the idea is that the world as a whole would be better off.

Equity issues are concerned more specifically with the distribution of benefits. An important source of debate on this front, in relation to R&D, has to do with the impact of IPRs, and the flow of royalities between users and innovators. This applies at the domestic level as well as the international level. On the latter front, issues surrounding the ability of poorer countries to pay for access to the benefits of R&D protected by IPRs are central to the discussion.

Though equity and efficiency arguments are usually treated distinctly, there is an obvious linkage in this case between distributional concerns and allocative efficiency. Both can be adversely affected through the exclusivity provisions that

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59 See for example, Kenneth Frederick (1997), *Adapting to Climate Impacts on the Supply and Demand for Water*, Resources for the Future Mimeo.

60 See Julian Alston and Philip Pardey, "The economics of agricultural R&D policy" in Julian Alston, Philip Pardey and Vincent Smith (eds) 1999, *Paying for Agricultural Productivity,* IFPRI, p 9.

are inherent to IPRs, and the impacts this can have on pricing. At an international level, distributional concerns can arise to the extent that these pricing effects entail a flow of income away from poorer countries. To the extent that the delivery of certain public goods is also affected, there is also likely to be a cost in terms of allocative efficiency.

While both these points have been used to underpin arguments about the desirability of public investment in R&D in developed countries – on the grounds that the spillover benefits are made freely accessible to poorer countries – they do not in and of themselves act as arguments against IPRS per se. Rather they point to the need to manage the relationship (and trade-offs) between dynamic efficiency (i.e. preserving the incentives to invest) on the one hand, and allocative and equity issues on the other.

4.1.2 Institutional issues

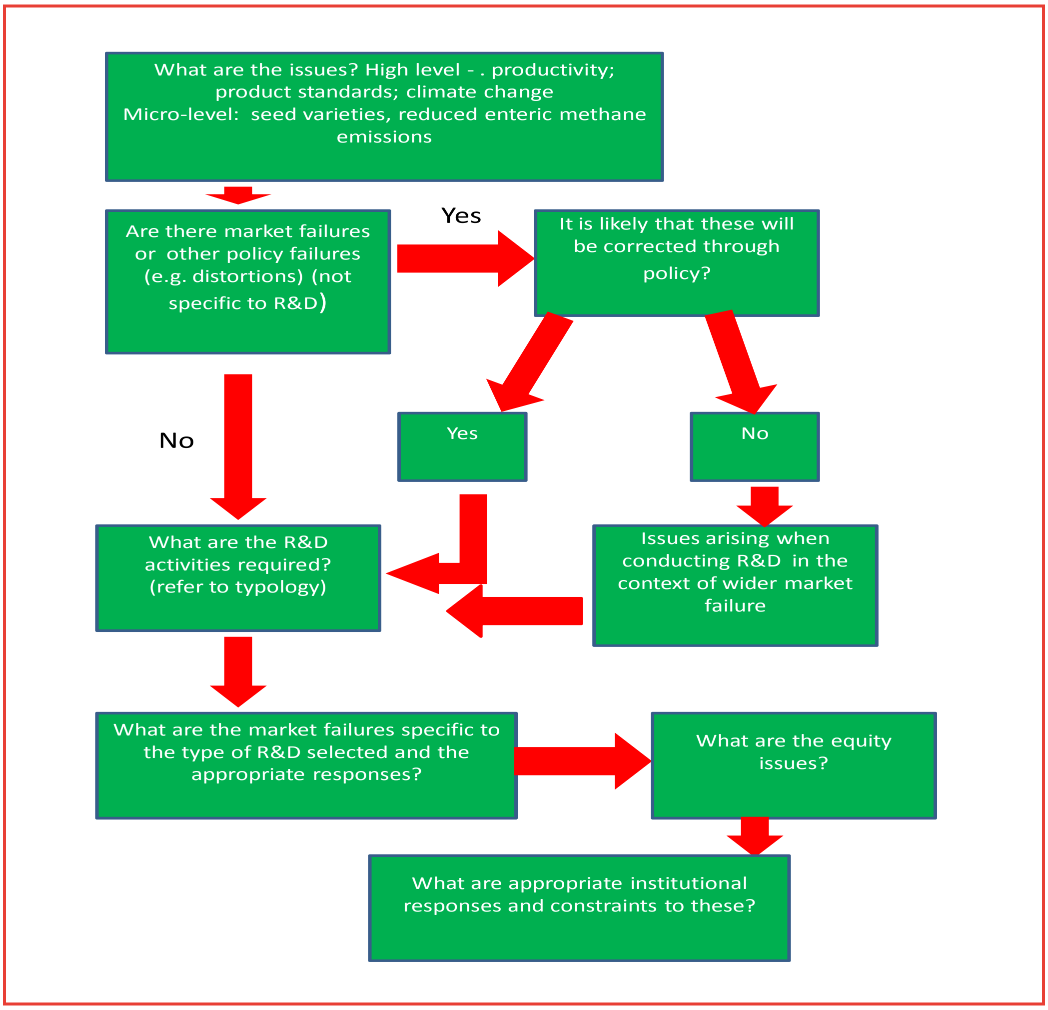
Public policy outcomes hinge crucially on the existing institutions that underpin them. We have already observed how institutional developments, including institutions that underpin IPRs, have played a crucial role in affecting the content of rural R&D policies. Similarly, the design of various forms of partnerships and networks at the national and international levels are examples of institutional responses to evolving policy requirements. Key questions that need to be addressed include:

- What institutional options exist to address the policy objectives sought?
- What constraints exist on the development of these institutional responses?

4.1.3 Assessing policy approaches to R&D

The next step is to bring these different elements together. This is done in Figure 6 below, which sets out a framework for understanding appropriate public policy interventions in relation to R&D in agriculture. The starting point is to identify the particular issue at hand (i.e. the driver for R&D). It is then important to identify whether there are general (i.e. not specific to R&D) market failures. These include policy induced distortions, which is an important subject given the incidence of policy interventions that have pervaded agriculture globally.

Figure 6 Decision tree for public policy towards rural R&D



The actual market failures that need to be addressed in the context of R&D will be conditioned by the type of R&D activities that need to be undertaken in response to the specific issues that have been identified. Once these specific market failures are understood, the appropriate type(s) of policy intervention (if any) can be determined.

4.2 What are the issues?

Recall that in the previous section we identified some of the broad areas targeted by R&D over the last two to three decades. We noted in particular the importance of productivity issues, and the emergence of cross cutting issues. In this section, we select the main headline issues that have elicited R&D, and that are likely to do so in the near to medium term future. We apply the different steps in our public policy framework, drawing on the insights we have gleaned from our overview of trends in section 3 and our analysis of the evolving policy stance, as set out in section 4.1.

Our selection of issues is not meant to be exhaustive. Rather, they reflect the main priorities that are identifiable, on the basis of recent history in the development of R&D policy, as well as current concerns identified internationally. The ones we have selected are:

- Productivity – this has been a key issue in relation to agricultural R&D and one that has gained renewed currency, if not urgency, over the last two years. It is obviously and intrinsically connected to the issue of food security, and by extension, to some of the wider policy goals, such as poverty alleviation and the delivery of global public goods such as security.

- Nutrition and health – these issues are partly related to productivity, in that they are also an important aspect of food security in developing countries, and also constitute an important issue in more advanced countries, as reflected in Australia by the findings of the National Preventative Health Strategy Task Force.

- Consumer preferences and tastes – as already alluded to in the previous sections, these factors have played an increasingly important role in eliciting R&D.

- Product standards – given their importance in regulating access to markets.

- Environmental and natural resource management issues – as noted, these have assumed greater importance in the research agenda over the last two decades.

- Climate change –this is really an extension of the previous category, but the issue is given specific treatment here because of its policy importance, and also because of its specific properties as a policy problem. These specific characteristics include the impacts climate change is likely to have on agriculture but also the role agriculture (and R&D in agriculture) can play in the delivery of the global public good of greenhouse gas mitigation.

We have chosen this range of issues both on the grounds of their global relevance, and their specific relevance to Australia.

4.3 Productivity, food security and poverty alleviation

4.3.1 Overview of the issues involved

Historically, improving productivity has been the key factor for investments in R&D. The development and dissemination of modern or high yield varieties as part of the Green Revolution was perhaps the most vivid demonstration of the contribution of R&D to meeting the productivity requirements imposed by rapid population growth.[61]

These issues are still current, since the world's population is expected to grow by some 3 billion people by 2050, with the total amount of arable land per head of world population projected to decrease to 0.15 per capita, down from 0.44 in 1960 and 0.22 in 2000. Moreover, scarcity in land interacts with a number of other factors, including: the competing claims for crops for bio-fuel and animal feed, water scarcity, and both the impacts of climate change and the impacts of policy to mitigate climate change on rural land use (the issue of climate change is discussed separately in section 4.7.2 below.) Consequently, higher production quantities will have to come from yield increases.[62]

As already observed in section 2.2, policies towards R&D and productivity have to be articulated in the context of poverty reduction strategies. Hunger is one dimension of poverty, so there is one direct linkage there. There are also other linkages, direct and indirect. One is the fact that the growth of the agricultural sector is, for most developing countries, a key determinant of overall rates of growth, and therefore a mechanism by which the number of people living in poverty can be reduced. The responsiveness of poverty rates to growth is known as the elasticity of poverty reduction with respect to growth. As an example, estimates for India suggest that the poverty reduction elasticity with respect to agricultural growth (i.e. once other growth factors were accounted for) was -0.25 in India, and -1.5 in China. There is also some evidence linking growth in farm yields to poverty reduction. [63] For many countries, there will be limits to the extent to which agricultural growth can be increased through increased inputs, hence the importance of productivity improvements to growth in the agriculture sector.

There are also some indirect connections between productivity, agricultural growth and poverty. One of these is through increased real wages; another is through the reduction of food prices.

There are various determinants of productivity. In regards to R&D, the main requirements relate to:

- On farm technologies including:

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[61] See R.R. Evenson and D. Collin (2003), " Assessing the impact of the Green Revolution, 1960-2000", Science, Vol. 300, pp 758-761.

[62] Klaus M. Leisinger, 2000, Trends in Private Sector Investments in Agricultural, Forestry and Fisheries R&D in Developing Countries: Implications for the CGIAR.

[63] See for example, Shenggen Fan and Joanna Brzeska (2005), How Can Government Promote Pro Poor Agricultural Growth – Synthesis of IFPRI case studies, IFPRI.

- The use of inputs such as pesticides, fertilisers, pharmaceutical products (for veterinary purposes), and machinery.
- Seed and plant varieties, as part of adaptive processes responding to factors such as water scarcity, changes in soil conditions, and pests.

- Farm management techniques and systems, such as pest control systems that reduce reliance on pesticides, irrigation and water use techniques, animal husbandry practices (such as cross-breeding and artificial insemination) and crop management techniques such as zero-tillage and the planting of nitrogen fixing products as part of rotational cycles to replenish nutrients.

One of the challenges in stimulating productivity is to address the issues set out above in the context not just of particular crops or livestock, but also in the context of the specific agro-ecological context in which application is sought. The successful application of both on-farm technologies and farm management systems are known to be contingent on the characteristics of the agro-ecological environment, and the prospects of successful diffusion through spillovers is somewhat limited.[64] The successful use of varieties calibrated to marginal production environments is one such example of this sort of adaptation.[65]

As already indicated, an emerging challenge is not simply to deliver on these fronts, but also to deliver in a manner that takes into account the other constraints impinging on agriculture, notably concerns regarding the management of environmental resources (for example, in relation to water use or the impact of pollutants), the management of health issues (for example in the context of intensive livestock practices), and in the context of climate change and policies to mitigate the impact of this. These are treated separately below.

4.3.2 Wider market failures not related to R&D

A number of supply side factors have impacted and continued to impact on productivity. These include:

- The absence of markets for inputs and for credit. This is mainly a developing country issue. These absences are partly due to a lack of institutional development, for example, a lack of marketing systems for inputs or high transaction costs in credit markets due to a lack of collateral. But they are also due to policy distortions such as directed credit schemes.

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[64] See for example Philip Pardey, Nienke Beintema, Steven Dehmer and Stanley Wood (2006), *Agricultural Research – A Growing Global Divide*, Agricultural Science and Technology Indicator's Initiative, IFPRI.

[65] M. Lanticam, P. Pingali, and S. Rajaram (2003) "Is research on marginal lands catching up? The case of unfavourable wheat growing environments", in *Agricultural Economics* 29, pp 353-361.

- High tax burdens. These include explicit taxes (e.g. export and production taxes) and implicit forms of taxation such as administered prices through marketing boards, administered exchange rates, and higher rates of effective protection for manufactured goods. Many of these distortions have been removed.

- Trade protection. In a sense this is the opposite of the point above. But while protection will attract resources to agriculture and could increase output, it can also blunt incentives for productivity by stifling competition.

- The state of infrastructure, notably rural roads.

Some progress has been made in addressing these issues, though this has been uneven. A large unfinished agenda remains to be carried out on the trade policy front in particular, through the reduction of trade distorting measures in both developing and developed countries. Simulations suggest that liberalisation would increase world commodity prices by 5.5% (1.3% for processed foods). It is expected to stimulate output growth in developing countries, particularly in Sub-Saharan Africa and Latin America, on account of greater efficiencies.[66]

Another outstanding issue relates to the impact of subsidies to biofuels, which has encouraged substitution in land use away from food production, as well as increased prices of those crops (principally canola and maize) and their close substitutes that are used as bio-fuel feedstock. Because these crops are also high users of fertilisers as well, there are some knock-on and pessimal environmental effects. There is also concern that R&D funding for bio-fuel development is crowding out other forms of R&D – both in agriculture and energy – that have higher payoffs once the external costs of biofuels are taken into account.[67]

Having stated these different factors, it remains the case that the investments in agriculture, and in agricultural R&D, tend to be amongst the most effective forms of poverty alleviation strategy. Data from an IFPRI survey of case studies from 5 countries placed investment of R&D in the top two forms of policy interventions in terms of poverty reduction effectiveness.[68]

The issues constraining productivity that have been enumerated here are essentially those concerning developing countries. In regards to developed countries, where increased productivity can also play a role in meeting issues of

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[66] World Bank (2008), op.cit, pp 1051-07.

[67] See Roland Steenblik (2007), *Biofuels – At What Cost? Government Support for Ethanol and Biodiesel in Selected OECD Countries*, Global Subsidies Initiative.

[68] IFPRI (2009), *Pro-poor Public Investment Program*, p2. The countries in question were China, India, Thailand, Vietnam and Uganda. The other types of intervention that were ranked were irrigation, soil and water conservation, electricity, telecoms, health, education, roads and anti-poverty prgrammes

food security and poverty alleviation through trade, most of these constraining factors on agriculture have been addressed. This is particularly the case in Australia. Consequently, the emphasis is more squarely on managing increased productivity through R&D.

4.3.3 Approaches to R&D required and issues relating to market failure

Developed countries

It is relevant to address the issues of developed countries in the context of policy toward food security, even though they are less directly impacted by the question. Even if food shortages are felt most acutely in poorer countries, it is still a global issue. Moreover, through the operation of trade flows, there is some opportunity for countries like Australia that are major exporters of agricultural products, including key staple food crops, to play a role in addressing global food security. But this, particularly given pressures on domestic food systems, will require addressing productivity issues.

In principle, the nexus between this need and R&D could be mediated by market responses – scarcity raises returns to production and investing in enhancing productivity. An enhanced system of intellectual property protection should contribute to improving the appropriability of R&D.

In practice, there are several issues that make a predominantly market driven response unlikely to succeed (even if one were to set aside complicating issues relating to the environmental effects of agriculture and climate change response issues, topics to which we shall return below). For a start, basic research (for example, in veterinary sciences and plant genetics) will continue to be an issue of importance. As already observed, the implementation of stronger intellectual property protection reinforces the need for complementarity between basic and applied research.

Secondly, an important criticism of intellectual property protection for plants is that while it may stimulate private investment in plant-related R&D, it has the potential to discourage plant diversity. Plant diversity is important, since in the long run this will encourage productivity because a wider pool of plant types has a greater ability to cope with shocks. The argument is that the terms of the UPOV, and the TRIPS agreement, have not been conducive to arrangements that reward farmers for *in situ* conservation and for informal breeding techniques that involve experimenting with the creation of new varieties adapted to local conditions.[69] Consequently, farmers have become reliant on seeds produced by third parties. This is an issue when private R&D is concentrated in the hands of a few entities, and when the differences in local conditions across agro-ecological

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[69] See L.Helfer (2004), p 16.

areas make the use of standardised varieties problematic (an issue that is likely to be particularly important to countries such as Australia with it specific fauna, flora and biodiversity conditions).

It is important to understand that this issue is an efficiency issue, rather than an equity issue associated with the private appropriation of rents by breeders. The efficiency issue in question is whether intellectual property protection stimulates an adequate level of investment in maintaining the degree of diversity in the plant resource base that can sustain productivity over the long run. One possibility would be to adapt intellectual property protection provisions to afford protection to plant varieties cultivated through in situ farming and breeding methods.[70] However, even if this were possible under treaty arrangements, it is not clear that it would be practically possible to develop a mechanism that could provide protection to, say, germplasm that is more heterogeneous than established plant varieties and sufficiently distinct to permit identification.

An alternative is to use financial mechanisms to affect the relative reward of in-situ innovation versus reliance on third party inputs, which in effect means attending to the cost side and benefit side of the equation. The former could take the form of direct R&D support geared to diversity programmes, while the latter could involve innovation prizes that mimic the "research pull-mechanism" of patents.

Developing countries

As observed in section 3.1.4, productivity in developing countries has on the whole increased over the last few decades. However, in a number of developing countries (and particularly those, especially in Sub-Saharan Africa, where vulnerability to food shortages and poverty are most persistent) there are concerns about the sustainability of these trends, and an acknowledgement that rates of technical change need to be increased. In practice, this will require increased investments in agriculture, and in public R&D. Given the constraints many of these countries face, and given competing budgetary claim, this is in the first instance an issue for development finance.

However, even assuming that there are additional resources committed to funding R&D, it will be important to ensure the effectiveness and efficiency of their delivery. In this context, a number of facilities come into play, including the capacity of developing country NARS, the role of regional networks and coherence among them, and mechanisms for identifying and coordinating

[70] See L. Helfer p 71.

research actions. We address these questions more directly when we consider the issue of institutional arrangements

But there are other aspects as well that cut to the way in which R&D is handled. One issue relates to the role of privately conducted R&D. Even given the role of publicly funded and conducted R&D, it is clear that governments will not be able to bear the entire burden of meeting the productivity challenge. This reflects the comparative advantages of industry, which lie in[71]:

- Large R&D resources for funding long-term and sometimes high return (but speculative) projects
- Diversity - from small dedicated biotechnology companies to large corporations that have extensive and collaborative links with the public sector, including universities
- A critical mass of scientific research resources
- Knowledge of and expertise in marketing and distribution systems
- Access to global markets and advantages of scale.

Given these, an issue is how to harness these capabilities to the required ends. The main questions that arise lie in the fact that: where innovations are privately undertaken in developed countries and protected by IPRs, there are often costs related to their access by poorer countries that are constrained in their ability to pay. Secondly, the fact that these countries have a low ability to pay may mean that potentially very useful R&D will not be conducted. Finally, IPR regimes in many developing countries are weak which can constrain both foreign and private investment in locally appropriate R&D.

Clearly, this reinforces the need for partnerships between public and private entities. This is true at the local level, but also internationally. On the latter front, this could involve mechanisms to fund access to innovations developed overseas, as well as to facilitate the interaction between developed country entities involved in the conduct of R&D and developing country counterparts.

As noted in section 2.2.3, there are various international public-private partnerships that have been established, some of which are supported by donors. An example is GalVMed, a not for profit public-private partnership that specialises in the provision of vaccines, medicines and diagnostics to livestock farmers. [72] Other efforts include the type implemented in Chile, that is, to fund

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[71] This list is taken from Clive James (1996), *Agricultural research and development: The need for public-private sector partnerships*, Issues in Agriculture 9, CGIAR, p 27..

[72] http://www.galvmed.org/about-galvmed

the acquisition of technology and to support adaptation efforts based on these (including, as required, through the payment of compensation to the rights holder). This does not address general issues of rent transfers from recipients of innovation to the innovating countries, though it can spread the impact of such transfers across a larger base.

4.3.4 Equity issues

As already observed, there are important distributional issues that motivate the pursuit of poverty reduction strategies. Moreover, the solutions envisioned also raise distributional issues. For example, access to innovation often implies a transfer of wealth to the innovators, which in global terms can have regressive impacts when developing countries are involved. Finding access to technology can have positive equity and distributional consequences. Insofar as they enhance the delivery of global public goods, they can also be said to have positive efficiency outcomes as well.

4.3.5 Institutional issues

As already observed, current approaches to development assistance place a heavy emphasis on country ownership and partnership, which in the R&D sphere involves engagement with country and regional NARS and policymakers. Historically, this has been a challenge, given weak institutional capacities in developing countries. Consequently, supporting effective increases in developing country R&D, through financial assistance, will require building the capacity to conduct research, but also to develop long term research strategies and programmes. Because of the need to integrate these strategies and programmes in overarching frameworks for poverty reduction, the engagement with partner countries cannot be limited to the NARS or the research community, but must also engage with central agencies, notably those in charge of finance. This will help to ensure that programmes are placed on a firmer policy footing, and that there is sufficient provision in local budgets and to provide stable levels of necessary counterpart funding. If this is accepted, it would require of entities such as ACIAR that it step up the policy design aspects of it activities, possibly on collaboration with other donors, and not limited to parties involved in R&D.

Another question relates to the coherence between multiple regional actors, whether these are developing country NARS or other donors. As already observed, there are many overlapping regional NARS initiatives, and there are also a number of regional donor initiatives. A revamped CGIAR may offer a mechanism for improving coordination and coherence on these fronts, insofar as the CGIAR reforms allow for a greater managerial latitude for decision making.

An important part of building the capacity of developing countries lies in "training trainers" i.e. in equipping local personnel to develop skills, for example, in extension methods. This is particularly important, given the value placed on techniques such as Participatory Rural Appraisals.

In terms of mechanisms within developed countries themselves, the main challenges involve developing mechanisms to strengthen the appropriability of investments by breeders (e.g. through ERPs) but also finding solutions to issues (such as the conservation of germplasm and of a sufficient varietal base) that may not be adequately addressed by IPRs.

4.4 Nutrition and health

4.4.1 Overview of the issues involved

While nutrition is linked closely to the issue of food availability and hence productivity, it is not reducible to productivity. This is for two reasons. First, increased availability in staple foods does not entail increased availability of important micro-nutrients (such as iron, iodine, folic acid, or vitamin A and D). Indeed, in some poor countries, the reverse has held true insofar as there has been an increase in high-energy low-nutrient food. This creates the scope for improving the availability of high nutrient food (a productivity issue), but also finding ways to enrich the nutrient content of staples. The development of Vitamin A-enhanced rice ("Golden Rice") is one such example of this. Some estimates based on the impact on the incidence of this product on Vitamin A deficiency health issues suggest high rates of return on R&D[73], though the commercialisation of Golden Rice has not been without its critics.

Secondly, as incomes increase, the demand for foodstuffs that have a high correlation with certain forms of non-communicable diseases will also increase. This in turn increases the scope for developing products such as low fat dairy, lean meat and unsaturated oils.[74] Recent trends in public policy towards preventable diseases appear to place an increasing emphasis on food related regulation, which in turn sharpens the focus on developing food products that meet these requirements. As already observed, nutritional issues are an important priority identified in the context of the USDA's "Roadmap".

4.4.2 Wider market failures not related to R&D

There are a number of other market and policy failures in both nutrition and health that, if addressed, could improve outcomes on these fronts, before drawing R&D for agriculture into the equation. In developing countries, there

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[73] Roukayatou Zimmermann and Matin Qaim (2004), "Potential health benefits of Golden Rice: A Philippine Case Study", *Food Policy* 29, pp 147-168.

[74] See L. Haddad (2000), "A conceptual framework for assessing agriculture-nutrition linkages", *Food and Nutrition Bulletin* 21(4): pp 367-272.

has been a substantial amount of controversy surrounding enriched staples such as “golden rice” – setting aside the (often ideological) objections to genetically modified crops, it is apparent that enhanced staples are unlikely to form a durable solution to malnutrition as long as issues of affordability hamper access to high nutrition foodstuffs. Developing mechanisms that enable producers to market products and to access inputs, and targeted income transfers, are likely to be necessary components to any policy response.

In developed countries, where concerns regarding obesity and non-communicable diseases dominate, a number of alternative health and nutrition policies can be, and are, implemented, such as the education, support for sport and various forms of persuasion.

4.4.3 Approaches to R&D required and issues relating to market failure

To the extent that nutrition issues are tied in with the expansion in output of high nutrition food products, many of the issues (in particular in the context of developing countries) are the same as those set out above. In developed countries, assuming there is an increased trend towards regulation (even of a fairly light nature involving labelling and awareness), the issue will be to what extent R&D will be needed and useful in meeting these requirements. In that sense, the issues are quite closely analogous to questions related to consumer preferences and tastes, which are tackled in the next section.

4.4.4 Equity issues

The main equity issues relate to the fact that consumption of energy dense, low nutrition food stuffs is inversely correlated with incomes. This means that if efforts are made to improve the nutritive quality of foodstuffs, they may not automatically be accessible to parties most at risk. However, this is not necessarily (or even likely) to be an issue for R&D policy per se.

4.4.5 Institutional issues

None specific to this issue.

4.5 Consumer preferences and product standards

4.5.1 Overview of the issues involved

The section on nutrition alluded to the increased demand for foodstuffs with certain types of nutrient content as a function of rising income, and a policy trend towards regulation. The concept can be generalised into the general notion of consumer preference and taste. These essentially relate to different attributes of the product in question. The attributes can be classified in a number of ways. Some relate to the actual product itself, such as nutrient content, texture or taste.

For example, consumers of beef typically express preferences in regard to colour or marbling, and this has been observed to affect willingness to pay.[75] The precise preferences are likely to be specific to particular markets, at national and regional levels.

Other determinants of consumer preference are production and processing mechanisms. This is reflected, for example, in preferences for organic food. An emerging trend is the concern for "credence" attributes such as animal welfare or socially and environmentally friendly practices in the production of commodities and food products. Examples include free range eggs, concerns over sheep mulesing, or low carbon food products. While the grounds for public policy intervention in mandating standards on these grounds are, at best, questionable,[76] the existence of these preferences is likely to result (and in some cases has resulted) in the development of market-based verification instruments, such as certification schemes. This in turn provides a role for R&D to meet these requirements.

4.5.2 Wider market failures not related to R&D

Market failures associated with meeting consumer preferences and tastes can arise in the collection of information. However, this needs to be set against the existence of commercially provided market intelligence by specialist providers of research services.

4.5.3 Approaches to R&D required and issues relating to market failure

These effects are typically market mediated, and there are likely to be significant private returns to addressing these, even accounting for any spillovers. Coordination costs may be an issue, particularly where the industry structure is widespread and diffuse. In those contexts, there would be a role for public policy, but this would be very much in line with the approach currently pursued through RDCs. This offers, through the levy system, a means of coordinating and enforcing the financing of R&D, and a means for evaluating and directing research.

4.5.4 Equity issues

To the extent that meeting evolving consumer standards and tastes involves an investment in R&D, at the risk of losing market share, there may be some distributional consequences for smaller producers that may find the R&D effort

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[75] See for example, K. M. Killinger, C. R. Calkins, W. J. Umberger, D. M. Feuz and K. M. Eskridge (2004) "Consumer visual preference and value for beef steaks differing in marbling level and color", *Journal of Animal Science*, 82, pp 3288-3293.

[76] See for example, Frontier Economics (2008). *Review of Animal Welfare – Application of the Role of Government Framework*, Report prepared for the Department of Primary Industries, Victoria.

more difficult to sustain. That does not in and of itself justify public investment in R&D, though it may justify the use of other transfer mechanism to help affected parties bear adjustment costs.

4.5.5 Institutional issues

None specific to this issue.

4.6 Product standards

4.6.1 Overview of the issues involved

Related to the issue of preferences is the issue of product standards, notably those developed for public health reasons, or for reasons of preserving animal and plant health, or the integrity of environmental assets. As both tariffs and quotas on agricultural commodities have declined, standards have increased in importance as a factor affecting market access. Standards can be either government enacted and mandatory, or they can be developed privately (e.g. by retailers, specifying that certain production practices and processes need to be met).

If they are enacted as official regulations, product standards will normally be subject to the disciplines of international trade agreements, notably those of the World Trade Organisation. The relevant agreements are the Agreement on Sanitary and Phytosanitary Standards (SPS) and the Agreement on Technical Barriers to Trade (TBT). These agreements do not prescribe particular standards, but do require, amongst other things, that in their implementation they meet principles of non-discrimination, that they are scientifically justifiable in relation to the level of protection or safeguards that are sought, and that there are procedures for harmonisation and recognition of equivalence. Private standards are not subject to these disciplines, and can be more far reaching in their application. They can, for example, cover production and processing methods (e.g. environmental impact and labour standards) in a manner that would not be open to government regulations coming under the purview of WTO agreements.

In the case of agriculture, managing product standards is usually a question of managing risk factors that affect production in the area of origin. For example, Australian stone fruits produced in the Sunraysia region are subject to certification requirements demonstrating pest freedom in that region, as a condition of access to major export markets. Similarly, developing countries will also face constraints emanating, for example, from biosecurity requirements in Australia. Because agricultural exports constitute an area of interest for a number of developing countries, meeting standards (whether official or private) has become an increasingly important condition for accessing markets. Private standards are becoming an increasing issue, particularly as they often touch on areas not covered by official regulations (such as the environmental impacts).

These developments in turn place an onus on R&D in importing countries – since they need to select and validate appropriate levels of protection – and in exporting countries, that need to meet the requirements that are set.

4.6.2 Wider market failures not related to R&D

Similar considerations apply as with consumer tastes and preferences. In cases related to human, plant and animal health, a key question is the extent to which producers bear the actual costs of, say pest outbreaks. If there is an expectation – for example, based on past practice – that governments will compensate them for this loss, then the incentives to invest in mitigating these losses will be reduced.

4.6.3 Approaches to R&D required and issues relating to market failure

There are privately appropriable returns from meeting market access requirements, in the sense that those with an ability to do so have an advantage over competitors. This creates incentives for private investment. It is noteworthy that in developing countries, such as Indonesia and the Philippines, that export products (largely fruit) that are sensitive to market access restrictions on the grounds of product standards, have seen an increase in privately funded R&D.

It is sometimes argued that the gains from investment in meeting product standards are appropriated by consumers, and hence that this creates a rationale for public support for R&D or other sorts of investments needed to meet these standards. However, that is not usually the case – as we have just observed, the ability to access markets does generate its own reward. Any case for intervention needs to rest on other grounds.

One such ground may be the fact that there are externalities in the type of R&D that needs to be conducted to meet the product standards. For example, R&D geared to mitigating the environmental impacts of production may have wider community benefits. If the investments that are required relate to on-farm processes, appropriability may be more of an issue since such processes are typically harder to protect through IPRs.

A second ground, applicable to developing countries, is that they do not have the ability or resources to carry out the required R&D. This is, strictly speaking, more of an equity issue (see below). It does however, have efficiency aspects. For example, if developing country producers (that would otherwise be competitive suppliers of a product) are not in a position to supply a particular market, the lower degree of competition in that importing market can lead to a loss of welfare (on the grounds that the reduction in consumer surplus, as a result of lower competition. outweighs the gain in producer surplus to local producers). Consequently, this can provide an efficiency rationale for taxpayer funded assistance to developing country R&D.

4.6.4 Equity issues

Developed country assistance to developing countries in helping meet product standards reflects an implicit quid pro quo – the costs to developing countries in terms of more difficult market access is (to a degree) offset by assistance in the form of R&D support. For example, assistance in respect of biosecurity and related issues is an important aspect of ACIAR's R&D cooperation programme.

4.6.5 Institutional issues

In terms of assistance to developing countries, coherence in the delivery of such assistance is important. Typically, a number of donors will be involved in such assistance activities, and though this can be seen as a reflection of the variance that exists across countries in terms of product standards, there is also scope for coordination and rationalising efforts.

A further issue is that the issue of product standards goes beyond R&D to include building local capacity for enacting and implementing standards. This can include anything from developing appropriate legislation and compliance mechanisms, to developing laboratory and testing facilities. Not all these activities will be covered by entities that deliver R&D assistance, and hence there will some need to ensure coordination between the various parties involved.

4.7 Environmental and natural resource management

4.7.1 Overview of the issues involved

Agriculture is usually the source of some environmental and natural resource externalities, negative and positive. Agricultural practices can cause resource degradation through land use practices (such as deforestation), through the impacts of inputs (notably fertilisers and pesticides) and through water usage. These are summarised in table 4.

Table 4 Environmental effects of agriculture.

	Onsite effects	Offsite effects	Global effects
Intensive agriculture	Soil degradation (salinization, loss of organic matter) Nutrient depletion	Groundwater depletion Agrochemical pollution Loss of local biodiversity	Greenhouse gas emissions Animal diseases (e.g. avian influenza, swine flu) Loss of in situ crop genetic diversity
Extensive agriculture	Nutrient depletion	Soil erosion downstream effects (reservoir salination) Hydrological change (e.g. loss of water retention in upstream areas) Pasture degradation in common property areas	Reduced carbon sequestration from deforestation and carbon dioxide emissions from forest fires Loss of biodiversity

Source: Adapted from World Bank (2008) *Agriculture for Development, World Development Report, p 181*

Many of agriculture's externalities stem from distortions to other markets or aspects of policy. Typical examples include the over-allocation or mis-pricing of water resources, or input subsidies. However, many of these externalities can also be mitigated through R&D, notably through the development and adoption of new farm and resource management practices and technologies. To some extent, the stimulus for R&D is likely to come with the development of instruments that cause agriculturalists to take into account the external costs created by their decisions. At the same time, and irrespective of the development of these instruments (and often, in the absence of such instruments) the R&D agenda has increasingly been influenced by groups articulating environmental concerns.[77] As already observed, this has tied in with a concern to reorient funding for R&D to issues that are more obviously characterised by public good characteristics, of which environmental and natural resource management assets are examples with a high and increasing public profile.

An important point to note here is that in the absence of wider policy efforts to address environmental issues, there can be two problems for R&D. First, the wrong type of R&D may be delivered (i.e. ones that aggravate externalities); and secondly, sufficient amounts of the right types of R&D will not be delivered. The former problem is one that has been frequently discussed in relation to the Green Revolution in developing countries – i.e. that the increased use of pesticides in combination with high yield variety plants caused significant damage to the environment. As the contribution of agriculture to pollution has grown, natural resources have been degraded, which in turn has created feedback loops affecting agriculture. As noted by one author, agriculture in developing countries has been "both culprit and victim".[78] Given the now pressing aim of increasing productivity in developing countries, the lessons of the past suggest that the investments undertaken now and in the future to meet these objectives need to be closely integrated with environmental policy.

4.7.2 Wider market failures not related to R&D

At least some of the environmental and natural resource management impacts of agriculture could be addressed by market -upporting interventions, or addressing distortions in existing markets. On the former front, some progress has been made in Australia in developing market based instruments, for example to address issues related to vegetation and habitat preservation. The establishment of water rights and trading mechanisms has sought to address water scarcity issues, though the efficacy of these measures has been affected by the over-allocation of water to consumptive uses over non-consumptive uses. Similar issues apply to developing countries, though here the problems are in practice much more challenging given institutional shortfalls (see below).

The general principle is that addressing these issues of missing markets can stimulate the correct types of R&D, in the sense that internalising the costs of these impacts in the farmer's production decisions will create incentives to minimise these costs.

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[77] Julian Alston et al, "Financing agricultural R&D in rich countries: what's happening and why" in the *Australian Journal of Agricultural and Resource Economics*, 42:1, pp 75-76.

[78] Gordon Conway (1997), *The Doubly Green Revolution – Food for all in the 21st century*, p 86.

4.7.3 Approaches to R&D required and issues relating to market failure

As we have seen, the management of environmental issues has been an important driver of public funding of R&D in developed and developing countries, and is likely to remain that way.

Having said that, it is important not to completely discount the possibility of market based measures. For example, if broader policy measures are taken to address the impact of agriculture on the environment by pricing externalities, this should create incentives to invest in appropriate R&D.

One complicating factor, however, is that many of the approaches to mitigating these impacts are in fact dependent on innovation in farm management practices. These are typically difficult to safeguard through intellectual property, and consequently, appropriability issues may provide some ground for public policy support. However, that line of reasoning should not be accepted uncritically. For example, there are plenty of other sectors in the economy that are also characterised by environmental impact issues, and where specialist service providers have emerged to advise on management issues. These service providers do not necessarily rely on formal intellectual property protection; many rely on the reputation they have acquired.

It is possible that the viability of privately provided advice may be compromised by the structure of the sector concerned – for example, in cases where there are a large number of small producers, it may not be viable to provide advice to individual producers, and hence there is likely to be a role for cooperative institutions, such as RDCs, to manage the collection and dissemination of advice.

In developing countries, it is much less likely that these market mechanisms will work, for many reasons. These include a low ability to pay, a large number of smallholders, which increases coordination costs, and transaction costs relating to the contract enforcement.

4.7.4 Equity issues

The combination of regulation and funding requirements to meet these could impose a disproportionate burden on producers, particularly smaller ones, when the benefits are widely spread across the community. This may create a case for government funding.

In developing countries, communities that are most affected by environmental externalities are likely to have the lowest ability to pay to mitigate their impact, creating scope for intervention.

4.7.5 Institutional issues

The main institutional issues relate to the coordination of R&D with environmental policies. This is an issue for developed countries, but is especially an issue in developing countries, where the need for increased productivity is particularly great, the risks of environmental damage are particularly high, and the level of institutional capacity is often weak. Consequently, in addition to targeting the "correct" types of R&D that have environmentally beneficial outcomes (something that most donors are currently doing), it will also be necessary to ensure that wider policy frameworks are set in place that address priorities relating to production and the environment, and that set the context within which specific R&D initiatives are funded and undertaken. In practice, this will require coordination amongst various agencies delivering aid, and that the sphere of contact is widened beyond developing country institutions that deal mainly with agriculture and R&D, to include central agencies (such as finance and planning ministries and departments).

4.8 Climate change

4.8.1 Overview of the issues involved

The impact of climate change is perhaps the single biggest challenge that agriculture has to face, on account of the intrinsic linkages between climatic phenomena and the biological processes underpinning agriculture, and because climate change and responses to it will have a fundamental impact on the ability of agricultural systems to meet all of the other issues discussed in this report.

There are two aspects to the climate change–agriculture nexus. The first of these relates to adaptation to the impacts of climate change. The second relates to the implications of mitigation policies followed in response to the risk of climate change, through the impact this has on the cost of direct and indirect emissions from agricultural activities.

Adaptation to climate change

Australia

The projected impacts of climate change on agriculture are complex, since they vary by agro-ecological region, the time-scale employed, assumptions about emissions pathways, and assumptions about the strength of carbon fertilisation effects (i.e. the extent to which increased concentrations in carbon dioxide impact on yields). The Intergovernmental Panel on Climate Change (IPPC) suggested possible initial gains in output in middle and high latitudes, followed by subsequent losses, and early losses in the lower latitudes. In particular, it projected:

- Modest increases in crop productivity at high latitudes from local mean temperature increase of 1-3 degrees Celsius, depending on the crop, and decreases beyond that. The "hill shaped" projection is partly a reflection of the initial combined effect of warming on lengthening growing seasons and of the carbon fertilisation effect.

- Lower latitudes, particularly seasonally dry and tropical regions, would experience drops in crop productivity for even small local temperature increases (i.e. 1-2 Celsius).

- Adaptation effort, such as altered cultivars and planting practices, allow high and mid latitude cereal yields to be maintained at or above baseline yields for modest warming.

- Australia is particularly vulnerable, with production expected to decline by 2030 over much of eastern and southern Australia.

Long range forecasts (i.e. towards the end of the 21st century) are generally pessimistic in terms of their outlook for agriculture, since under a business as usual case any carbon fertilisation effect would be totally overwhelmed by the negative impacts of warming, notably on water stress. Whole areas and practically all of Australian arable land, would move out of production.

Consequently, the prospects that R&D can play some part in mitigating the impacts of climate change, particularly over the long run, is heavily contingent on whether global attempts at stabilising atmospheric concentrations of greenhouse gases have some degree of success.

The types of R&D efforts that are likely to be needed to address climate change impacts include:

- Information management systems that link projected changes in climatic variables to impacts on production.

- Development of new crop, breeding, management and growing cycles; and management of soil fertility.

- Development of new livestock and aquaculture practices, such as pasture utilisation levels .

- Development of varieties and cultivars that have increased tolerance level to heat and water stress.

- Management of pests, including to changed patterns of prevalence and infestation as a consequence of climate change.

- Management of the agro-ecosystems within which activities take place

- Management of environmental externalities, given that climate change will inevitably place stress on environmental assets.

Developing countries

The precise impacts on climate change depend on the location of the country. For example, parts of Eastern Africa and the North Africa may receive more rainfall, while parts of west and central Africa may face more erratic rainfall. Sea level rise is a concern for densely populated low lying river delta areas, such as Bangladesh, and for pacific island countries. All countries are likely to face increased uncertainty regarding weather patterns, with increased uncertainties regarding cropping seasons. Moreover, in developing countries, especially, the rural poor will be affected disproportionately by climate change, given the vulnerability of small holder agriculture to climatic shocks, and given the lack of asset diversification of small holders.

Adaptive policy interventions extend well beyond R&D. The broad types of R&D needed are very similar to the list set out in the preceding subsection.

Climate change mitigation

Australia

Agriculture is a large emitter of green house gases in some countries – in Australia it accounts for about 15% of Australian greenhouse gas emissions, and of this proportion, roughly two thirds are accounted for by methane emissions from the digestive processes of certain livestock. Behind stationary energy, agriculture is the second largest source of greenhouse gas emissions. This, prima facie, suggests that there is scope for economy wide gains from including agriculture within an economy wide effort to mitigate emissions.

The main sources of Agriculture greenhouse gas emissions are set out in table 5 below.

Table 5 Main sources and types of agriculture GHG emissions.

Activity	Primary GHGs emitted
Enteric fermentation	Methane
Manure management	Methane
Rice cultivation	methane
Agricultural soils	Nitrous oxide

Burning of savannas	Methane, nitrous oxide
Field burning of agricultural residues	Methane, nitrous oxide

The means for mitigating agricultural emissions are still under research. The principal methods are listed below.

Process	Observations
Enteric emissions from livestock Includes demand side mitigation options: Reduced demand for meat, dairy and wool (note risk of carbon leakage)	Supply side options mitigation: Animal breeding, Animal Management, Diet manipulation, Rumen Manipulation.
Agricultural soils management Mitigation options: Fertilizer management to reduce nitrous oxide emissions from soil. Minimum tillage, controlled traffic, moisture management,	Improved animal waste management
Biosequestration options : includes options for increasing carbon removal from soils through conservation tillage on cropped land, changed practices on grazing land;	Emerging technologies such as char (improves soil structure and aids nutrient and moisture retention),
Manure management Utilising manure to fertilise crops and pastures (reduces indirect emissions through substitution of synthetic fertiliser)	Reduction in savanna burning

Table 6 Illustrative list of abatement options (including bio-sequestration)[79]

Mitigation efforts in relation to agriculture intersect with wider issues of land use change – notably the potential for developing bio-sequestration options through changes in rural land use practices. Some of these involve changes to agriculture

[79] Sources: Saddler H. and King H. (2008). Agriculture and Emissions Trading The impossible dream? The Australian Institute, Discussion Paper Number 102; *Garnaut Climate Change Review* – Final Report, p 542.

activities (for example, to improve the potential for carbon to be sequestered by soil); and some to activities outside agriculture (specifically land use, land use change and forestry). But even the latter set of options has a direct bearing on agriculture since they are likely to involve substitutions in land use. Moreover, they may present offset options for both agriculture and non-agriculture based emissions.

Mitigation in developing countries

Under the arrangements of the Kyoto protocol, there is scope for developing countries to undertake project based mitigation activities; and the scope for mitigation may well be strengthened following the negotiation of a successor to the Kyoto protocol. Stimulating the supply of mitigation and offset options, through R&D, is beneficial to developing countries (particularly if this means they can access payments for actual mitigation) and to the global community at large to the extent that this unlocks cheaper abatement options.

4.8.2 Wider market and policy failures that are unrelated to R&D

Adaptation

In Australia, agriculturalists and agricultural systems have a long track record of adapting to climatic variation and phenomena. For example, setting aside climate change issues, there are currently seven known weather related phenomena that contribute to rainfall variability in Australia over varying time scales, the most well known of which is the El Nino-Southern Oscillation (ENSO).[80]

This has contributed to building adaptive capacity in relation to climatic phenomena, and indeed there have been detectable shifts in management practices as a consequence. To some extent, responses to projected climate change impacts will emanate from an extension of practices already followed. Many of the impacts of climate change will be mediated through product markets, both locally and globally, which in turn can stimulate incentives for R&D. There will also be a range of non-market externalities that will be aggravated by climate change, and the extent to which agriculturalists respond to these will depend on measures taken to address these externalities (as discussed above).

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[80] See CSIRO (2008), *An overview of climate change adaptation in Australian primary industries – impacts, options and priorities,* p 46.

Mitigation

Introducing a price on carbon and applying it to agriculture will increase the costs of indirect emissions (principally the cost of electricity) and direct emissions (methane, nitrous oxides, carbon dioxide). The returns to investing in R&D would be measured through cost savings in terms of reduced emissions costs – the main driving force would be the "elasticity" of emissions with respect to changes in R&D.

Greenhouse mitigation efforts are also likely to increase the value of rural land based offsets and sequestration options, including forestry. Agents that invest in these options are likely to be rewarded if provisions for tradable offsets are created. The returns from these will act as a measure of the returns from R&D.

The climate change policy discussion provides a very clear example of the advantages of a whole of government approach to R&D in agriculture. In particular, one that ties in the development of a policy framework to approaches to accounting for and abating.

4.8.3 R&D policies required and types of market failure

Adaptation

Agriculture in Australia has a track record of adapting to climate issues and hence one of the policy requirements is to strengthen existing adaptive capacity. One requirement for efficient adaptation is information on climatic variables. Because of the economies of scope and scale in information collection, this is most efficiently done on a centralised basis, and because there are appropriability issues in relation to information, there is likely to be a role for public financing and support for information gathering. Having said that, investments in information technology that are used to support decision making based on this information is likely to be patentable, thus opening the scope for private provision. For example, software used in relation to grains (the Yield Prophet system) benefits from trademark protection.

As with environmental issues generally, changes to management practices are an important component of adaptation efforts. Consequently, similar observations to those made in the previous section regarding the role and rational for public support apply here.

There is significant overlap between climate change and the discussion relating to productivity – indeed, the central question is what impacts changes in climatic variables are likely to have on productivity. Insofar as these impacts reinforce some of the problems highlighted in relation to the reliance on private R&D (driven by intellectual property protection), notably in relation to plant varieties, they reinforce the case for public policy intervention. This is particularly true in developing countries.

Mitigation

A central issue in mitigation is pricing carbon emissions – if this is done and applied to agriculture, it will increase the willingness to pay of agriculturalists for innovations that reduce emissions, and hence the costs associated with them. Some of the types of R&D that are required – such as pharmaceutical and biomedical research to reduce animal-based methane emissions – are ones that can benefit from intellectual property protection. This provides avenues for privately funded R&D in relation to mitigation. At the same time, unlocking new options for mitigation and offsets (including through changed land use practices) can have an important effect on the structure of mitigation costs for the economy as a whole, which acts as an argument in favour of public support for R&D.

As with other aspects of environmental management, there are aspects of mitigation that will be governed by management practices. This is the case both for on-farm activities, as it is for offset and bio-sequestration options. Consequently, this may create grounds for public policy intervention, subject to the caveats already discussed.

In developing countries, the case for publicly funded R&D is stronger, given the constraints relating to the operation of markets that we have already enumerated in previous sections of this report. As already observed, there are gains to both developing countries and developed countries in unlocking mitigation options in developing countries, which creates global efficiency reasons for using public resources for investment in pro-mitigation R&D in poorer countries.

4.8.4 Equity issues

Equity issues are likely to arise as a consequence of the distributional effects of adaptation or mitigation. That is to say, it might be that the burden of adaptation will fall disproportionately on certain communities. Similarly, adjustment costs are a result of carbon pricing and mitigation efforts are also likely to be spread unevenly. These distributional effects can occur within a country or internationally.

Within Australia, there may be equity grounds for funding adaptation efforts, including R&D, for rural communities severely exposed to climatic shocks. At the same time, consideration needs to be given to whether support for R&D is sensible – particularly if the scale of climate change is such that activities in marginal areas are simply not sustainable.

From an international perspective, the main ethical motivation for support lies in the fact that poorer communities that are least able to bear the burden of climate change are likely to be the most exposed to its effects; and secondly, the fact that poorer countries as a whole bear less responsibility for the current stock of emissions than do richer countries.

4.8.5 Institutional issues

Similar observations to those made in the context of environmental issues apply here – namely the importance of integrating the delivery of R&D geared to climate change within the context of wider policy frameworks. This is particularly true in relation to activities geared towards mitigation, since policies towards mitigation (and especially the pricing of carbon) will create tangible and measurable returns to investments in mitigation-friendly types of R&D.

5 Conclusions and Key messages

The last two decades of the 20th century featured, in the developed countries, an increase in the role of private investment in R&D, and a recalibration of government efforts towards the delivery of public goods. Public spending on R&D increased in a few countries. At the same time, by the turn of the century, the international community also increased its efforts at poverty alleviation, developing particular objectives (the Millennium Development Goals) and processes (notably in relation to the delivery of aid), and these have had implications for the wider framework within which R&D policy is developed.

The increased profile of issues relating to productivity, environmental issues and climate change, has also brought more attention to the role of partnerships between public and private sources of R&D. This is on account of the different sorts of market failures that are associated with the delivery of these outcomes, both in developed countries and developing countries. The key issues therefore lie in defining the contours of these partnerships (i.e. what are the boundaries between public and private agents), and also the policy issues and opportunities that are raised.

- From an Australian perspective, the notion of "partnership" has clear resonance since it matches closely the practices that have been followed through institutions such as RDCs. The main issues relate to the operation of these partnerships. In particular, the appropriate level of government involvement remains an issue of contention.

- The scope for private investment in R&D can be enhanced in industry based activities. The experience of EPRs in relation to funding plant breeding is one example of a mechanism that can strengthen the returns to private investment.

- Generally speaking, a number of traditional arguments relating to the need for government intervention in relation to improved productivity are difficult to sustain, from an economic point of view. These include arguments to the effect that production units are too small, that the local market is too small, and that gains are appropriated by other parties. On the other hand, concerns that market mechanisms may lead to an under-provision of plant varieties in the long run offers a more cogent case for government intervention.

- Environmental issues, including natural resource management and responses to climate change are clear examples of areas where government involvement through a partnership approach would yield dividends, give the extent of spillovers and externality effects involved. However, it is necessary for R&D policy in these contexts to be firmly anchored within a wider policy framework, in particular one that begins to address the market failures that are often at the heart of environmental problems. This is because such wider approaches can create incentives for the right type of R&D, and avoid creating incentives for the wrong types of R&D.

- The emergence of food security and climate change as pressing international priorities creates an increased opportunity for Australia to engage internationally in the provision of R&D and support for R&D. As noted a number of developing countries will need to increase the contribution of technical change to productivity growth if the latter is to be sustained. Australia's "comparative advantage" in the provision of R&D internationally lies in its experience of agriculture in environments prone to climatic shocks and uneven productivity. This resonates with the needs of many of the more vulnerable developing countries. In this context, it may be opportune to consider expanding the range of countries to which assistance is provided through ACIAR, to include more countries in Sub-Saharan Africa.

- The fact that assistance to R&D (and agriculture more generally) is conducted within the overall framework of poverty reduction has implications for the evaluation of such assistance. In particular, it is important to take into account the different direct and indirect mechanisms linking rural R&D to poverty including, notably: (i) impacts on hunger, as measured by the availability of food calories and the impact this has on health (ii) impacts on economic growth through growth in the agricultural sector, and hence the reduction of poverty levels (iii) impacts on food prices and incomes.

- The principles of ownership and partnership in the delivery of aid create particular challenges for R&D policy. There is a need to strengthen developing country capacity to absorb and build on assistance that is delivered. In this context, the effective delivery of R&D will be contingent on the development of effective partner country policy frameworks that integrate R&D programmes (and assistance to agriculture more generally) into strategies that are geared towards poverty alleviation and that are properly funded. This in turn underlines the importance of policy support for developing countries (in addition to the provision of "traditional" R&D); and also reinforces the need for institutions involved in the delivery of R&D to engage with a wider range of institutions in developing countries (such as ministries of finance and planning).

- There is also scope for increased coordination between donors in the delivery of R&D assistance and assistance to agriculture more generally. The reform of the CGIAR, with the creation of a trust fund mechanism, may provide the opportunity to do so. It will also underline the importance of identifying how much and what types of assistance should be delivered through multilateral mechanisms, and when Australia would have a comparative advantage in delivering assistance bilaterally.

- Funding access by developing countries to innovation protected by intellectual property is likely to be a major policy issue, particularly given the confluence of food security issues and climate change. Options include funding.
- International not-for-profit public-private partnerships have emerged in agriculture (mirroring developments in other areas, such as health). Some donors, such as DFID, have begun to support these as part of their strategy of investing in R&D internationally, and the opportunities for Australia to do likewise can be explored. Part of the aim of these partnerships is to balance the trade-off between intellectual property protection and the preservation of incentives to innovate, on one hand, and issues related to accessing such innovation by counties with a low ability to pay.

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