FARMER - FUNDED R & D: INSTITUTIONAL INNOVATIONS FOR ENHANCING AGRICULTURAL RESEARCH INVESTMENTS

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Farmer-Funded R&D:
Institutional Innovations for Enhancing Agricultural Research Investments

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EXECUTIVE SUMMARY

In the United States and Canada, as in many other high-income countries, agriculture in the 21st century is faced with a variety of longstanding challenges, and some new ones. Among these challenges we can count:

(1) a widespread slowdown in agricultural productivity growth at a time when the global demand for food and fiber production is growing rapidly but key resources of land and water are increasingly scarce, and climate change will impose new constraints and challenges;

(2) a slowdown in growth of (and in some places a real decline in) support for public-sector agricultural research and development (R&D) and a commensurate slowdown in the growth in private agricultural R&D spending;

(3) within the public agricultural R&D portfolio, a diversion of funds away from investments in farm-productivity-enhancing innovations towards other areas of concern, such as food safety, human health and nutrition, and the environmental impacts of agriculture;

(4) within the private agricultural R&D portfolio, as dictated by appropriability requirements, an emphasis on certain types of (a) food technology, (b) chemical and mechanical farming innovations, and (c) varietal innovations for a few major crops (mainly feed grains, oilseeds, and cotton), for which intellectual property rights and the scale of the potential market make the investments attractive;

(5) high and rising royalty rates for private seed technologies;

(6) a comparative neglect by both the private sector and the public sector of many areas of farm-productivity-oriented agricultural R&D such as varietal

improvement for food grains, many horticultural products and much of the livestock sector—especially those elements that are not highly concentrated.

These trends are apparent in spite of a large and compelling body of evidence showing that the private and social, national and global returns to public and private agricultural research have been extraordinarily handsome—benefit-cost ratios in the range of 10:1 or 20:1, well better than can be expected from other uses of funds. Paradoxically, farm-productivity-oriented agricultural R&D is tending to become more neglected at a time when the demands for productivity growth are becoming more pronounced and the payoffs can be expected to be higher than ever before.

This outcome can be seen as a combination of government failure and market failure. The purpose of this report is to review options for alternative institutional arrangements to enhance agricultural research investments where these failures are serious. In doing so we recognized at the outset that simply calling for more government investment would not be useful, although such a policy would certainly be justified. Instead, we sought options for public-private partnerships to enhance research investments at the boundary between public and private interest: research that benefits a relatively narrow group within society but for which existing institutions are inadequate and fail to bring forth a socially optimal rate of research investment.

The main options we identified for detailed consideration are based on a review of institutional arrangements for financing agricultural R&D in Australia, and variants of those arrangements as used in other countries. Specifically, these include

(1) the use of end-point royalties (EPRs) as a mechanism for establishing and enforcing intellectual property rights (IPRs) to encourage private investment in

development of new varieties, as applied to wheat in Australia and, with modifications, France; and

(2) the use of a commodity levies, combined with matching government grants, to raise funds to be administered by producer bodies as a mechanism for enhancing total funding for commodity "collective-goods" type of R&D, such as varietal improvements, following the example of Australia's Rural Research and Development Corporations (RDCs).

Both of these ideas have potential for application in some form in North America. Each would require some specific legislation; and, before that, much analysis and consultation with industry and legislators, to develop the required support and the thrash out the details of the design that will have crucial implications for the ultimate consequences for agriculture and the economy more broadly.

Some key lessons from the analysis in this report include the following:

- The public sector seems to chronically under-fund research in total, even though this may be the only source of funds to produce pure public goods, and underfunds certain types of research in particular. Underfunding seems to be getting worse in at least some areas, perhaps especially those that offer potential to address global public goods problems associated with hunger and poverty, food security, climate change and, indirectly, natural resource preservation.
- More-complete IPRs have increased private and total investment in certain types of agricultural R&D, and have produced very substantial research gains. However, this approach has some drawbacks. First, in a private agricultural research industry with a few large firms dominating the business, the share of rents to the innovator are large and seem to be increasing over time such that the

cost of technology used by farmers is a substantial share of total costs in those industries where private research dominates. Second, some resources appear to be wasted in fragmentation, duplication of effort, and transaction costs. These outcomes exemplify the dilemma of the costs of creating monopoly privileges that accelerate invention but slow adoption of given inventions and can give rise to wasteful forms of competition.

- EPRs can be a very effective research funding tool, providing intellectual property protection comparable to that provided by hybrids and patents. They may allow some efficiencies to be gained in terms of costs of research and in the rate of adoption. Efficient royalty collection system may require regulation or industry coordination.
- While they have favourable potential, EPRs could evolve in the same directions as witnessed for private varieties in North America, such that the rates of EPRs and rents to innovators tend to increase over time. This appears to be happening to some extent with Australian wheat. The policies could be designed to limit these aspects: EPR rates can be regulated by the government or subject to negotiation with industry, as in France. Breeders' rights can reduce duplication of effort and provide a natural cap on rates.
- Australia and a few other countries have effectively used levy-based funds to substantially enhance funding for agricultural R&D. The approach gives voice to producers in the institution of a program and in the establishment of the levy, but substantial accomplishment with this approach requires mandatory contributions once the program has been established—like U.S. marketing orders. Voluntary or refundable levies are not able to operate at substantive scale.

- The details of the institutions matter both for effective governance and efficient performance, as well as getting the total levy and research funding right. These are democratic organisations and often implicitly if not explicitly require support from a very large majority of producers, which tends to lead to inadequate investment rates, large expenditures on communication with the industry, and some expenditures of resources on catering to the minority interests. In Australia the provision of matching support from the government has been crucial in helping to compensate for spillover benefits beyond the levy-paying industry and to reduce the tendency to set the levies too low.
- A combination of public funding, levy-based funding and private funding might be close to optimal, where each serves a specific purpose and plays a complementary role with the others:
    - Private funding where IPRs are applicable and enforceable
    - Levy-based funding for industry collective goods, for which the benefits accrue primarily to producers or consumers of the good on which the levy is collected, and for which the costs of collecting levy are reasonable compared with the amounts to be raised
    - Public funding for pure public goods types of research that can be expected to have broad spillover benefits to groups or individuals within society that may not be easy to identify and for which other funding mechanisms cannot be applied
    - A mixture of approaches for those areas that could in principle be funded by the private sector individually, using IPRs, or collectively, using levy-based funds but are not in practice adequately funded without some

public-sector involvement. This could include many areas of levy-based programs for which the Australian experience has demonstrated a crucial role for matching support.

- Public-private-producer-partnership (PPPP) approaches are working in Australia and have great potential in North America.

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1. Introduction

Economic assessments of public and private investments in agricultural R&D consistently have demonstrated very high returns to the investments (e.g., Alston et al., 2000; Alston, Andersen, James, and Pardey 2010). This evidence points to a persistent pattern of substantial underinvestment, in spite of significant government intervention aimed at both encouraging private investment and supplementing it with public investment. We have a combination of market failure and government failure in that governments have succeeded only partially in developing policies to correct the market failures that give rise to private-sector underinvestment in agricultural R&D. The failures are more pronounced for some parts of agriculture than others—for instance, the private sector has relatively little incentive to invest in improved varieties for wheat and many specialty crops, compared with hybrid maize, for which varietal innovations are protected by a combination of trade secrecy and utility patents.

Flying in the face of these well-known facts, over the past 20 years and more, the trend of public policy in more-developed countries, including the United States and Canada, has been to reduce support for agricultural R&D as a whole, and to reduce the share of that support directed at farm productivity enhancement (Pardey and Alston, 2010; Pardey and Alston, 2011). Perhaps reflecting this trend of slowing support for farm-productivity-oriented research, we have witnessed a slowdown recently in the growth rate of farm productivity in many countries, including the United States and Canada—whether this is measured using crop yields, measures of aggregate output per unit of land or labor, or using multifactor productivity indexes (Alston, Babcock, and Pardey 2010).

Recent productivity growth rates in the United States and Canada may be as little as half what they were just a decade or so in the past (James et al. 2009; Veeman and Gray 2009). This productivity slowdown has potentially serious long-term implications for international market competitiveness and pressures to be placed on the natural resource base, as well as for prices, the world food equation, and food security concerns. Nevertheless, in the current economic and budgetary environment in most countries, including Canada and the United States, we do not foresee a significant increase in commitment of government revenue to support agricultural research; in fact, the converse seems more likely unless we can find new ways of making such support seem attractive to policymakers. If total spending is to be sustained let alone increase, new models for financing agricultural R&D will have to be developed.

This paper explores some potential innovations in agricultural research funding institutions in North America, including approaches based on commodity levies and approaches based on new forms of intellectual property rights applied to new varieties, which have been employed in various forms in other countries. The alternatives differ in their implications for the time path of innovation, the distribution of the benefits among producers, consumers, and technology firms, and the total social benefits. In this paper we explore these aspects both in principle and in practice, and draw lessons for the potential use of these institutional innovations to enhance agricultural R&D in North America. In doing so we emphasize crop varietal-improvement research, and draw on the cropping industries for our primary examples, although most of what we discuss applies more broadly than that, albeit with some modification to suit particular cases. And we draw on the experience with similar institutional innovations in other countries—especially in Australia, and to a lesser extent in France and Uruguay.

2. Roles of Government in Agricultural R&D

Well-performing Agricultural Knowledge Systems (AKSs) foster productivity improvement by generating knowledge and developing technologies that are put into use by the agricultural sector. They thereby not only increase profitability and economic surplus for farmers, but also contribute to the ability of the sector to address food security and environmental goals. While some important innovations have been generated by the private sector, the policies of the public sector have been critical in shaping AKSs.

2.1 Market Failures in Agricultural R&D

Much of the knowledge created by agricultural research, whether it is embodied in seed for a new variety, a machine, or a technique for production, has one or more of the characteristics of a "public good." Specifically, knowledge can be "non-rival" in use in the sense that one person's use does not diminish its availability to be used by another person, and it can be "non-price-excludable" in the sense that the producer of the knowledge cannot preclude others from using the knowledge even if they do not pay for it. These characteristics give rise to market failures in agricultural R&D and a rationale for government intervention.

The characteristic of non-excludability means that producers of knowledge (say, those who develop a new crop variety) cannot appropriate the returns from their investments in creating knowledge and therefore have attenuated incentives to invest. The right to exclude others from using a good is central to the notion of private property. Without the ability to exclude others, goods are essentially in the public domain and private individuals have no incentive to provide the good. If the ability to use a good "spills over" to others, and they are not obliged to pay for it, the market demand will not reflect the good's full social value. It will reflect only the flow of benefits that can be excluded if payment is not made. In addition to excludability, goods differ in the extent to which use of them is rivalrous (often referred to as subtractability). Most economic goods are "rival" such that, if they are used by one individual, they cannot be used or consumed by another. For example, a sandwich is eaten only once. However, some goods, including knowledge, are non-rival and are not diminished by use. Once created, these non-rival goods can be used any number of times and shared without incurring a marginal cost. In many cases knowledge is a classic public good in the sense that it is both non-rival, and non-excludable. Such goods will not be produced privately and, if produced by the government, must be provided for free to users.

2.2 Intellectual Property Rights

One solution to the problem of non-excludability is to create intellectual property rights (IPRs). Governments have introduced a range of IPRs over time, many of which apply to agricultural innovations. The United States provides some relevant examples, as discussed by Alston, Anderson, James and Pardey (2010, pp. 189–193). Until relatively recently the U.S. Constitution offered little protection for biological innovations such as new plant varieties. Patents, trademarks, and copyrights that were introduced in the United States in the 18th Century, offered substantial intellectual protection to a broad range of product and process inventions, but not to plant breeders. Subsequent policy changes progressively extended the scope of intellectual property applied to inventions involving living things: the Plant Patent Act of 1930, extended protection to asexually produced plants such as grape vines, fruit trees, and ornamentals that are propagated through cuttings and graftings; the Plant Variety Protection Act of 1970, extended (somewhat limited and weak) protection to non-hybrid varieties of sexually produced plants such as wheat, cotton, soybeans, and canola; in 1980, the U.S. Supreme Court held that living organisms fell within the class of patentable subject matter, and in the same year the Bayh-Dole Act of 1980 established the right of grant recipients to apply for patents on results from most federally funded research. These changes facilitated the biotechnology revolution that followed soon after.

The private sector has played a very important role in agricultural R&D in contexts where IPRs have allowed firms to capture a return from their investments. Agricultural machinery and pesticides are good examples where this has occurred. Notably, the private sector has also played a large role in crop breeding where hybrid technologies, patented traits, or vegetative reproduction allow crop breeders to capture value from their investments. Still many technological "orphans" can be found within agriculture, in situations where the intellectual property protection is weak or narrow in scope, and among producers of specialty crops for which the potential market for new varieties or other specific technologies, such as pesticides, is too small to attract private investors (e.g., Alston and Pardey 2008). This problem is more pronounced in those instances where the investor can anticipate incurring a significant fixed cost from the regulatory approval process (e.g., see Kalaitzandonakes, Alston, and Bradford 2006).

The main drawback of the private property approach to agricultural innovation is that the owner of the intellectual property can price as a monopolist, whereas for a non-rival good social surplus would be maximized with a price of zero. The monopoly price stifles adoption compared with the socially optimal price for a non-rival good. Thus the solution to having too few innovations, the implementation of IPRs, has an offsetting drawback in that it leads to too little adoption of the resulting innovations—a dilemma for policymakers.[1]

2.3 Public Research Investments

To date, the main alternative to the creation of IPRs to foster private investment in agricultural R&D, from which the results are sold to farmers (treating R&D as a toll good), has been public investment in agricultural R&D, from which the results are given to farmers for free (treating R&D as a public good). Most countries have a long history of public-sector dominance in agricultural R&D. In North America, publicly funded agricultural R&D has been seen as a key economic development tool for more than a century. Early policymakers recognised that the ability of farmers to save seed and otherwise mimic their neighbours made it impossible for firms to capture the value from many research investments. Recognising the lack of private incentives, governments created large publicly funded R&D programs.

The long and extensive record of high returns to public research (see Alston et al. 2000; Alston, Andersen, James and Pardey, 2010 and 2011) demonstrates both the benefits from public expenditure on research and the persistent underfunding, even when we allow for the high opportunity cost of government funds. This persistent pattern suggests that, in spite of the very significant policy intervention in this area, we have a government failure in conjunction with market failure.

Some of the factors that contribute to the widespread, persistent government underfunding have been discussed in the literature. They include factors such as the tendency for political processes to undervalue long-term investments, as well as the roles

[1] If the firm with the IPR can price as a perfectly discriminating monopolist, then the socially optimal quantity would be produced but the distribution of welfare would be very different than if price were equal to marginal cost. This theoretical possibility does not seem to be practically or politically likely in practice.

of various interest groups within those political processes. In addition, many people may not believe that the reported rates of return were accurate or that they are relevant for making decisions about current investments.

At any time, the opportunity cost of spending taxpayer dollars on public agricultural research is a pertinent consideration for policymakers. Other constituencies compete with agriculture for these scare public resources, and it seems they are becoming increasingly effectively at doing so. These competitors include other elements of the public research agenda, such as health, medical, energy, and environmental research, as well as general science and military research that can to some extent make comparable claims about market failure and the like. Within the broad agricultural portfolio, agricultural R&D competes with food and nutrition programs, environmental programs, and farm subsidies (including crop insurance) all of which have very active and effective constituencies. In the United States, agricultural R&D has not been among the top priorities for the farm lobby, and continues to accounts for only a few (shrinking) percent of the total spending in the Farm Bill. The lack of a strong constituency, other than scientists, advocating greater rates of public investments in agricultural R&D will limit the scope for any public policy to bring about major changes in investment rates other than the creation of enhanced private property rights. In times as at present where government budgets are very tight, the scope for favourable changes in public funding for agricultural R&D seems especially limited.

2.4 Collective Action Programs

Governments and civil society have also used various forms of "collective action" to address the underfunding of agricultural research. Some commodity-specific agricultural R&D has the characteristics of a collective good—a public good for which the relevant "public" is a defined subset of the entire population that produces and consumes the good in question. To encourage the provision of these types of agricultural R&D, in addition to the other options for government intervention (government provision, government financing of private provision, or intellectual property rights to encourage individual private provision), governments can create institutions to enable collective private provision. One such institution is a research-funding program, financed by a commodity levy. Agricultural commodity levies are used to finance the provision of a range of commodity collective goods, such as commodity-specific generic promotion, marketing research, industry public relations, agricultural R&D, and the development, implementation, and enforcement of uniform grades and packaging standards[2].

Such programs are typically developed based on generic enabling legislation, according to which a specified majority of producers (defined as a share of the total number of producers or as a share of the total volume of production, or both) in a particular defined industry votes under a plebiscite to institute a program under which funds from a hypothecated tax will be used to finance specific activities. Sometimes they are developed under specific stand-alone legislation. While they are voluntary, in the sense that they require a producer vote, most levies are mandatory, one implemented, and non-refundable. Some Canadian programs entail refundable levies for research, in which case producers may apply for refunds.

Levy-based R&D programs are made possible by government policy through the application of the government's coercive taxing powers to collect the levies, the

[2] In the United States and Canada, the main use of levy funds has been commodity promotion programs. In some other countries, such as Australia and Uruguay, levies are more important as a source of funds for agricultural R&D.

exemption of levy programs from some types of anti-trust regulations, the use of government resources to develop and implement the programs, and, in some cases, the provision of government funds to support them. Hence, it is appropriate to ask how closely do program decisions correspond to those that would maximize national economic welfare, and how are the benefits and costs distributed among different groups in society. These issues are discussed later in this report with particular reference to the Australian approach to levy-funded agricultural R&D, which is the most extensive and most relevant to North America.

3. IPRs and Private-Sector Crop Improvement

The introduction of IPRs has been critical for the development of a private crop research industry. For many agricultural crops, a variety can be reproduced at a low cost by saving seed from the previous season's production, saving tubers, or taking vegetative cuttings. This biological feature of the plants creates the potential for an innovation to be widely and cheaply reproduced by farmers. As a result, without IPRs, a breeder's ability to profitably sell a new variety is quickly eroded, and the benefits from the innovation spillover to producers and consumers. Spillovers create a market failure because of the implied misalignment between the marginal social and private benefits and costs of research (Alston, 2002).

IPRs allow an innovator to legally exclude others from an innovation. By charging a fee in return for access to their property, innovators can capture some or all of the benefits resulting from their research investments, which creates incentives for undertaking private research. In instances where strong IPRs exist the innovator is given a monopoly over the legal sale of their embodied knowledge, which creates the basis for a private research industry. Incentives and outcomes created by these circumstances have been examined in the economics literature.

3.1 Knowledge as a Toll Good

Knowledge, when protected by IPRs, becomes a "toll good"—a good that is non-rival but excludable (Lesser, 1998; Fulton, 1997). Because the toll good input is non-rival, it only has to be purchased or created once. This property affects the cost structure of firms using IPRs as a major input in two very important ways: (1) creating economies of size in the sale of research products; and (2) creating economies of scope (and possibly economies of size and scale) in the production of new knowledge. Given these impacts on cost structures the non-rival nature of knowledge is likely to result in significant market concentration whenever knowledge creation is a significant part of industry costs.

Economies of size in the sale of research product arise because the fixed cost is incurred only once for each such good—for example, a new variety of soybeans—, and the same genetic material can be used again and again without reducing its availability to others and at no additional cost. This means that the average cost of producing the final output (i.e., seed using this genetic material) decreases with the quantity produced because the cost associated with purchasing, or creating, the non-rival input (the new variety) is spread over more units of output. The declining average cost implies that large firms will always have a cost advantage over smaller firms. Given the economies of size, lowest industry average cost can be achieved if the good is supplied by a single monopoly. Toll good industries for which fixed costs represent a large share of total costs, such as railways, software companies, or electrical distribution networks, are often referred to as natural monopolies.

Economies of scope are created when the knowledge generated for the production of one product can be used for production other products. Firms that can use the same knowledge to produce more than one type of research product (e.g., different varieties of the same crop, or varieties for different crops), will have economies of scope. For example, if a firm owns the patent for a "gene gun," this knowledge gives the firm a cost advantage in several transgenic crops. When a firm has owns a large pool of protected knowledge, this will tend to lower the average research costs across several crops. The presence of such economies is particularly evident in transgenic crops, where large multinational research firms are improving genetics for a wide portfolio of crops. Scope economies are becoming increasingly evident for most crops as genomic knowledge and genomic selection tools have wide, multi-crop applicability. Economies of scope imply that firms can achieve average lower per unit costs by producing intellectual property for many different products. Taken to an extreme, a single firm that had access to the total global knowledge related to crop research would have the lowest cost for creating an innovation in any particular crop. Likewise, firms may have substantial economies of size (or scale) in research over ranges of total research effort or research output within which particular lumpy research resources (such as physical capital or capacity of specialized scientists) are not fully or efficiently employed.

The toll-good nature of IP has profound implications for the cost structure of the research industry. Consider the case of breeding new wheat varieties. In a hypothetical situation where all research is organized in the most cost-effective manner and all the knowledge generated is shared globally without transaction cost, the industry average cost curve would be at its lower bound, where research costs are minimized for any quantity of research output. This average cost curve is downward sloping because, with increases in the total quantity of the innovation being used, the fixed costs of the research that generated the innovation are spread over more and more units of output that use it. The outcome is a natural monopoly, with price set such that marginal revenue equals marginal cost (i.e., zero), resulting in a price that exceeds marginal cost. Deadweight loss arises because the monopolist sets the price too high and stifles adoption, compared with a scenario where the technology is available for free (i.e., the price is zero).[3]

Competition reduces price but creates another issue. If the industry is profitable it will attract entry by other firms. Typically, research-intensive industries have more than one R&D firm. If firms are engaged in any form of price competition, this would decrease the price charged for seed and reduce the efficiency loss associated with the over-pricing of the research output. However, this increased competition also comes at a cost. If two identical firms were engaged in research, and each produced effectively identical varieties that were sold to one half of the market, each would incur the fixed cost of research. This duplication of effort would double the research cost, which would shift the industry average cost upward, imposing a loss on society. The net effect on social welfare is difficult to assess. On one hand competition reduces seed prices toward marginal cost, encouraging adoption, on the other hand the duplication of effort increases the cost of the research.

3.2 Moschini and Lapan: Analysis of a Patent Monopoly

The importance of market power and the pricing of crop innovation was explored by Moschini and Lapan (1997). They showed that when the innovator produces an

[3] If the innovator could price discriminate perfectly, and charge each farmer his all-or-nothing willingness to pay for the technology, the resulting quantity demanded would be the same as if the price was zero and deadweight loss would be avoided, though the distribution of benefits would be very different.

innovation and has complete IPRs, the innovator can capture a benefit from the innovation that is not reflected in the output market. In the case of non-drastic innovation, the pricing behavior of the resulting oligopoly is important. When the innovation is drastic the monopoly is in a position to capture a share of the social welfare gain, which depends on various market parameters. This seminal work illustrates the inherent friction between competitive behavior and toll goods created by IPRs.

3.3 Extensions to the Moschini-Lapan Analysis

Alston and Venner (2002) use a game-theoretic approach to examine the investment and pricing incentives with the partial excludability afforded by the U.S. Plant Variety Protection Act. In their theoretical framework, the inventor is a Stackelberg leader who anticipates the response of downstream seed firms in the industry. They show that stronger IPRs unambiguously increase the price of the invention and increases research output. However, the higher price of the invention retards adoption, creating an ambiguous effect on the rate of innovation. Empirically Alston and Venner examined the wheat seed market in the United States and could not find evidence that the partial excludability afforded by the Plant Variety Protection Act (PVPA) either increased the price of wheat seed or had increased the increased the rate of yield increase. The lack of PVPA impact was consistent with Perrin and Fulginiti (1998), who showed that the farmers' privilege in the PVPA, which allows farmers to save seed, erodes most of the ability to capture the return from a new variety.

3.4 Transaction Costs—Patent Thickets and Related Issues

As mentioned previously, the non-rival nature of knowledge makes industry cost a function of the degree to which knowledge is shared. While IPRs can encourage knowledge creation, they also create the ability and profit incentives to restrict the sharing of knowledge. Concerns over knowledge sharing and exchange in the crop research industry have been documented in a growing economic literature (Falcon and Fowler, 2002; Smyth and Gray, 2011). Several reasons could account for why a firm would not license its protected IP. The first is the management of strategic assets. When firms are in close competition, they may deliberately keep their proprietary knowledge to themselves rather than license it to a rival. Second, an anti-commons problem (Heller, 1998; Wright and Pardey, 2006) can exist. If many firms own complementary IP, the *ex post* bargaining behavior of the individual owners may make it difficult and sometimes impossible to reach an incentive-compatible sharing agreement among all of requisite owners. The classic case is GoldenRice™, which was estimated to contain 40 pieces of IP in the United States that were owned by at least 12 different organizations (Kryder et al. 2000). Finally, the large number of IP claims, often referred to as the patent thicket (Wright and Pardey, 2006), can give rise to excessive transactions cost. To illustrate the vast number of patents, on February 15, 2012, a simple search of the U.S. patent database revealed 3,530 patents related to stress tolerance and wheat. Searching this large database and identifying which patents are potentially useful, determining what patents are enforceable, and what IP can be safely used without violating other patents, is a time-consuming and costly undertaking. The *patent thicket* adds to cost of protecting and using IP. For some or all of these reasons firms often have not licensed their IP. As a result, many firms have been forced develop their own research platforms, duplicating effort and driving up the industry cost curve.

Despite the obstacles, some private mechanisms can and do evolve for sharing knowledge. This is valuable because the lowest industry average cost curve can be achieved with multiple firms in the industry if they are to find a way to “share” toll goods. Research consortia, in which the funding partners agree to jointly fund research share the knowledge generated, have been used occasionally by both public and private research institutions. Since 2005, the largely autonomous multinational biotech firms have developed numerous cross-licensing agreements among firms (Smyth and Gray, 2011; Howard, 2009). These agreements allow for genetic traits and processes used owned by separate firms to be combined (or stacked) and marketed as a bundle. This is a significant development because it allows the non-rival knowledge to be shared, which lowers the cost of creating superior genetics. However, these agreements can also constrain the nature of competition between firms, by establishing licensing fees, pricing protocols and bundling options (Howard, 2009).

3.5 Crop Research in North America

In North America, the Plant Variety Protection Act, utility patents and hybrid technologies have allowed strong intellectual property protection, and created powerful economic incentives for private investment in developing varieties for several field crops, most notably corn, soybeans, canola and cotton. As theory would predict, the toll good industry is dominated by a small number of firms, each with research programs large enough to capture some economies of scale (Howard, 2009). The impact on research investment in these crops has been substantial. As reported by Wilson and Dahl (2010), the five largest firms have made substantial and growing investments over the past decade, and invest a sum of approximately $2 billion per year in crop genetic improvement.

The impact of significant private investment is apparent in a number of ways. First of all, for the large crops in the United States, where IP can be protected by utility patents or hybrid technologies, the private sector has produced many crop varieties with a range of traits. Producers have chosen to adopt privately owned varieties even though they have become increasingly expensive. The adoption of private varieties is virtually 100% for corn and well over 90% for soybeans and cotton in the United States, and these largely U.S. derived technologies have been widely adopted elsewhere as well. Transgenic herbicide tolerance has been especially important for soybeans, allowing the crop area to expand considerably. In corn, insect resistance, herbicide tolerance, and other genetics have allowed yield to continue to increase. In cotton, insect resistance has reduced pesticide use. The gains from the research include increased farm productivity, greater crop production, reduced pesticide use, consumer benefits though lower prices, and a return to shareholders (Zilberman et al. 2010; National Research Council, 2010). Economists have estimated the annual social benefits from these biotech crops to be in the billions of dollars (Brookes and Barfoot 2009, 2010; Carpenter 2010; Carpenter and Gianessi 2001; Falk-Zepeda et al. 2000; Qaim, 2009; Sobolevsky et al. 2005).

In Canada, canola has become the second-largest crop after wheat and is a remarkable success story. Public research and breeding that began in the 1960s created rapeseed that was low in both glucosinolates and erucic acid, genetics that were trademarked as “Canola.” During this embryonic period, the Rapeseed Association of Canada was an important catalyst for industry development (Gray et al. 2001). In the 1980s, with the development of patentable transgenic processes, the private sector began to make significant investments in canola genetics. Soon afterward, Agriculture and Agri-Food Canada made a decision to withdraw from commercial seed development and move its research upstream to support the private seed industry. Privately produced, herbicide-tolerant varieties were introduced in the mid-1990s and reached nearly complete adoption by 2005. In the latter part of this adoption period, hybrid varieties were introduced and now dominate seed sales. This innovative industry recently developed and commercialized high-oleic canola creating a fatty acid profile that reduces trans-fatty acid development during frying. Grown on over a million acres, in value and volume terms, this may be the largest engineered functional food in the world.

Private research has been substantial during the past decade but little information is available publicly about private expenditures. Based on a survey of the industry, the Canadian Seed Trade Association (CSTA, 2008) estimated a total investment of $56 million in private plant breeding in 2007. Of the total of $102 million per year of planned investment in 2012, 75% was for canola research (CSTA, 2008). Although, public institutions no longer produce commercial varieties, public institutions continue to invest up to $20 million per year in pre-breeding research and germplasm development.

Yield potential has grown much faster for canola, for which R&D is primarily privately funded, than wheat, for which R&D is primarily publicly funded in Canada. As shown in Figure 1, in rough figures the yield index for adopted canola varieties has grown 75% since 1960 and has shown strong growth in the past decade; in contrast, the yield index for wheat and durum varieties increased by only 25% during the same period. As a result, canola has increasingly become the crop of choice for many producers, with the expanding seeded area being constrained only by climate suitability and crop rotations for the management of fungal diseases.

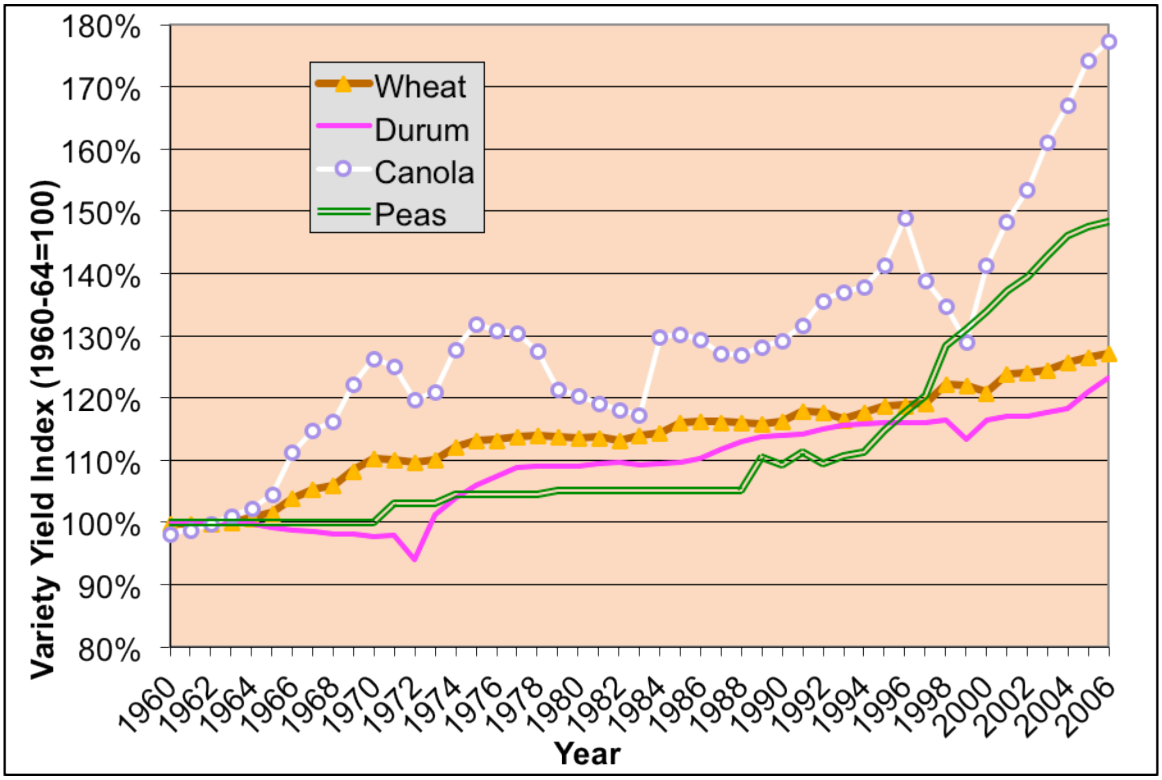

Figure 1: Adoption Weighted Crop Variety Yield Indexes Western Canada 1960-2006

The benefits from private investments in canola have been widespread. Producers enjoy higher yields, lower herbicide costs and more flexibility in the timing of herbicide application. The canola processing industry has also expanded and the seed companies enjoy strong seed sales with high seed prices. Positive human health benefits may have accrued to consumers from lower saturated fats and the higher oleic acid profiles.

Despite the widespread adoption of privately developed varieties, and the apparent gains from the additional research investment, the developments in the North American seed industry have not been without controversy. Issues of market power, seed pricing and knowledge sharing have come under some scrutiny from economists and regulatory bodies (Stiegert et al., 2010; Wright and Pardey, 2006; Wilson and Dahl, 2010).

The protection of intellectual property afforded by hybrid technologies and patents has had a significant impact on the development of a private seed industry for several important crops. As shown in Table 1 the pattern of seed sales and research expenditure for U.S. corn, U.S. soybeans and Canadian canola, have some striking similarities. In each industry, seed sales represent roughly 10% of gross crop income, seed production costs are a small fraction of the seed prices, and each seed industry invests about 10% its gross sales into research (i.e., about 1% of gross crop income).

The approximate rate of 1% of gross farm sales invested in variety development by the private firms for corn, soybeans, and canola is significant. This investment rate is two to three times the total public and private investment rate for wheat breeding in Canada. Thus, IPRs are a policy tool that can be used to address the underfunding issue as identified at the outset of this paper. This funding mechanism may represent a significant improvement to an underfunded public research system, especially considering the scale economies enjoyed by these large multi-national private firms.

A striking feature of these profiles is the 10% share of farm gross income going to seed purchases. This large share of gross income is similar in size to the factor share for land rental. This indicates both that producers benefit a great deal from these new varieties and are willing to pay for them and that, with IPRs, the seed firms are able to capture a significant portion of the benefits from varietal improvement. It also suggests that seed prices are high enough to materially affect adoption decisions and that at lower seed prices the adoption of these crops would be even more widespread.[4]

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[4] At such high seed prices farmer have an incentive to restrict seeding rates to socially sub-optimal levels, creating another source of inefficiency.

The fact that seed prices are well above the marginal cost of seed production is consistent with the toll-good nature of the industry (Moschini and Lapan, 1997). The economic significance of seed cost has attracted the attention of economists. Several recent studies by Stiegert, Shi, and Chavas (see Stiegert et al., 2010) have found that the pricing of traits is correlated with measures of market concentration. Wilson and Dahl (2010) and Fernandez-Cornejo and Caswell (2006) argue that, on balance, the economies of size realized by concentration more than offset the higher pricing incentives. As recently as 2007 the Anti-Trust Division of the U.S. Department of Justice held an inquiry into Monsanto's pricing behavior (Wilson and Dahl, 2010). While unresolved, this issue continues to be a concern for policy makers.

As mentioned previously, the non-rival nature of knowledge makes the industry cost a function of the degree to which knowledge is shared. A firm might not license its protected IP for several reasons, including strategic concerns and because of transactions costs and the patent thicket problem. Consequently firms often have not licensed their IP and have opted to develop their own research platforms, which duplicates effort and drives up the industry cost curve. Despite the obstacles, some private mechanisms for sharing knowledge can and do evolve, including research consortia and cross-licencing agreements, which allow non-rival knowledge to be shared, and thus lower the cost of creating superior genetics but can also constrain the nature of competition among firms.

In summary, the strong IP protection brought about by biotech-related utility patents and hybrid technologies has been successful in simulating substantial private investment, and created significant economic benefits by reducing the underfunding of crop varietal research. In doing so, this strong IPR regime created a concentrated toll good industry, with extensive economies of size giving rise to concerns over incentive problems related to pricing, versus fragmentation or duplication of effort. As has occurred in other sectors of the economy, the emergence of a toll good industry may have implications for economic policy, the role of public research, and the viability of alternative institutional arrangements in AKSs. The remainder of this paper explores some of these alternatives.

4. End-Point Royalties and Alternatives

The mechanism by which the inventor is compensated for IP is also important. In most non-vegetatively produced crops varietal research is supported from the collection of seed royalties or payments generated through the seed industry from the sale of seed. In patented biotech crops, per acre technical use fees are also employed for particular crop traits. In some jurisdictions and for come crops (e.g. wheat in Australia and France; vegetatively reproduced crops in the United States) royalties are collected at the point of sale of harvested product produced from protected varieties rather than from the seed used as an input. These are called "end-point royalties" (EPRs).

EPRs differ from seed royalties in at least four ways. First, having the royalty payment based on harvested material the breeder is able to collect a royalty even if a grower saves seed or does not buy new genetic material. Second, because EPRs are paid on harvested material, the breeder and the grower share production risk. Third, eliminating the seed royalty encourages growers to use optimal seeding rates. Finally, with EPRs, breeders no longer rely on the seed industry to collect royalties and instead must rely on crop marketers to enforce the royalties.

For many self-pollinating or *inbred* crops, the practice of saving seed is very common. From a production point of view, farm saved seed can be less costly than commercial seed production, can reduce transportation and distribution costs, and is less subject to seed shortage brought about by drought or other weather events.[5] With standard seed royalties, farm saved seed represents a very significant loss in revenue to the breeders (Perrin and Fulginiti, 2008) as farmers will purchase seed for a very small proportion of their anticipated multi-year area for a variety. With EPRs growers are required to pay a royalty on all the harvested material for the protected plant variety for the life of the protection. Like hybrid technology this gives the breeder to ability to earn royalties each year on each acre on which the variety is successfully grown.

The collection of the royalty on harvested material means that the breeder and the growers share production risk. In years of high production yields growers pay more royalties and in years of a poor yields payments are reduced. This risk-reducing feature royalty structure increases the farmers' willingness to pay for the new variety, increasing adoption rates and returns to the variety owner. The risk sharing also increases the income variability for the variety owner, particularly in countries like Australia where yield variability is large.

Replacing seed royalties with EPRs should result in more optimal seeding rates especially in crops with high seed royalties. Building royalties into seed prices creates a situation where the price of seed is far higher than marginal seed production costs. Faced with high seed prices farmers rationally reduce seeding rates. Collecting an equivalent

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[5] These potential advantages can be offset, in some crops, with the returns to the specialization of seed growers and the economies of scale in seed cleaning and treatment.

royalty amount through EPRs rather than seed requires a smaller proportional price distortion.[6]

Finally, with ERPs the breeders rely on grain marketer rather than the seed industry for royalty collection. This shift in the point of royalty collection creates incentives for the breeder to find a rapid and low-cost way of disseminating their varieties. The marketing plan could include widely distributing breeder seed and promoting the use and distribution of non-pedigreed seed. Such moves could have large impact on the pedigreed seed industry that may be interested in maximizing only pedigreed seed sales. The collection of EPRs requires the cooperation of grain buyers who control the marketing channel for harvested product. Breeders must establish contracts, protocols and incentives for grain marketers to correctly identify the varieties being sold so the EPRs can be collected. Without their cooperation it could be prohibitively expensive for breeders to enforce and collect EPRs.

While EPRs are not used in the North American grain industry, they have been employed in the grain industry elsewhere. To illustrate how these systems work and some of the variants in approaches used, the EPR systems for wheat in Australia, bread wheat in France, and vegetatively propagated horticultural crops in the United States are described briefly.

4.1 The Australian Wheat Model

EPRs are now the primary source of funding for wheat breeding in activities in Australia. After a decade of development the wheat-breeding industry reached the point of commercial self-sufficiency about two years ago. Now EPRs provide sufficient

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[6] In the case of hybrid corn, a $100 per acre royalty requires an implicit 1000 % increase in the price of seed. The same amount of royalty revenue could be collected with a 10 % EPR on corn produced.

revenue to support all downstream commercial wheat-breeding activities. As we describe more below, EPR revenue is poised to continue grow very rapidly over the next few years, creating a very research-intensive wheat-breeding sector.

The 1994 Plant Breeder's Rights (PBR) Act created the legal framework for the creation of EPRs. Prior to 1994, the IPRs for wheat were similar to those in North America. In the Plant Variety Rights Act of 1987 the *farmers' privilege* undermined the ability of breeders to capture value from their varieties. There was no royalty payment on farm saved seed and, because farmers in Australia were using mostly saved seed, the seed industry had very limited returns (Kingwell, 2005; Kingwell and Watson, 1998). After signing the UPOV 1991, and receiving pressure from industry and grower groups, the Commonwealth Government introduced the 1994 PBR Act.

The 1994 PBR Act extended breeders' rights to harvested material produced from seed. While the farmers maintained the ability to save seed these provisions gave the breeders the right to collect royalties on harvested product each time their variety was grown, for a period of 20 years. The royalties on harvested material became known as "end-point royalties," which Kingwell and Watson (1998, p. 324) described as "a levy imposed on the first sale of harvested material derived from varieties protected by plant breeders' rights." At the time when they were introduced, EPRs were recognised as a very promising way of dealing with underinvestment, which for years was an issue in agricultural research (Lazenby et al. 1994).

The potential for EPRs to generate revenue to fund private research took many years to be realised. At least three important barriers slowed their implementation. First, an affordable enforceable system of levy collection had to be developed. This required the development of new licensing agreements, collection agreements, and the education of industry participants. These processes required more than a decade to develop, but the industry has now developed a standardized set of contracts, and the major breeders have agreed to use SeedVise as a single agent to negotiate and coordinate the EPR collection system (McGrath, 2011). Currently, growers agree to a bag license contract when they purchase seed that obligates the grower to pay an EPR on harvested product. When producers harvest wheat and deliver it, they declare the variety they have grown. When the grain is sold the grain company either deducts an EPR from the sale and sends this amount to the variety owner (referred to as the "automatic system") or the company sends a report to the variety owner indicating the quantity of the variety purchased from the farmer, and the breeder invoices the farmer for the outstanding EPR payment. This system has produced nearly complete compliance and EPR collection in Western Australia and other export wheat regions. Notably the collection of EPRs has proven to be much more difficult in Queensland, where a large proportion of the grain produced is used in the feed industry. Second, when EPRs were first introduced, new EPR varieties had to compete with royalty-free varieties already used on farms. The availability of free varieties made it difficult to charge a significant EPR on the new varieties until they had improved to the point where producers were willing to pay a significant amount of EPR to access them. Finally, a private industry with the incentive to charge EPRs had to evolve. As long as some public breeders in the industry were reluctant to charge EPRs, the ability of the remaining firms to charge significant EPRs was limited.

In Australia, the creation of a "private industry" was the result of deliberate actions of several public and producer organisations. In 1999 the Grains Research and Development Corporation (GRDC) announced that it intended eventually to cease to provide financial support for public wheat-breeding programs; instead it was inviting tenders for up three partnerships to create for-profit private wheat breeding organisations that would generate revenue through EPRs. As result of the GRDC tender process there are currently four wheat- breeding companies in Australia. The largest is Australian Grain Technologies Pty Ltd, followed by InterGrain Pty Ltd, LongReach Plant Breeders, and HRZ Wheats.

LongReach Plant Breeders, was Australia's first commercial wheat breeder with multinational interests. It began as a joint venture between the producer-controlled Australian Wheat Board and Syngenta in 2002, who choose not go into partnership with the GRDC. Syngenta Seeds purchased the AWB share of Landmark in 2006 and in late 2007 Pacific Seeds purchased a majority share in the company from Syngenta. As of 2011, LongReach was the third-largest wheat-breeding firm in Australia with 10 employees (LongReach, 2012).

Australian Grain Technologies (AGT) was established in 2002. The original shareholders of the AGT were the GRDC, the South Australian Research and Development Institute (SARDI), and the University of Adelaide. AGT licensed the majority of the former Victorian Department of Primary Industries' (DPI's) wheat-breeding germplasm. In 2005, AGT merged with SunPrime Seeds Pty Ltd. to become a fully integrated wheat breeding and Commercialization Company. In 2007, AGT started partnership with the Council of Grain Grower Organizations. In July 2008, Vilmorin & Cie, which is a wholly owned subsidiary of Limagrain Holdings, purchased a 25 percent shareholding in AGT (AGT, 2012). AGT is currently the largest breeding firm in Australia with 48 full time employees, breeding a wide range of crops with research operations in five states (AGT, 2012).

InterGrain Pty Ltd was formed in October 2007 with GRDC owning 30% of the shares and the Government of Western Australia owning 70% of the shares. This new Corporation took over the wheat-breeding activities of the Department of Agriculture and Food, Western Australia (DAFWA), transforming a government crop-breeding unit into a commercial company structure. InterGrain was assigned all DAFWA breeding material and associated Intellectual Property (IP) for current and future commercial wheat varieties. InterGrain's current wheat-breeding programs target Western Australia, South Australia, Victoria and New South Wales. InterGrain has developed an alliance with Nuseed, which is a subsidiary of Nufarm, for the production, sales and promotion of its varieties. InterGrain and Nuseed provide rapid access for growers to new varieties and have established an on-line trading site (www.seedpool.com.au) to facilitate farmer-to-farmer trading. As a result of the Nuseed alliance, InterGrain has also obtained access to some of the former Victorian DPI wheat-breeding germplasm (InterGrain, 2012). On August 2010, Monsanto joined DAFWA and GRDC as a minority shareholder, owning 19.9% of the shares. At present, Monsanto has 19.9% of the InterGrain shares but has the option to increase to 26%. As of 2011, InterGrain was the second largest breeding firm with 30 employees (GRDC, 2012).

The smallest breeding firm with GRDC shareholding is HRZ Wheats Pty Ltd, which was established in 2003. The firm has specialized in developing milling-quality wheat targeted to the high-rainfall zone (HRZ) of Australia. The shareholders of HRZ Wheats are the Commonwealth Scientific and Industrial Research Organisation (CSIRO), New Zealand Plant and Food Research, the GRDC, and Landmark Operations Ltd. In September 2011, Dow AgroSciences Australia Ltd announced an equity investment in HRZ Wheats Pty Ltd (CSIRO, 2012). HRZ Wheats is a small firm with five full time employees (GRDC, 2012).

Table 1: Major Wheat Breeding Corporations in Australia 2010

Australian Grain Technologies Pty Ltd **Location and staff:** Adelaide, Narrabri, Dubbo, Horsham, Roseworthy, Esperance, Perth: 48 full-time employees. **Shareholders/owners:** Vilmorin & Cie (Limagrain), SARDI, University of Adelaide, GRDC (39%). **Breeding program:** Five wheat breeding programs for varieties adapted to different agronomy/growing conditions and soils including daylight length, temperature, soil type, diseases and specific regional quality needs.
HRZ Wheats Pty Ltd **Location and staff:** Canberra and Lincoln (New Zealand): equivalent of 5 staff under contract with CSIRO and New Zealand Institute for Plant and Food Research (NZPFR). **Shareholders/owners:** CSIRO, NZPFR, Landmark Operations Ltd, GRDC (40%). **Commercial partner:** All HRZ varieties are marketed through AWB Seeds. **Breeding Program:** International and national gene pools; spring wheats and winter wheat's; hard milling wheats.
InterGrain Pty Ltd **Location and staff:** Perth, Wongan Hills, Melbourne, Horsham: 30 staff. **Shareholders/owners:** WA State Government, GRDC (35%), Monsanto. **Commercial Partner:** All InterGrain wheat varieties are marketed through Nuseed, www.seedpool.com.au. **Breeding program:** Three regional breeding programs servicing WA, SA, Victoria and NSW; a specialist program provides support in fast-tracking disease resistance and elimination of critical defects; and a research and development program in collaboration with Monsanto to increase the use of genotypic technologies in the core breeding programs.
Longreach Plant Breeders Pty Ltd **Location and Staff:** Narrabri, Clare, Melbourne, York, Adelaide: 10 staff. **Shareholders/Owners:** Pacific Seeds Pty Ltd, Syngenta. **Breeding Program:** Breeding for four distinct regions, plus breeding alliance for soft wheats

Source: GRDC 2011.

When EPR rates for new varieties increase over time and newer varieties are adopted over time, the revenue generated from EPRs can rapidly increase. Figure 2 is a scattergram of the EPR rates (Australian dollars per ton) for varieties plotted against their year of release. This shows a strong upward trend with the most recent varieties having EPR rates of A$3 per ton or higher.

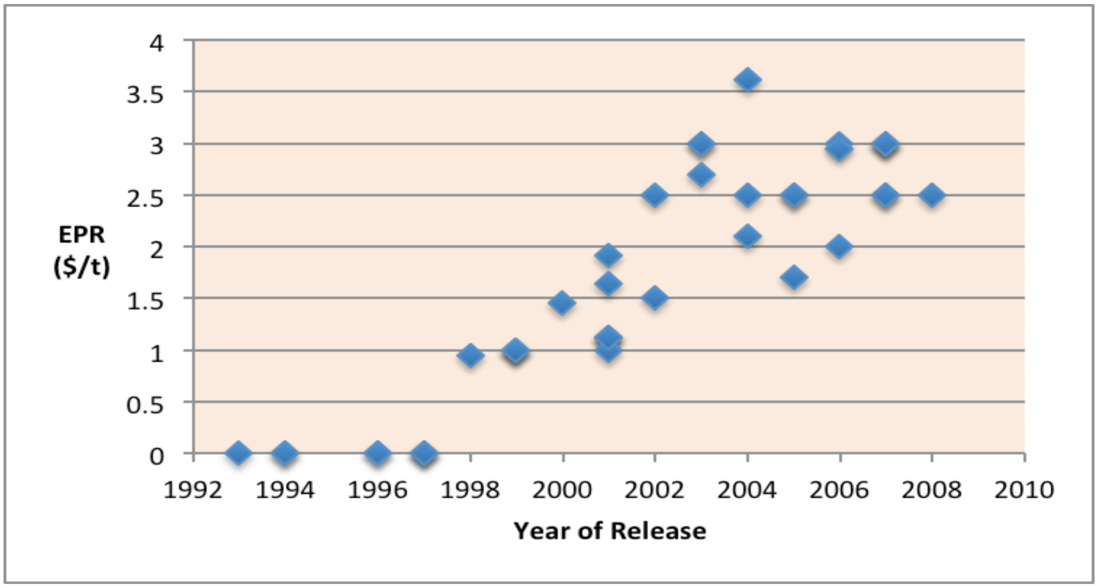

Figure 2: Average EPR Rates (A$ per ton) for Wheat Varieties by Year of Variety Release

Source: SeedVise, 2011

Figure 3 shows annual measures of the royalties collected by the variety owners, expressed per ton of wheat produced in Western Australia (WA), estimated by combining data on EPR rates and adoption, by variety. This Figure shows that the industry EPRs have increased from an average of less than A$0.50 to over A$1.00 per tonne in a six-year period. As the process of variety adoption continues, and the EPR rates for new varieties increase, the average royalty rate and revenue will increase steeply. Given the recent trend in EPR rates and much larger production, EPR revenue for the 2011/12 crop year should easily exceed A$15 million in WA, which is about double the 2008 record.

At this point is clear that EPRs have become a very significant source of revenue for the youthful private wheat-breeding industry in Australia. Given the upward trend in EPR rates and the adoption lag, this revenue stream will certainly grow in the short term and will address the underfunding of research in the wheat sector. It is little wonder that the Australian firms were able to attract foreign investors. Looking forward, the increasing revenue stream begs the questions of "How high will EPR rates be set in the future?" and "If these firms become profitable, how this outcome be received by producers and governments who are making investment decisions?" While there is consensus that EPR rates will increase in the near term, it remains to be seen how high EPRs will eventually go. Will Australian wheat follow the path of the hybrid seed industries, will the government intervene, or will the presence of public and GRDC share-holding change the behaviour of the industry?

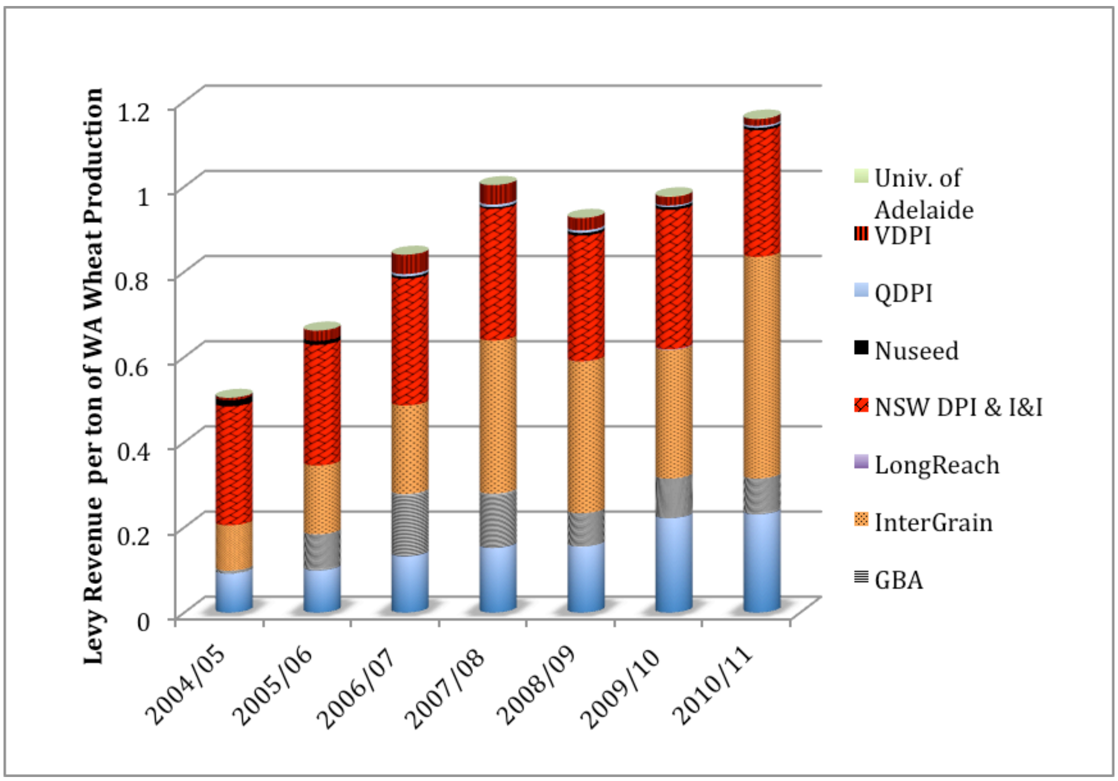

Figure 3: EPRs per ton of Wheat Produced in western Australia, by Owner

Source: Authors' calculations based on EPR rates and DAFWA reported variety adoption rate

4.2 End-Point Royalties in France

France has a significant seed industry with a wholesale seed trade of $3.2 billion (2.4B Euro) in 2009/10 (GNIS, 2012). Fifty-five percent of seed revenue comes from corn, sorghum, and vegetables, where the IPRs are strong. With 14% of sales, small grains and pulses (dominated by bread wheat) were the third-largest category of seed sales in 2009/10 (GNIS, 2012). While most seed categories have a large share revenue from exports, 96% of small grains and cereal seed was produced for the domestic market.

LimaGrain (a French producer-owned cooperative), is the second-largest seed company in the world, and plays a leading role in the domestic seed industry. For total seed sales, Limagrain's sales values are followed by RAGT Seeds, Syngenta, Monsanto and Pioneer. LimaGrain is also the number one producer of wheat seed in the EU. RAGT Seeds, which recently signed an IP sharing agreement with Bayer Crop Science, is also an important player.

INRA, founded in 1946, is a public research institution under the joint authority of the Ministry of Higher Education and Research and the Ministry of Food, Agriculture and Fisheries. With a 2008 budget of nearly $1.2 billion dollars, and over 1,800 scientists, it is the second-most published agricultural research institution in the world. INRA actively partners with universities and other public research institutions, and is directly involved in the education of 1,800 Ph.D. students. In 2009, INRA had over 200 research contracts with private companies, and participated in over two dozen research clusters (INRA, 2012).

INRA is involved in the full spectrum of crop research, from basic science to variety development. INRA is currently leading an international project to map the bread wheat genome. In 2008, 52 new plant variety licences were granted by Agri-Obtentions, which is INRA's subsidiary in charge of the commercial development of new plant varieties (INRA, 2012).

Despite some success in commercialization, INRA does not focus on wheat cultivar release. Only when the development of a new trait results in a wheat genotype suitable for release as a cultivar is the cultivar commercialized through Agri-Obtentions (DePauw, 2008). Wheat breeding is mainly carried out by the private sector. However, Limagrain, which plays the dominant role, is a farmer-member cooperative, giving producers some voice in wheat breeding.

France is a member of UPOV (Union for the Protection of New Varieties of Plants) and is compliant with UPOV 1991. Most grain varieties are protected by a licensing management system called SICASOV (Société coopérative d'intérêt collectif agricole des sélectionneurs obtenteurs de variétés végétales), which collects seed royalties and licenses authorized users of the plant patents.

The current royalty system used to fund wheat research in France first came into operation in 2002, following a long period of discussion between farmers, breeders and government. The royalties are collected in two parts. First, farmers are subject to a private royalty paid on purchased commercial seed or a royalty on farm saved seed of 68.8 Euros per tonne. Second, all wheat sales are subject to an EPR paid at the first point of sale.[7]

The EPR was established in July 2001. The levy is a uniform 0.5 Euros per metric tonne of wheat delivered by the farmers to an end-user. The levy is collected by grain handling companies at the time of delivery. SICASOV allocates royalties among breeders according to their market shares, reserving 15% of the total collected for variety testing. Notably, these levy rates, and implicit EPR rates are uniform across varieties,

[7] A rebate of EPRs equal to 20 Euro per ton of certified seed is paid to farmers who have purchased certified seed.

which reduces collection costs and eliminates any producer incentive to mis-declare varieties. The royalty rates are negotiated between industry and government, which limits the ability of seed companies to profit from variety sales. The EPR rates of 0.5 Euros per ton are also low and provide only a modest amount resources for research funding. This low EPR rate could be the result of a collective action problem of the type that levy-funded research can face, as discussed later in this report.

5. Levy-Funded R&D

Levy-based funding is used in several countries as a mechanism to finance the provision of agricultural R&D, in particular for R&D related to particular commodities for which the output from the investment can be seen as a commodity collective good rather than a public good with benefits to the broader community. In this section we explore in-principle economic arguments pertaining to this approach to providing agricultural R&D and present evidence on how well levy-funded programs work in practice, as a basis for discussing the potential for a substantial increase in the use of levy-based funding for agricultural R&D in North America. Since the most-developed examples of this approach can be found in Australia, the discussion here draws heavily on the Australian experience, but some attention is also paid to counterparts in California and Canada.

5.1 In-Principle Arguments

Levy-based R&D programs are made possible by government policy through the application of the government's coercive taxing powers to collect the levies, the exemption of levy programs from some types of anti-trust regulations, the use of government resources to develop and implement the programs, and, in some cases, the provision of government funds to support them. Hence, it is appropriate to ask how closely do program decisions correspond to those that would maximize national economic welfare, and how are the benefits and costs distributed among different groups in society.

Implicitly, when governments introduce levy-based programs they must be seen as a fairer or more-efficient solution than any of the alternatives, including laissez faire. One efficiency argument in favor of levy based funding is that it is cheaper than general government revenues. In the absence of other distortions, the marginal social cost of revenue raised using a commodity tax of less than one percent is close to one dollar per dollar, whereas the marginal social cost of general government revenue is significantly more than a dollar, perhaps $1.20 per dollar, owing to the deadweight costs of general taxation (e.g., Ballard and Fullerton 1992).[8] A commodity tax is even more efficient if the country has market power in trade, and therefore can shift some of the burden onto foreigners, such that the marginal domestic cost of funds is less than one dollar per dollar. A commodity tax might also be fairer in the sense that the costs are borne by the producers and consumers of the same commodity, who would be expected to benefit from the subsequent expenditure, rather than general taxpayers.

Cost of funds is only one element of efficiency; another is how effectively the funds are spent. Similarly, fairness extends beyond the distribution of benefits and costs among taxpayers, consumers of the commodity as a group, and producers as a group, since there are distributional impacts within these groups as well. The two elements are related, since distributional impacts determine incentives. Decisions about the size of the

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[8] The deadweight loss from taxation as a share of the revenue raised is proportional to the square of the tax rate and is virtually zero for a tax rate of one percent (e.g., see Alston and James 2002).

programs (the tax rate and thus the amount spent) and the balance among alternative investments may be dominated by the interests of a subset of producers (sometimes including first handlers), and should therefore not be expected to coincide exactly with the national interest, or even with the interests of all producers. Hence, whether a program is in fact fairer and more efficient than laissez faire depends in complicated ways on the distributional aspects.

Commodity levy programs have implications for the welfare of consumers, producers, and taxpayers in addition to their effects on those producers who are allowed to vote on the programs.[9] From a public policy perspective, these implications for others ought to be considered in the design of the enabling legislation and the operating rules, and in the evaluation of the specific programs. Similar issues can arise among producers within a levy program, with the main difference being that all those within a program are allowed to vote even if they cannot always have their preferences followed.

The distribution of the costs of funding a particular activity and the benefits resulting from it allow for a comparison of the privately and socially optimal funding of that activity. If the producer group that comprises the constituency of the levy program bears a higher share of the costs than the benefits from a levy funded activity, then the levy program is likely to undersupply that activity, from a national perspective. Conversely, the levy program is likely to oversupply activities for which the producers bear a lower share of the costs than the benefits. In other words, producer groups are likely to overinvest in those activities for which a higher proportion of the costs can be

[9] This section draws heavily on Alston, Freebairn, and James (2003, 2004) who examined determinants of the producer and national benefits from levy-funded research and promotion programs, and the distribution of benefits and costs of both the expenditures made under the programs and the levies used to finance them.

shifted onto others (e.g., consumers, taxpayers, input suppliers, and consumers or producers of competing products).

5.2 Determinants of the Distribution of Benefits and Costs

Assuming for the moment that an aggregative model (i.e., a model of a single commodity, with no vertical or horizontal linkages) is appropriate, it is clear that the producers' share of costs and benefits depends on the magnitude of the supply or demand shift induced by the levy funded activity. Less obvious, but critically important, is the nature of the research-induced innovation and the resulting commodity supply shift as a determinant of the producers' share of the costs and benefits. A parallel shift in supply induced by levy-funded research implies that the producers' share of the costs is equal to their share of benefits, and so there is no distortion in the incentive to invest in research activities. In contrast, when levy-funded research induces a pivotal shift in supply, the producers' share of the costs of the levy is greater than their share of the benefits, and so that activity will be underfunded from a national perspective.[10]

Distortions in commodity markets change the distribution of the benefits from research and thus the incentives to invest in them. Government commodity programs may mean that producers pay a disproportionate share of the costs (relative to their share of benefits) from a levy-funded activity, creating an incentive for the levy to over- or under-invest in that activity. Similarly, the exertion of market power by agribusiness firms may distort the incentives for levy-funded investments in research, in addition to distorting the allocation of resources in production and consumption. Distortions have

[10] Specifically, as shown by Alston, Freebairn, and James (2003, 2004) the ad valorem levy rate (or research intensity) that would maximize national benefits in this case is equal to one-half the counterpart that would apply in the case of a parallel supply shift, and is greater than the levy rate that would maximize producer benefits, unless demand is perfectly elastic (if demand is inelastic, or supply is more elastic than demand, the producers' optimal levy is zero).

significant effects on the distribution of benefits. Hence, in relation to levy-funded research, distortions will have important implications for resource allocation and should be treated as first-order considerations. In contrast, for government-funded research, changes in the distribution of benefits might reasonably be regarded as second-order.

Measures of producer welfare in single-market models aggregate the welfare of suppliers of all inputs used in production, and may mask important distributional implications of levy-funded activities. In order to compare private and social optima, producer welfare measures must be defined in terms of the benefits and costs accruing to constituents of the levy program, who determine the allocation of the levy funds. An appropriate measure of producer benefits will often require vertical or horizontal disaggregation.[11] Vertical disaggregation, among participants across stages of the production and marketing chain, allows us to measure benefits accruing to suppliers of particular inputs used in production or processing of the levy commodity, as well as final consumers and, in some cases, taxpayers. When inputs may be used in variable proportions, the farmers' share of the costs of a levy applied to the farm product is greater than their share of the benefits from research applicable at previous or subsequent stages.

Similarly, horizontal disaggregation allows us to measure the distribution of benefits and costs either between producers of the commodity covered by the levy program and producers of related commodities, or among producers within a program covering commodities that are differentiated in space, time, or form. When producers of different qualities or categories of the same basic commodity bear different shares of the

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[11] In the case of internationally traded goods, a disaggregated approach is necessary to obtain a meaningful measure of national impacts.

benefits and costs, certain levy activities may be over- or under-supplied, even from the perspective of the levy constituents.

The issue of (perceptions of) the distribution of benefits and costs among different producers of the same commodity is likely to be of primary importance in determining the effectiveness of a particular levy-based program. For instance, those producers who do not adopt the new technology resulting from levy funded research will not benefit but they will help pay for the research; and they may lose even more, if the research results in a lower price for their product. The producers paying the levies may live (and produce) in a very different place and at a very different time than the producers reaping the benefits from the levy funded activities. The temporal dimension is less important for promotion than in relation to levy-funded research for which the research lags are very long, especially for livestock and perennial crops. The incidence of the tax is immediate, whereas the incidence of the benefits from research may take 20 years or more to become felt. Only in the best of all worlds is it likely that the current levy payer will be entirely convinced that the future benefits—to be collected by his successors—will be capitalized fully into his current asset values, and that the temporal aspects of agricultural R&D are irrelevant in the issue of who benefits relative to who pays. For this reason, levy-funded research may be less oriented towards longer-term projects than efficiency would dictate.

A related issue is the distribution of benefits and costs among producers of different commodities. In some cases the different commodities may be covered by a single levy program and in some other cases by competing programs; and in other cases again, some commodities may be covered while others are not. In any of these instances, there will be divergences between the incidence of costs of a levy and the benefits from research, and between the national optimum and the objectives of managers of the levy funds. Levies and the programs they fund often will have spillover effects on the prices and quantities and economic surpluses of producers and consumers of other commodities. Interdependencies of product demand or supply mean that price changes for a particular product shift the demand and supply curves for substitute and complementary products resulting in changes in prices (and quantities) for these other products, and price feedback effects, adding complications to the welfare effects. In addition, R&D oriented to one product may give rise to technology that can be used by producers of other products. In seeking to maximize benefits for their producer constituents, managers of levy funds can be expected to ignore cross-commodity welfare impacts, so that their incentives will diverge from the interests of the broader society.

Given the role of democratic processes in setting the levy rate and research priorities, levy-funded programs are likely to underfund particular types of research, and to underfund commodity-specific research overall, from the perspective of the producer group. Specifically, there will be a tendency to underfund activities for which the benefits are confined to a narrow subset of producers, even if those activities are the most profitable for producers as a group, and to fund instead activities for which the benefits are more broadly shared among the constituents. This exchange of efficiency for equity will in turn mean that the return to the total portfolio is diminished, and thus the total investment is smaller than the amount that would, if allocated among investments to do so, maximize the total payoff to producers.

5.3 Forms of Levy-Based Funding and Incentive Effects

The arguments presented above provide a variety of reasons for expecting that a simple levy-based approach is likely to fail to provide the quantity and mix of research investments that will maximize benefits either for the producers in the industry from whom the levy is being collected or for the nation as a whole. This seems likely to be especially so in the case of "voluntary" or "refundable" levies under which producers may opt not to pay a levy or may opt to request a refund of levies they have paid. In many past instances, voluntary programs have either failed completely because too many constituents opted to be free-riders (e.g., see Messer, Kaiser, and Shulze, 2008 on voluntary generic commodity promotion programs), or have survived only by setting very low rates of levy, as in a number of present-day Canadian research programs.

When levy-based programs are enabled jointly to fund both research and promotion programs, typically the lion's share of the funding goes to promotion, probably because it has a comparatively immediate and broad payoff (all firms enjoy the benefit of high prices from promotion-induced increases in demand, which are felt almost immediately, whereas only those firms that adopt the resulting innovations benefit from research, and possibly not until a decade or two later). This observation suggests that it might be better to establish separate funds for research and promotion.[12]

Even when the funds are separated, the observed rates of levy for funding research (and the corresponding total budgets) tend to be low relative to their promotional counterparts, a result that might reasonably be attributed to the many incentive problems identified here, in particular those resulting from diversity of interests in financing collective research investments among diverse types of producers. One option, as adopted by the Australian government, is to encourage producers to set a higher levy rate by offering them matching support to augment the funds raised by the levy.

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[12] In contrast, the Productivity Commission (2011) recommended moving in the opposite direction, and further combining funds for research and promotion under a single authority.

5.4 The Australian Rural Research and Development Corporation Model

Statutory levy-funded Research and Development Corporations (RDCs) have had a profound effect on the Australian agricultural research system. The RDCs play a pivotal role in a better-funded and better-coordinated agricultural innovation system. In Australia, historically agricultural research had been conducted and funded primarily by individual State governments. The introduction of the RDCs in the late 1980s changed the balance.[13] The RDCs have given a much greater voice to industry at the national level, while providing a mechanism for an enhanced Commonwealth government role in financing R&D, and an avenue for better coordination of activity among the States through competition for funds from the RDCs.

Australia's agricultural research system currently includes 15 RDCs, comprising six statutory corporations and nine industry-owned corporations of which all but one (the Rural Industries Research and Development Corporation, RIRDC) cover single rural industries although often these are broadly defined such as "grains" or "horticulture." The discussion here refers to these commodity- or industry-oriented RDCs in particular. In 2008/09 the RDCs were responsible for spending $490 million per year comprising $270 million from industry levies along with $220 million of matching support contributed by the Commonwealth government. Table 2 shows the details of levy income, matching government support, and spending by each of the 15 RDCs in 2008/09.

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[13] Alston, Harris, Mullen and Pardey (1999) describe these innovations and their implications for Australia's agricultural innovation system as it stood in the late 1990s. More recent discussions of these institutions can be found in the draft report by the Productivity Commission (2010) and final report by the Productivity Commission (2011).

Table 2: Sources of Income and Expenditure by Australia's RDCs, 2008/9

Rural R&D Corporation	Industry Contribution	Government Contribution	R&D Expenditure
Statutory RDCs	*A$ million in 2008-09*		
Cotton	2.4	2.4	9.4
Fisheries	9.5	16.3	27.8
Grains	89.2	43.9	121.3
Grape and Wine	13.3	11.7	26.2
Land and Water Australia	0.0	13.3	29.6
Rural Industries Research Fund	3.9	16.5	23.8
Sugar	4.3	5.1	10.3
Industry Owned Corporations			
Australian Egg Corporation	1.1	0.9	2.0
Australian Meat Processor Corp.	12.5	0.0	7.6
Australian Pork Limited	3.1	2.8	5.5
Australian Wool Innovation	22.6	11.4	38.2
Dairy Australia	14.5	19.2	33.7
Forest and Wood Products	3.6	3.7	7.7
Horticulture Australia Limited	40.9	39.8	83.2
Live Corp.	0.8	0.0	0.8
Meat and Livestock Australia	25.9	31.4	61.1
Total	*247.6*	*218.1*	*488.2*

Source: Productivity Commission (2011).

In some years, spending is greater than or less than the sum of levy income and government matching support reflecting the use of reserves. Some RDCs have levies greater than the critical rate that would represent 0.5 % of GVP (e.g., the GRDC levy is twice that rate) while others are below that critical value. In some cases the matching support is very small (where the funding is primarily for marketing activities), and in other cases the role of levies is very small (e.g., the RIRDC, which is to provide research for broader purposes). Through their funding arrangements with research providers, such as State departments of agriculture, universities, and the CSIRO, RDCs are able to leverage significant additional funding for agricultural R&D in directions supported by the RDCs and their industry constituents. Thus, although they spend less than one-third of the total directly, the RDCs have substantial influence over the entire rural R&D enterprise that spent almost $1.2 billion in 2008/09 (Keogh and Potard, 2011, p. vii).

5.5 Productivity Commission Reviews

The RDCs have been comprehensively reviewed by the Australian Government Productivity Commission since their inception, with reports published in 1995, 2007, and 2011. A recurring theme in these reports has been questions concerning the justification for the matching government support, the appropriate rate for that support, and the conditions under which it should be provided. These are reasonable questions for which compelling and answers are elusive because empirical evidence on the consequences relative to the alternatives are non-existent. Nonetheless, the Productivity Commission has made specific recommendations in this regard.

Within its broader review of Australia's science and innovation policy, the Productivity Commission (2007) concluded that the RDCs work very well as a mechanism for internalizing externalities within a defined group of agricultural producers and that, therefore, government matching grants were justified only in cases where the benefits would accrue as "spillovers" outside the producer group covered by the RDC. This conclusion is based essentially on an implicit theoretical argument (it is not presented formally) about the incentive effects of a mandatory commodity levy, an argument that applies only under certain assumptions and flies in the face of empirical evidence. Nevertheless, the same position was echoed in the subsequent Inquiry undertaken by the Productivity Commission dedicated to the issue of RDCs, which reported in February 2011. The most significant recommendation by the Productivity Commission (2011) is for a reduction in the rate of matching support to be provided by the Government from the current rate of one-to-one up to 0.50 % of GVP and zero thereafter to a lower rate of one-to-one up to 0.25 % of GVP and 0.20-to-one thereafter.

One basis for questioning that recommendation is the available empirical evidence, which suggests that the returns to agricultural R&D—whether funded by levies or taxpayers, conducted in the public sector or privately—are very high, much higher than the social opportunity cost of the funds (Evenson 2002; Fuglie and Heisey 2007; Alston et al. 2010; Alston et al. 2011). A clear implication of this evidence is that, in spite of the significant government intervention to correct the market failure in agricultural R&D, the world as a whole has continued to underinvest in it. The same conclusion applies to the research funded by Australia's rural RDCs. Benefit-cost evaluations have consistently found that the investment has paid very handsome dividends, sufficiently so to indicate a persistent underinvestment, even with well-established levy-funding arrangements encouraged by the support of matching government grants.

The RDCs have amassed a very substantial body of evidence on the returns to their investment, the results from which were summarized and interpreted by the CRRDC (2011). They reported the results from a random selection of benefit-cost assessments of 160 RDC projects undertaken over three years, 2008 through 2010, allowing different adoption horizons. Aggregating these data, they reported an average benefit-cost ratio of 5.14 after five years, 9.24 after 20 years, and 10.69 after 30 years (the corresponding median benefit-cost ratio among the 160 was 2.70 after five years, 4.50 after 20 years, and 5.00 after 30 years, reflecting the left-skewed shape of the distribution of estimated benefit-cost ratios). One can question some of the evidence, and there are grounds for suspecting a tendency for the estimates to be biased up (as noted by the Productivity Commission 2011, p. 110), but not enough to change the main finding of a very large benefit-cost ratio, which unequivocally implies persistent substantial underinvestment.

5.6 Alston and Fulton (2012): Institutional Failure and Underinvestment

The Productivity Commission (2011) failed effectively to reconcile the evidence of the apparent paradox of very high benefit-cost ratios in the presence of an institutional arrangement that had been in place for more than 20 years and was supposed to have resolved the prevailing incentive problems. Alston and Fulton (2012) set out to resolve this paradox. They present arguments and evidence to suggest that various factors in reality contribute to types of "institutional failure" such that RDCs are likely to set levy rates too low, and invest too little, compared with the rates that would maximize returns to their producer members and the nation as a whole. These issues arise from several factors including (1) diversity of producers in terms of their expectations of benefits from levy-funded research and their attitudes to the programs, (2) effective supermajority requirements that mean that industries will propose a lower levy rate to engender support from a much greater majority than 50 % of producers and which will therefore more likely to be approved in subsequent stages by the Department of Agriculture, Forestry, and Fisheries (DAFF) and the Minister, (3) information problems that arise because returns to individual producers from collective research investments are inherently uncertain, especially because of the long time lags and diversity among producers, combined with increasing scepticism generally about the effectiveness of public sector science agencies, (4) agency problems that arise because industry representatives in peak industry bodies and employees within RDCs may have interests that do not align entirely with those of their grower (and taxpayer and consumer) constituents, and (5) transaction costs (and related information costs) in that the processes of establishing levy-based programs and revising levies are very cumbersome and expensive, such that levies will be changed infrequently and only by large amounts to justify the high cost –to the extent some levies have not changed since their inception.

Diseconomies of Diversity. Agricultural producers within an industry are very diverse in characteristics (such as their age, education, farm size, farm type, location, and the like) that together determine their likelihood of adopting innovations and benefiting from them, their expectations of their likely benefits from the levy-funded program, and their attitudes to contributing to levy-funded R&D programs. It makes economic sense to encompass diverse producers within a single RDC, to capture benefits from achieving economies of scale, size, and scope (for instance, the Grains Research and Development Corporation, for example, encompasses a large number of grains grown across a wide rage of agroecological environments throughout Australia) but this come to some extent at the expense of diseconomies of diversity. One of the less-well-understood or appreciated implications is that a more diverse producer constituency will find it more difficult to agree on a particular levy rate or a particular pattern of research investments, and is likely to require more convincing and at greater cost of investment in supporting evidence and communication to increase the levy rate.

Long Lags. In addition to issues of producer heterogeneity, the temporal dimension of agricultural innovation is particularly important for levy-funded research because typical research lags are very long. The incidence of the tax is immediate, whereas the benefits from research typically flow many years later. Only those producers who adopt the innovation stand to benefit, though all will pay their share of the levy. Given the long time lags and spatial specificity of many agricultural innovations, the producers paying (most of) the levies may live and produce in a very different place and at a very different time compared with the producers reaping (most of) the benefits from the levy-funded activities. Moreover, because research funded by a levy today yields uncertain benefits over an almost indefinite horizon, different individuals may perceive a given potential stream of benefits differently. Farmers may also differ in the extent to which they discount uncertain, distant future prospects. Diversity among producers in these various aspects can give rise to significant differences among producers in their views about the optimum that are not captured by the simple model used by Alston, Freebairn, and James (2004) nor the assumptions of the Productivity Commission.

Transaction Costs. As discussed and documented by the Productivity Commission (2011, pp. 259-262) it is very costly and takes several years of effort to change levy rates. Further, it is risky: many steps in the process require justifying the continuation of the program to enable a change in the rate within the given program; trouble could arise at any step, each of which involves some degree of political consensus or specific majority support. The fact that review and revision of levy rates is costly, time-consuming, and risky has implications for both the frequency with which industries with RDCs will find it worthwhile to propose an increase in the levy rate and the size of the increase they will propose.

Supermajority Requirements. In addition, and partly for related reasons, it seems likely that a very substantial supermajority of producers will be required to support any specific proposal for change, and an expectation of widespread support will be required before any proposal for change is made. The minimum legal requirement for changing a levy (or for establishing a levy *de novo*) is that the proposal is supported by a simple majority of the industry (defined as a 50 % plus one of the producers who chose to vote in a "one vote per producer"' ballot, or 50 % of production plus one producer of those who chose to vote if the ballot is based on production). It seems likely, however, that proposals supported by the bare minimum of just half the industry would not pass easily through the subsequent sequence of DAFF, Ministerial, and Parliamentary approval processes. Indeed, even proposals supported by a large majority of producers might be expected to run into trouble at some point if they were opposed strenuously by some parts of the industry.

Informal discussions with managers of RDCs, representatives of DAFF, and others leaves us with a clear impression that proposals for changes in levies are typically conducted with a view to having very broad support from within the industry. Hence, while the minimal *legal* requirement is for support from a simple 50 % majority, the constraints and political peculiarities of the DAFF, Ministerial, and Parliamentary approval processes imply an informal *political* requirement for support from a supermajority much greater than 50 %. Moreover, reflecting the principal-agent problem mentioned above, risk averse or otherwise rationally self-interested leaders of peak industry bodies and RDC managers may have a *managerial* requirement for an even larger supermajority (if the consequences to them personally may be asymmetric between a failed proposal versus a successful one).

The size of the required supermajority is a matter for conjecture and is likely to vary from RDC to RDC, or within an RDC over time, depending on the nature of the diversity of interests within the body, the particular preferences of politically powerful individuals within the industry, and the mood and disposition of the administrators in DAFF and the Minister, which may depend on the economic and political circumstances of the time. Anticipated support in excess of 75 % may be required to initiate what can be an extremely costly process.

The implications of the work by Alston and Fulton (2012) are several. First, in the design of levy-based programs for funding agricultural R&D, effort should be spent to minimize the factors they have identified that contribute to institutional failure and underinvestment. Second, even if those factors have been effectively minimized, it seems likely that matching government support will be required to engender the required enthusiasm within the industry for establishing a program and to encourage producers to support levy rates that are closer to the rates that will maximize benefits for the industry and the nation as a whole. Third, continuing attention to such design features will be required as circumstances change or as the institutions evolve autonomously, as illustrated by recent changes in the Australian RDC setting.

5.7 Evolving Private-Public Partnerships within the RDC Framework

The GRDC is the largest of the RDCs and by some measures the most accomplished. Its role has evolved over its 25-year history. Relatively recently, the GRDC was instrumental in the creation of market-oriented firms for the commercialization of wheat breeding. The result is a cereal innovation system making an investment of over $20 million per year in pre-breeding research and $60 million in largely private wheat-breeding activity (GRDC, 2010), which is about four times the current Canadian wheat breeding expenditure, even though Canadian wheat production is around 26 million metric tons compared with around 22 million metric tons in Australia (2009 figures). Furthermore, as Australian EPRs inevitably increase in importance over time this rate of investment will grow considerably.

While the funding system appears to have preserved and even increased Commonwealth support for agricultural research, it failed to prevent and may have exacerbated a decline in the State government commitment to research investment, with especially pronounced reduction in some States.[14] The additional funding from RDCs may have served to crowd out some State government finding. At the same time, the RDC framework did not eliminate the pre-existing duplication of effort and fragmentation of research infrastructure and, because of the incentives in the competitive grant structure, may even have encouraged some duplication of effort and fragmentation.

5.8 The National Framework

The "National Primary Industries Research, Development and Extension Framework" was introduced recently as part of a national strategy, aiming to facilitate cooperation and coordination among the State and Commonwealth government agencies with the RDCs in agricultural innovation. This reform was introduced in the face of

[14] Typically the RDCs would provide operating funds to research providers, such as State government agencies, which provided capital and salaries of scientific staff. In this way, the GRDC was sometimes able to obtain leverage over the use of State agricultural agency funds. Project cost-sharing arrangements were commonplace, whereby the State agency would supply 60 percent of a project's funding in order to secure the remaining 40 percent from the GRDC. Despite this leverage, State government expenditures have declined over time.

perceived weaknesses in the evolved form of the "Kerin Plan"—in terms of wasteful competition for resources, duplication of facilities, and failure to capture economies of size, scale, and specialization—and in the face of ever-tighter research budgets. It is still too early to tell how well the strategic plan for grains will be put into practice. This reform was developed under the shadow of a Productivity Commission inquiry that threatened to propose reforms to the funding structure of the RDC model by eliminating the matching Commonwealth government support for industry-specific research—as epitomized by the varietal improvement R&D undertaken by the GRDC.

5.9 Summary and Conclusion

In summary the main perceived strengths of the RDC system include:

- greater total research funding, with an increase in funds from both the industry (through the levy) and the Commonwealth government (through its matching support);
- hence, a smaller shortfall relative to the amount of funding that would generate maximum national and producer benefits;
- as a consequence, greater net benefits to the nation and to producers as a group;
- more efficient (lower cost) funding compared with 100 percent funding from general taxpayer revenue;
- fairer funding (in the sense that costs are borne more-nearly in proportion to benefits compared with the use entirely of general revenue funding based on income taxes);
- greater industry voice in the allocation of research funds, with potentially more-efficient research resource allocation as a result compared with a model in which resources are allocated according to interests of scientists or bureaucratic process;

- greater national coordination while retaining regional voices; and
- enhanced capacity for public-sector researchers to work with the private sector.

The main perceived weaknesses of the RDC system include:

- it may have contributed to the withdrawal of State government funding for agricultural research, especially by crowding out State-funded varietal improvement research;
- it may have exacerbated unnecessary duplication of research effort, though this effects is hard to measure and it is hard to know how much interagency competition is desirable or what form it should take;
- producer-dominated boards might prefer a research portfolio emphasizing projects with a lower national benefit but a higher benefit to producers (e.g., with smaller environmental spillover benefits) or a more-immediate benefit to producers (i.e., with shorter research lags or less uncertain payoff);
- the RDC management might prefer a research portfolio emphasizing projects with a lower national benefit but a distribution of benefits among producers that is more satisfactory to a larger majority (e.g., choosing a range of projects that will yield benefits in every State even if the total benefits would be smaller than a set of projects with more spatially concentrated benefits);
- the institutional design and administrative requirements may impose onerous burdens on the industry and government that have implications in turn for the total investment and the efficiency with which the funds are used;
- in spite of matching government support, rates of investment remain too low, as evidenced by high benefit-cost ratios;

- the requirement to use essentially political processes, through plebiscites, to establish or revise levies gives rise to a number of undesirable aspects relative to a theoretical ideal, including (a) costly processes (for communicating with growers or demonstrating benefits to growers and government), (b) incentives to distort the research portfolio away from the benefit-maximizing allocation, (c) effective supermajority requirements with their consequences for levy rates.

6. Lessons and Options for North America

The high returns to agricultural R&D have been extensively documented by hundreds of studies (e.g., see Alston et al. 2000; Evenson 2002; Fuglie and Heisey 2007; Alston et al. 2010; Alston et al. 2011). The overwhelming evidence of high returns implies persistent underinvestment in spite of extensive government intervention—a type of government failure in that policies have failed to overcome the market failure in agricultural R&D. Paradoxically, although the evidence of persistent underinvestment is very clear governments have become increasingly reluctant to make adequate investments in productivity-enhancing agricultural research. As documented by Pardey and Alston (2011), especially in the high-income countries, such as Australia, Canada and the United States), we have witnessed a progressive slowing in the rate of growth and in some places a decline in real public (and possibly also private) spending on agricultural R&D, in particular R&D oriented to enhancing farm productivity. The waning of government support for agricultural R&D has exacerbated the underfunding of research, especially in areas of research where the private sector plays a limited role. Given the increasing challenging fiscal environment it is unlikely that governments will reverse a pattern of underinvestment that has persisted for decades.

Unless some other mechanism can be found to enhance the rates of investment in agricultural R&D in North America, the implications will include (1) a significant foregone opportunity for economic growth and net economic benefits both at home and abroad, as other countries receive spillover benefits from North American innovations, (2) a slower rate of productivity growth compared with the recent past and compared with other countries (especially China and Brazil) that have accelerated their rates of research investments, (3) consequently, a progressive reduction in international competitiveness, as a result, (4) higher global trend prices for food and fiber commodities with implications for global food security and poverty concerns, (5) increased pressure on the natural resource base at home and abroad as producers strive to straddle the productivity gap.

In this paper we explore two other potential pathways to increase investment in agricultural research, with a particular focus on non-hybrid, non-GM crops where research funding has been especially meagre. We examine the role of levy-based research and IPR induced private research, from both conceptual and empirically based perspectives. We draw heavily on the experience in Australia, which has been able to significantly increase the funding for wheat research through the use of EPRs and research levies. We conclude that public, levy-based and private research funding can each play important and distinct roles in an agricultural innovation system and that mixed approach to research investment is needed is address the underfunding of research in an efficient manner.

6.1 The Theory of Research Funding

Economic theory would suggest that public, levy-based, and private research investments could each play distinct, perhaps complementary, roles and functions within a modern agricultural knowledge system. Given the high opportunity cost of public expenditures, the role of public funding can be confined to activities for which levy-based and private research are not applicable or do not have the incentives to adequately invest in research.

When the value of research can fully captured by the innovator either through technology or strong IPRs, a private firm has the incentive to invest to the point where the private marginal benefits of research is equal to private marginal costs. The resulting investment will be equal to the socially optimal amount if the relevant IPRs are complete and there are no spillovers of knowledge or other spillovers. In many cases IPRs are not complete and knowledge does spillover to create benefits for other firms in the industry or for the broader public in general. In such cases private firms will have inadequate incentives to make socially optimal investments, an unsatisfactory outcome that can be remedied with stronger property rights or some form of subsidy or tax that better aligns private and social cost.

The non-rival nature of knowledge adds a significant complication to the role of the private sector in research. Knowledge, once protected by IPRs, becomes a toll good, creating economies of size and scale for industries using knowledge in their production processes. The result is that private research is toll good industry, with strong forces for consolidation and ultimately a requirement for firms each to have enough market power such that it can price above marginal cost. The higher prices impede the adoption of the research products. With some forms of IPRs, the prices may escalate over time. In addition, any duplication of effort or fragmentation of knowledge will increase industry costs. These complications suggest that strong IPRs are at most a second-best solution to underfunding.

Levy-based research is generally enabled through some form of legislation that allows an organisation to collect a levy on product sales for the purposes of investing in research. This research funding structure has at least three advantages. First, the organisation has the ability to fund research that creates industry public goods, even when it is not possible to have enforceable IPRs for the output—for instance, agronomic research or varieties that are not protected by IPRs. Second, the industry organisation gives voice to type of knowledge demanded by the industry. Third, the non-rival research output can be priced at its (near zero) marginal cost, which accelerates adoption. These are democratic organisations, in industries with very diverse constituents, which often have implicit or explicit supermajority rules of governance such that levy rates are proposed and implemented only if a very large majority of growers are in favor. As a result of these characteristics, and other real-world features of collective action programs, the levy rates tend to be set well below the rates that would maximize industry and national benefits. In other words, institutional arrangements for levy-based funding are at best only a partial solution for the underfunding problem.

Public research investment has distinct role in creating knowledge that has value to the general public, beyond the benefits to a specific industry or to private interests within an industry. Basic discovery based research, or applied research designed to solve a public health or environmental problem would fall into this category. Government funding has historically been used to fund research where the lack of levy funding or the lack of IPRs has created a market failure. As evidenced by persistent high rates of return, and the waning level of support this use of public money as a supplementary or secondary source of support is unlikely to address the chronic under-funding.

6.2 Research Funding in Practice

In our assessment the primary choices before policy makers in North America are to:

a. maintain the status quo in research funding
b. stimulate private research through EPRs
c. enable the creation of research levies with matching support
d. introduce a combination of b. and c. above.

a. Maintain the status quo in crop research funding

Maintenance of the *status quo* has very different implications for the different industries. Non-hybrid and non-GM crops (e.g., wheat, barley, and pulse crops), which currently lack strong IPRs, have very little private research investment compared to those crops where IPRs are strong. Figure 4 provides a comparison of research funding intensity of wheat in Australia, versus wheat in Canada, canola in Canada and corn in the United States.

Wheat research in Canada, which is only protected by Plant Breeders Rights, generates very limited seed royalties and has virtually no private research investment. The Western Grain Research Fund is financed by refundable levy of $.30/ton (approximately 0.15 % of value). The Government of Canada provides the bulk of the wheat research funding. The result is a total research investment of about $20 million per year, which, for a crop having $5 billion in sales, represents a research intensity of less than 0.5 % of gross sales.

In contrast, wheat in Australia, where firms can collect end point royalties, and producers pay a research levy of 1 % gross sales matched 0.5 % by government, the research funding is much higher with total intensity of over 2 %. The research intensity for canola is also close to 2 %. In this industry private research investment makes up the bulk of the research expenditures, supported by a refundable producer levy and government support for per breeding activities. Notably in this industry producers pay nearly 10 % of their gross canola receipts for canola seed each year and about 10 % of this amount gets reinvested in research. Corn in the United States, also based on well-protected hybrid technology has similar seed pricing and research intensity ratios. Notably the Australian wheat research system provides a greater overall research intensity at a much lower cost to growers.

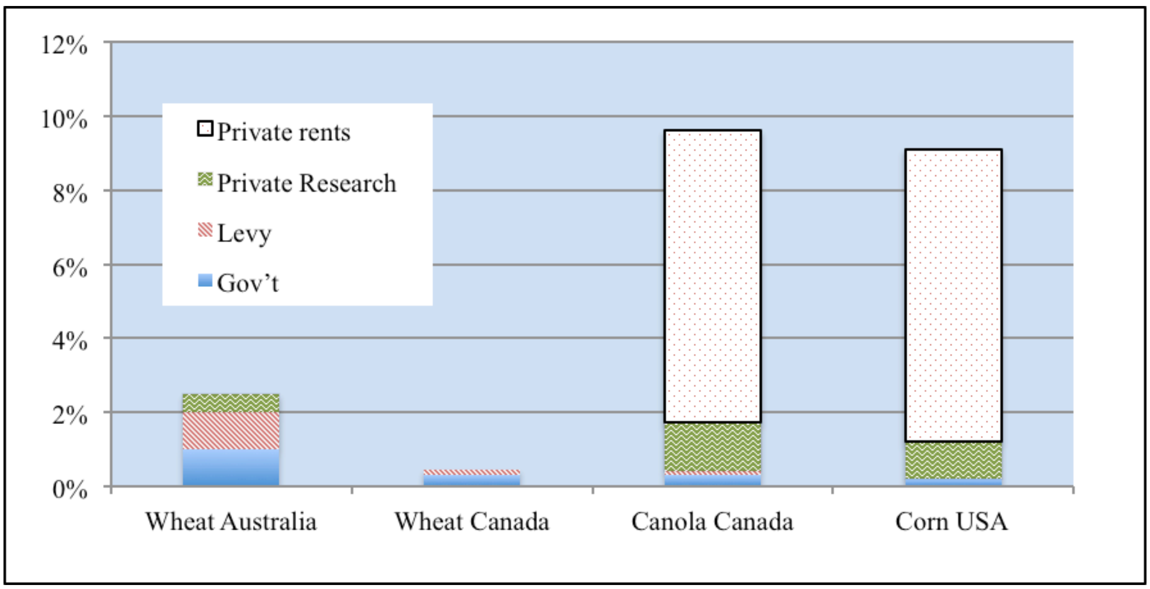

Figure 4: Comparison of Research Intensity Across Funding Regimes

The difference across crops is also illustrated by comparing seed sales of hybrid corn versus wheat and rice at the global level. Fuglie et al. (2011) reports that corn, which was planted on 168 Mha (FAS, 2012) made up 25 % of seed sales, whereas wheat, planted on 222 Mha (FAS, 2012) had only 4 % of seed sales, and rice, planted on 160 Mha, only had 1 % of seed sales. Fuglie et al. (2011) also report that globally corn makes of up 45 % of global private seed biotech research. Thus seed revenue has attracted research investment.

In the case of wheat, if the *status quo* is maintained, IPRs could eventually come from the introduction of GM wheat. In the past two years, several firms have started up wheat research programs in North America, perhaps anticipating a change in policy. However, without the introduction of GM that would enable patenting, the ability to extract value from private wheat breeding will remain limited. For smaller crops such as barley and peas, the probability of GM introduction is even more limited.

The *status quo* option would most likely perpetuate a lack of funding for crops with weak IPR or other characteristics that contribute to their research orphan status, and a resulting lack of innovation and productivity gains. This will erode the productivity and the competitiveness of these crops over time, resulting in reduced area grown and reduced production, and higher prices. The lack of investment will create greater opportunities for competing crops and competing countries to meet the growing market demand. The main enduring consequence will be a progressive reduction in food security and competitiveness, a challenge that will grow over time.

b. Stimulate private research through EPRs

Governments in North America could stimulate private research by introducing legislation that would enable breeders to collect EPRs, and would be consistent with UPOV 91 by allowing seed saving and the breeders' right to use protected varieties for future breeding programs. The ability to collect revenue on harvested material would give breeders a potential revenue stream and create the incentive to invest in breeding activities. Given the large wheat area in North American even a 1 % EPR levy would result in significant revenue for wheat breeders. As illustrated by the long path of the development of EPRs followed by Australia, EPR legislation would take several years to reach the point where it would support a viable wheat-breeding industry. If they follow the pattern exhibited by the existing private crop research industry, these companies will invest about 10 % of their additional revenue in research. EPR rates will increase over time driven by variety improvement and the need to signal quality improvement. As EPR rates rise over time increase this will increasingly impede the adoption of latest varieties.

The French model, which imposes a uniform EPR rate negotiated between the wheat producers and the seed industry, has the advantages of simplicity for royalty collection and creating a revenue stream much sooner, even for existing varieties. However, the French system does not allow price discrimination across varieties, and the negotiated EPR rate might be too low to attract sufficient private investment.

The introduction of EPRs will not address the provision of industry public goods. Research outcomes, such as agronomic knowledge or discovery-based research will not generate income and therefore will not be funded in this model. Given the international competition to attract private investment, public or levy-based research might be required to complement EPR-based research. There is some evidence that without a supportive knowledge environment, private industry will tend migrate to those countries and locations where there is a supportive pool of knowledge.

The introduction of EPRs can also influence the economic relationship between seed breeders and seed growers. When seed royalties are collected, the variety owners and seed growers both have the incentive to discourage the use of farm-saved seed and the use of brown bag markets. When the breeders can charge EPRs, they have an incentive to stimulate as much adoption as possible, which can include encouraging the use of farm-saved seed and secondary seed markets. InterGrain the primary wheat-breeding firm in Western Australia has contracts with seed firms to ensure the rapid distribution of new varieties and has encouraged the development of secondary farm-to-farm seed markets. In France the use of certified seed continues to be encouraged by offering farmers a rebate on EPRs when the growers can show they purchased certified seed.

c. Introduce research legislation creating a matched research levy

With the support of the industry the government could develop and implement legislation similar to Australia's PIERD Act to create levy-funded RDCs, where industry levies are matched by government and the research funds are administered by producer/industry boards. This move would allow a rapid increase in funding for industry collective goods R&D. Such levy-based funding could be used as development tool, perhaps following the Australian GRDC path of creating producer/public/private EPR-funded firms down the road. This model would allow the industry to quickly address the underfunding problem, while at the same time enabling producers to play a larger role in shaping the national research system. Care should be taken with the institutional design to minimize the costs of the diseconomies of diversity and producer political processes that have restricted the benefits from the Australian RDC system, but concern over these aspects should not overshadow the fact that the Australian RDC model has been very effective as a supplementary source of funding for agricultural R&D, still mainly conducted in the public domain.

d. Introduce a combination of b. and c. above

The combination of a research levy and EPR legislation has several potential advantages. First, it can address the chronic underfunding issue. Second, the combination can enable the different elements of public, levy-based, and private research each to assume its appropriate, incentive-compatible, complementary roles in the innovation system, with the public sector moving to fund research that has broader public benefits, levy-based research creating industry collective goods, and the private sector doing research when it has a cost advantage or other advantages over levy-based research.

Many innovation success stories have been brought about by public-private partnerships. In crop research, levy-funded producer organisations have a very good track record of development when they can work with government and the private sector to fund research. This suggests that public-private-producer-partnership (PPPP) models of innovation can play a valuable role in crop research. Each source of funding brings additional resources to the table, with incentives to fund the whole range of research required for successful industry innovation.

6.3 Concluding comments

We should be investing much more in agricultural research in North America, especially in those areas of research where IPRs are weak. Not investing more foregoes an important economic opportunity: we have every reason to expect investments in agricultural R&D to yield very favourable returns as they have done consistently in the past. Given that the public sector is unlikely to reverse the long record of fading support for funding agricultural research, especially for some areas such as crop improvement or other aspects emphasizing farm productivity, it is important that governments work with producers and industry to develop and implement new funding models to address those comparatively neglected areas.

In this paper we examined the potential use of EPRs and research levies to supplement public agricultural research funding. Having examined these models in use in Australia, and variants used elsewhere, we conclude that both approaches represent viable means to increase research funding and that benefits are likely to be maximized when they are used in tandem.

If these paths are to be taken a great deal more work remains to be done. First, developing the needed consensus requires a great deal of leadership and communication. As was in the case in Australia, the implementation process will involve some trial and error, some refinement and evolution—all of which will take time. Fortunately, North America, well behind Australia, has the advantage of being able to learn from Australia's successes and avoid some of problems that they did not anticipate.

References

Alston, J.M. 2002. "The 'Domain' for Levy-Funded Research and Extension: General Notions with Particular Applications to the Australian Dairy Industry." *Connections: Farm Food and Resource Issues* 3(August): 3-8 http://www.agrifood.info/connections/winter_2002/Alston.html

AGT, 2012. (Australian Grain Technologies www.ausgraintech.com. Accessed January 12

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. 2010. *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending.* New York: Springer.

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. 2011. "The Economic Returns to U.S. Public Agricultural Research." *American Journal of Agricultural Economics* 93: 1257-1277.

Alston, J.M., B. A. Babcock, and P.G. Pardey (eds.). 2010. *The Shifting Patterns of Agricultural Production and Productivity Worldwide.* CARD-MATRIC Electronic Book. Ames, IA: Center for Agricultural and Rural Development, Available at http://www.matric.iastate.edu/shifting_patterns/

Alston, J.M., and J.S. James. "The Incidence of Agricultural Policy." Chapter 33 in B.L. Gardner and G.C. Rausser, eds, the *Handbook on Agricultural Economics*, pp. 1869-1929, Volume II(a), Amsterdam: Elsevier, 2002

Alston, J.M., J.W. Freebairn, and J.S. James. 2003. "Distributional Issues in Levy Funded Programs." *Agribusiness: An International Journal* 19(3)(Summer): 277-288.

Alston, J.M., J.W. Freebairn, and J.S. James. 2004. "Levy-Funded Research Choices by Producers and Society." *Australian Journal of Agricultural and Resource Economics* 48(1)(March): 34-64.

Alston, J.M., and M.E. Fulton. 2012. "Sources of Institutional Failure and Underinvestment in Levy-Funded Agricultural Research." Presented at the Invited Papers session on *Financing Rural Research: Opportunities for Public-Private Partnerships*, Australian Agricultural and Resource Economics Society 56th annual conference, Fremantle, February 2012 (revised March 2012).

Alston, J.M., M.S. Harris, J.D. Mullen, and P.G. Pardey. 1999 "Agricultural R&D Policy in Australia" Ch. 5 in J.M. Alston, P.G. Pardey, and V.H. Smith, eds. *Paying for Agricultural Productivity*, Baltimore MD: Johns Hopkins University Press.

Alston, J.M., M.C. Marra, P.G. Pardey, and T.J. Wyatt. 2000a. *A Meta Analysis of Rates* *of Return to Agricultural R&D: Ex Pede Herculem?* Washington D.C.: IFPRI Research Report No 113.

Alston, J.M., M.C. Marra, P.G. Pardey, and T J Wyatt. 2000b. "Research Returns Redux: A Meta-Analysis of Agricultural R&D Evaluations." *Australian Journal of Agricultural and Resource Economics*, 44(2)(June): 185-216.

Alston, J.M. and P.G. Pardey. 2008. "Public Funding for Research into Specialty Crops." *HortScience* 43(5): 1461-1470.

Alston, J.M. and R.J. Venner. 2002. "The Effects of the US Plant Variety

Protection Act on Wheat Genetic Improvement." *Research Policy* 31(4): 527-542.

Ballard, C.L. and D. Fullerton. 1992. "Distortionary Taxes and the Provision of Public Goods." *Journal of Economic Perspectives* 6(3): 117-31.

Brookes, G. and P. Barfoot. 2009. "Global Impacts of Biotech Crops: Income and Production Effects 1996-2007." *AgBioForum* 12(2): 184-201.

Brookes, G. and P. Barfoot. 2010. "GM Crops: Global Socio-economic and Environmental Impacts 1996-2008." PG Economics Ltd, Dorchester, UK.

Carpenter, J. E. 2010. "Peer-Reviewed Surveys Indicate Positive Impact of Commercialized GM Crops." *Nature Biotechnology* 28(4): 319-321.

Carpenter, J. E. and L. P. Gianessi. *Agricultural Biotechnology: Updated Benefit Estimates*. Washington, DC, National Center for Food and Agricultural Policy, 2001.

CRRDC (Council of Rural Research and Development Corporations). 2011. *Evaluating RDC Investment Returns: A Summary of Three Years of Results from the Randomly Selected Projects*. Confidential report prepared for the CRRDC, Canberra.

CSTA. 2008. (Canadian Seed Trade Association) *Quick Facts* http://cdnseed.org/library/facts.asp accessed on April 12, 2011.

CSIRO, 2012. http://www.csiro.au, Accessed January 12.

DePauw, R.M. 2008 "Report on Roles of Public and Private Institutions in Genetic Enhancement in France, Germany and United Kingdom, June, 2008. ?

Evenson, R.E. 2002. "Economic Impacts of Agricultural Research and Extension." Chapter 11 in B.L. Gardner and G.C. Rausser eds. *Handbook of Agricultural Economics*, *Volume 1A: Agricultural Production*. New York: Elsevier, 2002.

Falcon, W.P. and C. Fowler. 2002. "Carving up the Commons–Emergence of a New International Regime for Germplasm Development and Transfer." *Food Policy* 27: 197–222.

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson. 2000. "Surplus Distribution from the Introduction of a Biotechnology Innovation." *American Journal of Agricultural Economics* 82: 360-369.

FAS (Foreign Agricultural Service). 2012. *World Agricultural Production* Circular Series WAP 03-12 March 2012 United States Department of Agriculture.

Fernandez-Cornejo, J., and M.F. Caswell. 2006. "The First Decade of Genetically Engineered Crops in the United States." Economic Information Bulletin No. 11. April. U.S. Department of Agriculture–Economic Research Service. Washington, D.C. Available online at http://www.ers.usda.gov/publications/eib11/eib11.pdf. Accessed, March 24, 2011.

Fuglie, K.O. P.W. Heisey, J.L. King, C.E. Pray, K. Day-Rubenstein, D. Schimmelpfennig, S.L. Wang, and R. Karmarkar-Deshmukh. 2011. *Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide*, Economic Research Report No. (ERR-130) 147 pp. December.

Fuglie, K.O. and P.W. Heisey. 2007. "Economic Returns to Public Agricultural Research." USDA, ERS Economic Brief No. 10. Washington D.C.: USDA, September.

Fulton, M.E. 1997. "The Economics of Intellectual Property Rights: Discussion." *American Journal of Agricultural Economics* 79(5): 1592–94.

Gray, R., S. Malla and P. Phillips. 2001. "Industrial Development and Collective Action." In P.W.B. Phillips and G.G. Khachatourians (eds.), The Biotechnology Revolution in Global Agriculture: Invention, Innovation and Investment in the Canola Sector. Wallingford, Oxon, UK: CAB International Publishing. Chapter 6.

GNIS (Groupement national interprofessionnel des semences et plants) 2012. Website http://www.gnis.fr/index/action/page/id/635/titre/Seed-sector (Accessed January 23, 2012).

GRDC. 2010. (Grains Research and Development Corporation) Wheat Breeding Information Sheet http://www.grdc.com.au (Accessed December 10, 2010)

GRDC. 2011. (Grains Research and Development Corporation) Website, http://www.grdc.com.au (Accessed March 23, 2011),

Heller, M.A. 1998. "Tragedy of the Anticommons: Property in the Transition from Marx to Markets." *Harvard Law Review* 111(3): 621-688.

Howard, P.H., 2009. "Visualizing Consolidation in the Global Seed Industry: 1996–2008." *Sustainability.* 1: 1266-1287.

INRA (National Institute for Agricultural Research) 2012. Website http://www.international.inra.fr/research (accessed January 23, 2012)

InterGrain, 2012. www.intergrain.com, Accessed January 12.

James, J.S., J.M. Alston, J.M., M.A. Andersen, and P.G. Pardey. 2009. "Structural Changes in U.S. Agricultural Production and Productivity." *Choices* Fall (available at http://www.choicesmagazine.org/magazine/block.php?block=42).

Kalaitzandonakes, N., Alston, J.M., and K.J. Bradford. 2006. "Compliance Costs for Regulatory Approval of New Biotech Crops." Chapter 3 of R.E. Just, J.M. Alston, and D. Zilberman (eds). *Regulating Agricultural Biotechnology: Economics and Policy.* Springer-Verlag publishers.

Kingwell, R. 2005. "Institutional Change and Plant Variety Provisions in Australia." *Australian Agribusiness Review Paper 5*, February 25th, 2005, downloadable at http://www.agrifood.info/10pub_rev_vol13_2005.htm

Kingwell, R. and A.S. Watson. 1998. "End-Point Royalties for Plant Breeding in Australia." *Agenda* 5(3): 323-34.

Keogh, M. and Potard, G. 2011. *Private Sector investment in Agricultural Research and Development (R&D) in Australia*, Research report, Australian Farm Institute, Sydney.

Kryder, R.D., S.P. Kowalski and A.F. Krattiger. 2000. "The Intellectual and Technical Property Components of Pro-Vitamin A Rice (GoldenRice™): A Preliminary Freedom-to-Operate Review," ISAAA Briefs no. 20-2000.

Lesser, W. 1998. Intellectual Property Rights and Concentration in Agricultural Biotechnology. *AgBioForum* 1(2): 56-61. Available at: http://www.agbioforum.org.

Lazenby, A., M. Bartholomaeus, B. Boucher, W.R. Boyd, A Campbell, R. Cracknell, H. Eagles, J. Lee, G. Lukey, and B. Marshall. 1994. *Trials and Errors: A Review of Variety Testing and Release Procedures in the Australian Grains Industry*. Grains Research and Development Corporation, Canberra, pp. 224.

LongReach, 2012. http://longreachpb.com.au, Accessed January 12

MacGrath, D. 2011. Personal Interview, April, Adelaide, Australia

Messer, K.D., H.M. Kaiser, and W. Schulze. 2008. "The Problem of Free Riding in Voluntary Generic Advertising: Parallelism and Possible Solutions from the Lab." *American Journal of Agricultural Economics* 90(2): 540-552

Moschini, G., and H. Lapan. 1997. "Intellectual Property Rights and the Welfare Effects of Agricultural R&D." *American Journal of Agricultural Economics* 79: 1229-42.

National Research Council, 2010. *Impact of Genetically Engineered Crops on Farms in the United States*. Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability. Washington, D.C.: The National Academies Press.

Pardey, P. G. and J.M. Alston. *U.S. Agricultural Research in a Global Food Security Setting*. A Report of the CSIS Global Food Security Project. Washington, D.C.: CSIS, January 2010. (available at http://csis.org/publication/us-agricultural-research-global-food-security-setting)

Pardey, P.G. and J.M. Alston. 2011. *For Want of a Nail: The Case for Increased Agricultural R&D Spending.* Report in the series, *American Boondoggle: Fixing the 2012 Farm Bill*. Washington, D.C.: American Enterprise Institute.

Perrin, R.K. and L.E. Fulginiti. 2008. "Pricing and Welfare Impacts of New Crops: The Role of IPRs and Coase's Conjecture Revisited." *AgBioForum* 11(2): 134-144. Available at: http://www.agbioforum.org.

Productivity Commission. 2007. *Public Support for Science and Innovation*. Research Report. Canberra: Productivity Commission, March.

Productivity Commission. 2010. *Rural Research and Development Corporations*. Draft Inquiry Report. Canberra: Productivity Commission, September.

Productivity Commission. 2011. *Rural Research and Development Corporations*. Inquiry Report. Canberra: Productivity Commission, February.

Qaim, M. 2009. "The Economics of Genetically Modified Crops." *Annual Review of Resource Economics* 1: 665-694

SeedVise. 2011. "Wheat Varieties" http://varietycentral.com.au/varieties-and-rates/2011-2/wheat.

Smyth, S. and R.S. Gray. 2011. "Intellectual Property Sharing Agreements in Gene Technology: Implications for Research and Commercialisation." *International Journal of Intellectual Property Management* 4(3): 179-90.

Sobolevsky, G., G. Moschini, and H. Lapan. 2005. "Genetically Modified Crops and Product Differentiation: Trade and Welfare Effects in the Soybean Complex." *American Journal of Agricultural Economics* 87(3): 621-644.

Stiegert, K.W, G. Shi, and J.-P. Chavas. 2010. "Innovation, Integration, and the Biotechnology Revolution in U.S. Seed Markets." *Choices* 25(2).

Veeman T. S. and R.S. Gray. 2010. "The Shifting Patterns of Agricultural Production and Productivity in Canada" Chapter 6 of J.M. Alston, B. Babcock, and P.G. Pardey (eds.) *Shifting Patterns of Agricultural Production and Productivity Worldwide.* CARD-MATRIC Electronic Book. Ames, IA: Center for Agricultural and Rural Development, May.

Wilson,W.W. and B. Dahl. 2010. *Dynamic Changes in Market Structure and Competition in the Corn and Soybean Seed Sector.* Agribusiness & Applied Economics Report No. 657 Dept of Agribusiness and Applied Economic Agricultural Experiment Station, North Dakota State University

Wright, B.D. and P.G. Pardey. 2006. “Changing Intellectual Property Regimes: Implications for Developing Country Agriculture.” *International Journal of Technology and Globalisation*. 2(1-2): 93–114.

Zilberman, D., S.E. Sexton, M.C. Marra, and J. Fernandez-Cornejo. 2010. “The Economic Impact of Genetically Engineered Crops.” *Choices* 25(2).