*The Australian Journal of Agricultural and Resource Economics*, 46:3, pp. 315–346

# Spillovers*

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Interstate and international spillovers from public agricultural research and development (R&D) investments account for a significant share of agricultural productivity growth. Hence, spillovers of agricultural R&D results across geopolitical boundaries have implications for measures of research impacts on productivity, and the implied rates of return to research, as well as for state, national and international agricultural research policy. In studies of aggregate state or national agricultural productivity, interstate or international R&D spillovers might account for half or more of the total measured productivity growth. Similarly, results from studies of particular crop technologies indicate that international technology spillovers, and multinational impacts of technologies from international centres, were important elements in the total picture of agricultural development in the 20th Century. Within countries, funding institutions have been developed to address spatial spillovers of agricultural technologies. The fact that corresponding institutions have not been developed for international spillovers has contributed to a global underinvestment in certain types of agricultural research.

## 1. Introduction

> 'R&D spillovers are both prevalent and important.'
> (Griliches 1992, p. 29)

Given the role played by agricultural productivity in economic development and the wealth of nations, explaining agricultural productivity growth is important work for agricultural economists. Much agricultural

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* This article draws on several elements of a joint program of work with Phil Pardey that has been partially supported by the International Food Policy Research Institute, the University of California's Pacific Rim Program, the UC President's Program for Industry-University Cooperative Research, the Giannini Foundation of Agricultural Economics, and a cooperative research project with the USDA-ERS. Thanks are owed to Albert Acquaye, Connie Chan-Kang, and Patricia Zambrano for valuable research assistance, and to Jock Anderson, Jennifer James, John Mullen, Phil Pardey, Roley Piggott, Rich Sexton, Vince Smith, and Dan Sumner for helpful comments on drafts and other help. Special thanks are owed to John Quilkey, whose early encouragement and guidance made this and other spillovers possible.

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productivity growth is attributable to public agricultural R&D, and, as I will document, agricultural research and technology spillovers among states and nations account for a large share of the total social payoff to public agricultural research investments. As a result, the stakes associated with the distortions in research policy caused by agricultural R&D spillovers are very large, probably much bigger than those for most other agricultural policy distortions.

R&D spillovers among geopolitical entities arise when research conducted by one state (or nation) confers benefits on other states (or nations) that are able to adopt the results. Such spillovers have implications for research policy at the state, national and international levels, in two ways. First, they add complications to already awkward policy questions that arise when research is being conducted and funded by state and national governments – such as how much and what mix of research should be undertaken, who should pay for it, who should do it and what institutional arrangements should be put in place. Second, and perhaps more importantly, they introduce an additional dimension for incentive problems. The fundamental economic basis for government provision of agricultural research is incomplete appropriability of research benefits by inventors. Research and technology spillovers among research providers within a state can be addressed (at least in principle) by state-government policy, but state-government policy cannot effectively address spillovers across state boundaries. Similarly, federal-government policy might address spillovers among research providers in different states within a nation, but national-government policy cannot effectively address spillovers among nations.

These are not new ideas. Much has been written about agricultural R&D and technology spillovers and some of that has touched on the policy aspects. My purpose here is to bring together ideas and evidence from the literature, as well as some newer results. The emphasis is on spillovers of public agricultural R&D among geopolitical entities, such as states and nations, as state and national governments determine research policies. In the next section, information is presented on the overall importance of agricultural productivity growth and the general problem of identifying the specific contributions of different sources of growth. Then, evidence is presented on agricultural R&D spillovers both among states of the USA and among nations. Drawing on these results, policy implications are raised.

The main findings can be stated simply. First, intranational and international spillovers of public agricultural R&D results are very important. In the small proportion of studies that have taken them into account, spillovers were responsible for a sizeable share – in many cases, more than half – of total measured agricultural productivity growth and the corresponding research benefits. Second, spillovers can have profound implications for the distribution of research benefits between consumers and producers and thus among countries, depending on their trade status and capacity to adopt the technology. Third, it is not easy to measure these impacts, and the results can be sensitive to the specifics of the approach taken, but studies that ignore interstate and international spillovers are likely to obtain seriously distorted estimates of the returns to agricultural research. Finally, because spillovers are so important, research resources have been misallocated both within and among nations. In particular, international spillovers contribute to a global underinvestment in agricultural R&D that the existing policies have only partly succeeded in correcting. The stakes are large as the benefits from agricultural technology spillovers are worth many times more than the investments that give rise to them.

## 2. Context – agricultural productivity, spillovers, and the wealth of nations

Since 1960 the world's population has doubled from three to six billion people. Over the same period, grain production more than doubled – almost entirely because of unprecedented increases in yields – as did agricultural production in total (Johnson 2000). The fact that the Malthusian nightmare was not realised in our lifetime is attributable in large part to growth in agricultural productivity (Pardey and Beintema 2001), but this knowledge by itself is not directly useful. As suggested by Griliches (1961, p. 446), 'productivity' is a 'measure of our ignorance, of the unknown, and the task that is before us.'

Writing just before this period of unprecedented growth in agricultural production (and productivity), Schultz (1956) showed that most of the increase over time in agricultural production could not be explained by increases in 'conventional inputs.' Since then, beginning with Griliches (1964), a host of economists have worked on elements of the problem of accounting for agricultural productivity, devising approaches to account for the roles of things such as infrastructure investments, economies of scale, input quality changes, education of the farm workforce, and changes in technology attributable to private and public investments in agricultural R&D. Even with the most diligent efforts to account for the other factors, however, the lion's share of total productivity growth is left as a residual to be attributed to changes in technology coming from investments in agricultural R&D and extension (e.g., see Griliches 1992, 1994).

This research-induced productivity growth is economically important, even in wealthy countries where agriculture plays a comparatively minor role in the economy; and it is crucial in the world's poorest countries. For instance, in the USA, studies using different methods agree that growth in agricultural productivity attributable to technological innovation has been around 2 per cent per year during the post-WWII period (e.g., Ball *et al.* 1999, and Acquaye *et al.* 2001).[1] Comparable rates of productivity growth have been found in other countries, and a reasonable guess is that global agricultural productivity also has grown at about 2 per cent per year. Compounding forward at 2 per cent over only 40 years, an index of agricultural productivity that was 100 in 1960 would be equal to 220 in 2000. This means that, of total USA agricultural production in 2000 with a gross value of about US$220 billion, less than half can be explained by conventional inputs using 1960s technology. In other words, agricultural technology adopted since 1960 in the USA yielded a flow of benefits worth about US$120 billion in the year 2000 alone.[2] This measure of USA benefits is a very large number relative to the annual USA investment in agricultural R&D, and well exceeds even the global total investment.[3] Hence it is not surprising that studies typically find very large benefit-cost ratios or rates of return to agricultural research. The measured annual flows of benefits are very large relative to the annual flows of research costs, and it is only the very long lags that keep the measured rates of return as low as they are.[4]

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[1] These studies have accounted comprehensively for input quality aspects and other aggregation and index number issues, but they have not dealt entirely with every other potential measurement issue, such as changes in the stock of infrastructure, the effects of which might have been positive or negative, the impacts of changing technological regulations, or environmental impacts, and other 'unmeasured' inputs and outputs.

[2] Applying the same growth rate and comparable other assumptions to the world as a whole for which the gross value of agricultural production in the year 2000 was about US$1600 billion the flow of benefits in 2000 from productivity improvements associated with changes in agricultural technology since 1960 were worth more than US$800 billion. Oceania's share of the total was 2.1 per cent, which implies a flow of benefits to Oceania (i.e., Australia and New Zealand) in the year 2000 worth around US$17 billion. These figures were obtained by extrapolating from the estimate in Wood *et al.* (2000), that the average annual value of the world's agricultural production over 1995–1997 was US$1322 billion (in 1989–1991 agricultural PPP dollars). Using a similar approach, Mullen (2002) estimated the present value in 2000 of Australia's benefits from agricultural productivity over the 47 years from 1953 at about A$1100 billion.

[3] Pardey and Beintema (2001) estimated that in the mid-1990s an annual total of about $33 billion (1993 international dollars) was spent globally on agricultural R&D, of which two-thirds ($21.7 billion) was spent by the public sector and one-third by the private sector. The corresponding USA totals were, approximately, $4 billion for private agricultural R&D, $3 billion for public agricultural R&D, and a further $1.7 billion for extension. For Australia, Mullen (2002) estimated the present value in 2000 of total expenditure on agricultural research and extension since 1933 was about A$77 billion; annual expenditure in 1999 was about A$1 billion.

[4] Alston *et al.* (2000a, 2000b) documented the estimates in the literature and discussed possible sources of (mostly upward) bias.

It is not sufficient to be persuaded that agricultural productivity growth is important and that agricultural science causes it. For informed policy decisions, we want to know details about which research, conducted when, and by whom was (or will be) responsible for the productivity growth. This 'attribution problem' in measuring the returns to agricultural R&D has received considerable attention but it is fair to say only partial progress has been made in resolving it.[5] A particular aspect of the attribution issue is associated with spillovers. A study that fails to account appropriately for 'spill-ins' – the adoption of research results from other places – will overestimate a state's benefits from its own research investments. Conversely, if state-to-state spillovers are important, a study that measures only the own-state effects and ignores the 'spillouts' will understate the national social returns to a state's research. Similarly, national benefits might be overestimated if the benefits from international spill-ins are attributed to domestic agricultural R&D, while spillovers among countries mean that the global benefits from a country's research will be underestimated by a study that measures only national benefits. Since R&D spillovers are pervasive and important, and most studies do not account for them, much of the evidence on rates of return to agricultural R&D may be questionable.

## 3. An overview of the literature on R&D and technology spillovers

Spillover problems, arising from a mismatch between the geopolitical entity conducting research and the geopolitical entities in which benefits accrue, apply to all kinds of industrial research, not just agricultural research. Indeed, much has been written recently about R&D and technology spillovers in relation to general industrial technologies in the context of models of economic growth.[6] As well as being of value in its own right,

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[5] This observation, like many of the important ideas in this literature, can be attributed to Zvi Griliches. Among other things, Griliches suggested that at least some elements of the empirical problem are intractable given the available data and methods, asking 'for a lowering of expectations as to what the available data base can tell us ...' (Griliches 1979, p. 92). In relation to the empirical problems more generally, and the limited nature of our progress in dealing with them, see Griliches (1974, 1979, 1992, 1994 and 2001). Other related contributions may be found in Griliches (1957, 1963, 1964 and 1980, among others).

[6] In the 'new' growth theory, firm-to-firm and industry-to-industry technology spillovers are a key source of economic growth, but much of that literature relates to private research investments more than public research investments. See Coe and Helpman (1995) among others. A related literature is the new economic geography, as exemplified by Krugman (1991), emphasizing economies of scale and the implications for the spatial pattern of production. Some of these contributions may have involved the 'rediscovery' of ideas that had been introduced into agricultural economics a long time previously, but failed to 'spill over' into the economics mainstream (e.g., Griliches 1992).

the study of agricultural R&D spillovers using our comparatively rich agricultural datasets may offer insights into the more general topics of economic growth, convergence, and so on. But the biological nature of agricultural production means that the spatial dimension is different for agricultural technology than for most other industrial technologies. The applicability of agricultural technology in a particular location is governed to a great extent by the agroecological characteristics of the location – climate, terrain, soil types – in conjunction with the other economic factors, such as relative prices of inputs and outputs, and the institutional setting, that are relevant for all types of industrial technologies.[7] Even though agroecological aspects impose additional limitations that do not arise for many other industrial technologies, spatial spillover issues may still be comparatively important for agricultural technologies owing to the relatively important public-sector role in some types of agricultural research.

Another set of literature discusses the spatial pattern of adoption and adaptation of agricultural technologies without making any explicit links to agricultural research investments.[8] For instance, in his Pullitzer Prize winning *Guns, Germs and Steel*, Jared Diamond (1997) reviews the role of agricultural technology over the past 13 000 years of human history with a particular emphasis on the roles of fundamental endowments of domesticable plant and animal species, the geoclimatic specificity of agricultural production systems, and geographical impediments to the movements of people and ideas. All of this more-general literature has some relevance for the topic at hand, but the key ideas have been generally captured within the more-specific literature on agricultural R&D and technology spillovers. This more-specific literature can be divided into case studies of specific technologies or institutions, such as Evenson and Kislev's (1973) work on wheat and maize, and studies measuring the effects of agricultural research on state or national productivity with regression-based methods, such as Huffman and Evenson (1993).

Whether they were concerned with spillovers or not, studies have imposed implicit or explicit assumptions about the spatial spillover effects of agricultural research based on geopolitical boundaries. For example,

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[7] Similarly, medical research spillovers might have a spatial dimension akin to that in agricultural research, when geoclimatic factors play a significant role in the incidence of diseases; similarly for mining, forestry, fisheries and other industries based on natural resources.

[8] Examples include Griliches's (1957) pioneering work on the spread of hybrid corn in the USA, Dalrymple (1977, 1980, 1986a, 1986b), taking an international perspective on the early adoption of semi-dwarf wheat and rice varieties in the USA and in developing countries, Byerlee and Moya (1993) and Heisey *et al.* (2002) on the adoption of CIMMYT wheat varieties in developing countries, and Morilla Criz *et al.* (1999, 2000) dealing with the global spread of Mediterranean agriculture.

most past studies of the effects of USA agricultural research on national agricultural productivity implicitly assumed that agricultural research is totally fungible, such that USA national agricultural output depends on the national aggregate of USA spending on public agricultural R&D, regardless of where it was spent or by whom.[9] Many state-specific studies, however, simply ignored the effects of research done in other states or by the federal government. Likewise, almost all of the regression-based studies of agricultural R&D have ignored the possibility of international spillovers, unless they were specifically emphasising that possibility (e.g., Bouchet *et al.* 1989, and Schimmelpfennig and Thirtle 1999). Few studies of national systems, irrespective of the method used, have allowed for spill-ins or spillouts.

## 4. Spatial spillovers in USA public agricultural research

Significant interstate research spillovers from USA State Agricultural Experiment Stations (SAESs) were first found in studies published in the 1960s, and in several studies since.[10] The studies that have measured spatial spillovers of USA public agricultural research have emphasised geographical proximity in the specification of the spillover variables. For instance, Khanna *et al.* (1994) grouped states into six regions and, for each state, a spillover variable consisted of the pool of research done by other states in the same region. Similarly, Yee and Huffman (2001) constructed a spill-in stock of publicly generated knowledge as the sum of public research stocks of all states in the relevant region less the state's own research stock. In both these studies research done by states outside a particular region is of no consequence for states within that region.

Several other studies, beginning with Huffman and Evenson (1989), have incorporated geoclimatic information while retaining the restriction that technology spillovers occur only among states within a contiguous geopolitical region. Drawing on earlier work by Evenson (1988, 1989), Huffman and Evenson (1989) defined a composite own state and spill-in research variable as a weighted sum of the research stocks for states within a region, with one weight for states in the same subregion as the state of interest and a

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[9] Examples include Griliches (1964), Evenson (1967), White and Havlicek (1982), and Chavas and Cox (1992).

[10] The earlier studies that found significant interstate spillovers of SAES research include Latimer and Paarlberg (1965), Evenson (1967), Bredahl and Petersen (1976), Norton (1981), White and Havlicek (1981), and Sundquist *et al.* (1981). More recent examples of state-level studies accounting for spillovers among SAES include Leiby and Adams (1991) in their study of Maine, Norton and Ortiz (1992, 1992) in their study of Virginia, and the multi-state studies of Davis (1979), Huffman and Evenson (1989, 1992, 1993, 2001), Khanna *et al.* (1994), McCunn and Huffman (2000), and Yee and Huffman (2001).

lower weight for other states in the same geoclimatic region but in different subregions. The assignment of states to regions and sub-regions was based on the geographical concordance of state boundaries and the 16 geoclimatic regions and 34 geoclimatic subregions described in USDA (1957). The same set of constructed spillover weights were used subsequently by Huffman and Evenson (1992, 1993 and 2001), and McCunn and Huffman (2000): Huffman and Evenson (1993), for example, found that upwards of 45 per cent of the benefits from research conducted in SAES was earned as interstate spillovers.

In work still in progress, Alston *et al.* (2002, hereafter AJPZ), have used a measure of technology spillover potential expressed in terms of the agricultural technological similarity of states, defined by their agricultural output mix, rather than geographical proximity of states. Across the states the uncentred output-mix correlation coefficients, which are used to construct state-state knowledge spillover stocks, range from 0.05 to 0.98.[11] The patterns are plausible and interesting. While some of the largest spillover coefficients are between neighbouring states (such as Indiana and Illinois or Kansas and Oklahoma), close proximity does not always imply agroecological (or economic) similarity; and greater distance need not imply a greater agroecological (or economic) difference. As well as being intuitively reasonable, this alternative approach is more consistent with the early results that found very important spillover effects among USDA geographical regions (see White and Havlicek 1981, for instance), not just within regions as assumed by many studies.

AJPZ estimated a logarithmic model in which state-specific agricultural productivity depended on four types of state-specific knowledge stocks from public agricultural R&D: (i) the own stock of knowledge from past extension investments (assuming no interstate spillover effects from extension), (ii) the own stock of knowledge from past research investments, (iii) the spillover stock of knowledge from past research investments in other states (a weighted sum of the knowledge stocks in the other 47 states), and (iv) the spillover stock of knowledge from past intramural research investments by the USDA. The elasticities of productivity with respect to the various knowledge stocks were restricted to be equal across the states, and a single gamma lag distribution was used to define state-specific knowledge stocks, with a

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[11] This specification of the state-state spillover coefficients is based on an approach introduced by Jaffe (1986, 1989) to measure inter-firm or inter-industry spillover effects. The spillover coefficients are measured using the states' vectors of shares of up to 55 different outputs (see Acquaye *et al.* 2001, AAP). AJPZ have also experimented with a measure based on the similarity of the agricultural R&D portfolio, rather than the agricultural output portfolio. The output mix reflects other relevant economic factors, as well as agroecological ones, that together define the agricultural R&D spillover potential.

**Table 1** Elasticities of USA state-level agricultural productivity with respect to own-state and spillover knowledge stocks

| | AJPZ model | Spillovers in USDA regions | Excluding interstate spillovers | Excluding federal and interstate R&D |
|---|---|---|---|---|
| Own-state | 0.094 | 0.112 | 0.132 | 0.217 |
| extension | (5.3) | (6.42) | (7.48) | (12.08) |
| Own-state | 0.199 | 0.196 | 0.318 | 0.387 |
| research | (12.48) | (11.56) | (30.95) | (38.49) |
| State-state | 0.173 | 0.157 | | |
| spillovers | (9.55) | (8.97) | | |
| Federal | 0.365 | 0.400 | 0.475 | |
| research | (12.26) | (13.88) | (16.88) | |

Source: Based on a gamma lag distribution model as described in Alston *et al.* (2002).
Note: Figures in parentheses are *t*-statistics.

gestation lag of 3 years followed by up to 50 lags of research investments (for extension, they assumed no gestation lag and a maximum lag of 20 years).[12] Models were estimated using state-level data on USA agricultural productivity (for the period 1949–1991, taken from AAP) and federal and state-government investments in agricultural research and extension (for the period 1890–1990, slightly revised from Alston *et al.* 1998).

The elasticities of productivity with respect to knowledge stocks from the preferred model are reported in the first column of table 1. Otherwise identical models using alternative state-to-state spillover structures (but holding the federal-state spillover structure constant) are also shown in table 1. The second column refers to a model in which the state-state spillover coefficients are 1 for states within the same USDA region, and 0 otherwise (similar to that used by Yee and Huffman 2001). While the elasticities and other model statistics were not much affected, this difference in the definition of the state-state spillover knowledge stock has very different implications for the interpretation of the roles of particular states as sources of productivity growth, especially where geopolitical proximity is not a good indicator of technological similarity. For instance, the AJPZ model shows very substantial spillovers between California and far distant states such as Pennslylvania,

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[12] As a practical matter, restrictions must be imposed to reduce the number of parameters to be estimated. The practical problem then becomes one of finding an appropriate blend of sample (data) and non-sample information (restrictive assumptions). For instance, in relation to R&D lags, Griliches (1979) suggested that 'it is probably best *to assume* a functional form for the lag distribution on the basis of prior knowledge and general considerations and not to expect the data to answer such fine questions. That is, a "solution" to the multicollinearity problem is a moderation of our demands on the data our desires have to be kept within the bounds of our means.' (p. 106, emphasis in original).

New York, and Florida that, like California, are comparatively specialized in dairy, beef, or horticulture, but these spillovers are assumed away in the model based on proximity. The third column shows the results for a model that does not include state-state spillovers, and the fourth column shows results for a model that does not include the federal knowledge stock. By conventional standards either of the last two models might appear to be quite satisfactory. However, they were statistically rejected by models that include the spillover effects and, as would be anticipated, the omission of the state-state spillover effects resulted in much larger elasticities of multifactor productivity (*MFP*) with respect to the own-research and federal research knowledge stocks than in the model that included state-state spillovers. Moreover, when spillovers from federal knowledge stocks also were excluded, the estimated elasticity of *MFP* with respect to own-research knowledge stocks was biased up even further. Hence, the omission or mis-specification of the spillover impacts might have led to substantial upward biases in estimates of own-state rates of return to research in some studies.

AJPZ partitioned the predicted productivity growth from the preferred model into elements attributable to different knowledge stocks, and found that on average across the states, more than half of the total *MFP* growth in a state is attributable to spill-ins of knowledge and technology resulting from research conducted federally (19 per cent) or in other states (36 per cent). AJPZ also used the estimated productivity model to simulate the effects of alternative hypothetical small changes in past research investments, and used the results to compute marginal benefit-cost ratios. Specifically they computed the state-specific (private, in some sense) and national (social, in some sense) benefits from a small (one thousand dollar) change in a particular year (1950) in expenditures on either: (i) research by a particular state, (ii) extension by a particular state, or (iii) research by the federal government. Table 2 summarises the results in terms of the minimum,

**Table 2** Marginal Benefit-Cost Ratio for a US$1000 Increase in Spending in 1950

| | State-specific benefits per dollar of | | | Spillover benefits per dollar of SAES research | National benefits per dollar of SAES research |
|---|---|---|---|---|---|
| | Own extension | Own SAES research | Federal research | | |
| California | 9.40 | 26.69 | 6.34 | 23.02 | 49.71 |
| Minimum | 2.29 | 7.38 | 0.10 | 12.18 | 19.86 |
| Maximum | 16.76 | 75.46 | 6.34 | 34.33 | 101.12 |
| Average | 6.60 | 26.69 | 1.61 | 24.70 | 51.39 |
| 48-state total | | | 77.12 | | |

Source: Based on the model in Alston *et al.* (2002), using $r = 3$ per cent per year and the elasticities in table 1. Connecticut and Rhode Island are excluded from the minimum since their values were extremely small, but the state-specific average and the 48-state total include all 48 states.

maximum and mean values across states of: (i) the own-state benefits from its extension investments, (ii) the own-state benefits from its research investments, (iii) the state's benefits from federal research investments, (iv) spillover benefits to the other 47 states resulting from the state's research investments, and (v) national benefits from the state's research (the sum of the own-state benefits and the benefits to all other states). All of these figures are in common terms, expressing real (year 2000 US$), marginal benefits per dollar invested (associated with a small change in expenditure in 1950).

Using these estimates we can compare the 'private' payoff to each state from investing in extension versus own-SAES research. For instance, in California the relevant marginal payoffs are US$9.40 per dollar for extension and US$26.69 per dollar for own research, compared with US$6.34 for a dollar of USDA research. The spillover benefits to other states are typically of similar magnitudes to the own-state benefits, but occasionally much larger and occasionally somewhat smaller. The sum of the own-state and spillover benefits is the national or 'social' benefit from increases in state-specific agricultural research spending (US$49.71 per dollar for California's research), which can be compared with the national benefits from a marginal increase in federal research expenditure, given by adding up the state-by-state benefits from federal research across all the states (US$77.12 per dollar of USDA intramural research). These comparisons would suggest that, even with federal government action to address state-state agricultural R&D spillovers, serious distortions remain in the quantity and mixture of USA agricultural research and extension, compared with the allocation that would generate the greatest national payoff (and thus would equalise the marginal national returns among states for research and extension investments, across the rows in the last column of table 2, with the return to USDA intramural research). While these are preliminary results, and the continuing work is using revised data and different models, it is expected that generally similar patterns will be found.

## 5. International agricultural R&D and technology spillovers

A potentially important weakness of the AJPZ model is the authors' failure to account for the impacts of technological spillovers from other countries and from international agricultural research centres, but they are not alone in this. In their meta-analysis of the published literature on rates of return to agricultural R&D, Alston (2000a) reported that only 12 per cent of the 292 studies in their sample (22.2 per cent of the corresponding estimated rates of return to research) made any allowance for technology spillovers; even fewer allowed for international spillovers. Like state–state spillovers, the neglect of country–country spillovers can be expected to give rise to distorted measures of both 'private' (in this case, national) and 'social' (in this case, global) research impacts.

### 5.1 Country–country spillovers in models of aggregate productivity

Of the studies that have measured the benefits from international agricultural technology spillovers, relatively few have been based on an econometric analysis of aggregate agricultural productivity – i.e., a country–country counterpart of the various studies of USA state–state spillovers – partly because the demands for data are onerous.[13] Schimmelpfennig and Thirtle (1999) measured country–country spillovers within the EU and from the USA to the EU (see also Thirtle *et al.* 1995). They found that omitting country–country spillovers could give rise to very substantial biases: '… the estimated rate of return to public agricultural R&D falls from over 60 per cent in the closed economy model to 10 per cent in the model that takes account of international spillovers' (Schimmelpfenning and Thirtle 1999, p. 457). This type of conclusion is also supported by the other studies allowing for international agricultural research spillovers.

By far the majority of research impact studies that have allowed for international agricultural technology spillovers were commodity-specific studies, rather than national aggregate studies, and mostly they were studies of crop varietal improvements – wheat, rice, maize, beans, and soybeans, in particular. Among these, a small number were ex-ante studies and a high proportion were ex-post studies of new varieties of particular crops.

### 5.2 Country–country spillovers in ex-ante models of specific crops

In ex-ante studies allowing for international spillovers, much of the work is in determining the likely multinational adoption patterns of new technologies developed in a particular location after having estimated the odds of successful research and the extent and nature of the resulting technological improvement. The issue of country–country spillovers of one country's research often arises in agencies such as the Australian Centre for International Agricultural Research (ACIAR), or international agencies such as the Inter-American Development Bank (IDB), or in the Consultative

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[13] Among the exceptions, Bouchet *et al.* (1989), allowed for spill-ins of agricultural R&D in a model of agricultural productivity in France, as did Evenson and McKinsey (1991) for India, Khatri *et al.* (1996) for South Africa, Khatri and Thirtle (1996) for Zimbabwe (see also Thirtle *et al.* 1993), and Nagy (1984, 1985) for Pakistan.

Group on International Agricultural Research (CGIAR), seeking to determine where best to spend international agricultural research funds, with a view to achieving the greatest multinational benefits. In pioneering work of this type, Davis *et al.* (1987) used FAO data on agroecological zones to define matrices of commodity-specific spillover coefficients among countries for each of 12 different commodities, and found that 'spillover effects from regions where research is conducted to other regions with similar agroecologies and rural infrastructures ranged from 64 to 82 per cent of total international benefits.' (p. 8)[14]

Maredia *et al.* (1996) estimated a global spillover matrix for wheat varietal technology, which Maredia and Byerlee (2000) used subsequently to conduct ex-ante analyses of 69 specific national and international wheat improvement research programs. They distinguished among different types of research programs and considered both spillovers and the related topic of economies of size and scope (see also Byerlee and Traxler 2001, and Traxler and Byerlee 2001). They found that, '... given the magnitude of potential spill-ins from the international research system, many wheat programs could significantly increase the efficiency of resource use by reducing the size of their wheat research programs and focusing on the screening of varieties developed elsewhere.' (Maredia and Byerlee 2000, p. 1)

More recently, Alston *et al.* (2000c) measured the impacts among countries of the Latin America and Caribbean (LAC) region, resulting from research conducted within individual LAC countries. The analysis included edible beans, cassava, maize, potatoes, rice, sorghum, soybeans, and wheat, which in 1997 collectively accounted for almost half of the value of all crop output (and one-quarter of all agricultural output) in Latin America. The authors combined information on the geographical location of agroecological zones, with other information on the spatial location of production within agroecological and geopolitical location boundaries, to define the adoption of technologies within states across countries in Latin America. Specifically, research conducted in one location was assumed to be fully applicable throughout the corresponding agroecological zone, regardless of national borders, but not applicable in other agroecologies. The results reveal the agroecological, country, and sub-regional incidence of the benefits from research-induced shifts in supply. They illustrate the important consequences of choice of crop and targeted agroecology on the overall benefits for LAC and for sub-regions (and agroecologies) within LAC. Importantly, when allowance was made for spillovers to other regions of the world, outside

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[14] Evenson and Kislev (1975) were perhaps the first to use measures of spillover potential based on agroecological zones. Their spillover weights were used in various subsequent studies (see Evenson 1994).

LAC, the resulting price impacts had important consequences for the distribution of benefits between producers and consumers and thus among countries within LAC.

## 5.3 Spillover impacts in ex-post models of specific commodities

In ex-post studies of commodity-specific research spillovers, much of the work is in attributing the benefits from new varieties that actually were adopted among the various sources of genetic improvements (after having obtained data on the actual adoption patterns and the consequences of the adoption). The same methodological issues arise in both country-specific studies of varietal improvement research, allowing for spill-ins or spillouts of varietal technologies from other countries (or from international centres), and studies of the multi-country impacts of varietal improvement research done in international centres.

Beginning with John Brennan's work on the impacts, in Australia, of wheat varieties from the international wheat and maize research centre, CIMMYT (Brennan 1986, 1989), a number of studies have attempted to value the benefits to particular countries from research conducted at CG centres, and in some cases comparing them against donor support provided by the countries in question.[15] The general story in these studies is that the estimates of total benefits from varietal improvement research conducted by centres of the CGIAR greatly exceed the total research costs, and the benefits to particular countries that support the CGIAR (such as Australia and the USA) well exceed their expenditures on support for international agricultural research.

In the first such study, Brennan (1986, 1989) reported that for the period 1973–1984, Australia gained US$747 million in terms of cost savings to wheat producers as a result of having adopted CIMMYT-based wheat varieties (he noted that Australia's annual contribution to CIMMYT was about US$340 000 while the average expenditure on wheat breeding in

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[15] Brennan (1986, 1989), Burnett *et al.* (1990), Byerlee and Moya (1993), and Pardey *et al.* (1996) estimated the benefits from adopting CIMMYT wheat in Australia, New Zealand, developing countries collectively, and the USA, respectively. More recently, Heisey *et al.* (2002) updated the Byerlee and Moya estimates of benefits to developing countries. Bofu *et al.* (1996) and Fonseca *et al.* (1996) estimated the benefits from adopting particular varieties of potatoes from CIP in China and Peru, respectively. Pardey *et al.* (1996) measured the USA benefits from adopting IRRI rice varieties. Johnson and Pachico (2000) estimated the benefits to various countries from the adoption of varieties of rice, beans, forages, and cassava from CIAT. Brennan and Bantilan (1999) and Brennan *et al.* (2002) estimated the impacts on Australian producers and consumers resulting from varietal releases from ICRISAT and ICARDA for a range of crops. Other studies in the list of references documented adoption of CG releases without going as far as estimating the value of the benefits.

Australia had been approximately US\$4–5 million per year).[16] On the basis of parentage, he attributed two-thirds of the cost-savings to CIMMYT per se with the remaining one-third attributable to the inputs of Australian wheat breeders who used CIMMYT releases as parental lines. Specifically, a variety that was the product of a direct cross between a CIMMYT line and an Australian line had 50 per cent of its contribution attributed to CIMMYT; if a variety was released by CIMMYT or was a result of crosses of two CIMMYT lines, 100 per cent of the credit was given to CIMMYT. To implement this approach required detailed knowledge of the genetic history of all of the relevant varieties, the yield performance of the varieties, and the adoption patterns over space and time.

All of the subsequent work of this type has used mechanistic rules such as this one for the attribution of credit for new varieties among their breeders and the breeders of their antecedents, but with some variation in the specifics of the rules in terms of how many past generations were considered, and the weighting on the different generations. Pardey *et al.* (1996) compared the results for five such rules in estimating the USA benefits from its adoption of wheat varieties from CIMMYT and rice varieties from IRRI, the international rice research institute. Under their 'any ancestor' rule, CIMMYT was accorded 100 per cent of the benefits from every variety with any CIMMYT releases in its ancestry, going back as far as great-grandparents. Other rules gave CIMMYT less credit, with the most-conservative giving geometrically declining weights to breeders of antecedents back to great-grandparents.[17] They found that, depending on the attribution rule used, the USA economy gained at least US\$3.4 billion and up to US\$14.6 billion from 1970 to 1993 from the use of improved wheat varieties developed by CIMMYT. In the same 23-year period, they found that the USA economy realised at least US\$30 million and up to US\$1 billion through the use of rice varieties developed by IRRI.

These are large numbers relative to the USA support of CIMMYT and IRRI (US\$131 million in present value terms up to 1993), or even the total budget of the entire CGIAR system (approximately US\$200–300 million per year in the 1980s and 1990s, but much less than that during the 1970s). However, when Pardey *et al.* (1996) measured the benefits from USA *adoption*

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[16] This 'deadweight gain' from technology spillovers, which has been paid relatively little attention, is quite large relative to the deadweight loss from Australia's wheat marketing policy. For instance, Longworth and Knopke (1982) estimated that the cumulative effects of Australia's wheat price policy over the period 1948/49–1978/79 represented a net social welfare loss of A\$677 million (1979 dollars). See also, Myers *et al.* (1985).

[17] The geometric rule gave 1/2 to the variety's breeder, 1/8 to the breeders of each of its parents, 1/32 to the breeders of each of its grandparents, and 1/64 to the breeders of each of its great-grandparents.

of CIMMYT wheat varieties holding the world price constant, they did not count the cost to the USA as an exporter associated with the rest of the world having adopted CIMMYT wheat varieties and thereby driving down the price of wheat.[18]

It is difficult to be clear about what is right to hold constant in this kind of analysis, and thus what elements of overall benefits might reasonably be compared with particular elements of donor support for research programs financed multilaterally.[19] A simple first approximation is to assume all else constant and make an adjustment for the price effects of the adoption of CIMMYT varieties globally. That even this is not easy to do, and requires a considerable amount of data, accounts for why we have not already done it.[20] A crude approximation is feasible, however. A back-of-the-envelope calculation using plausible elasticities and other assumptions would suggest that in the absence of the past 40 years of productivity growth, wheat prices would be perhaps 30–50 per cent higher than they are today. If one-third of the total growth in wheat productivity over the past 40 years were attributable to the CGIAR, then in the absence of CGIAR research, current wheat prices would be 10–20 per cent higher. For exporting countries such as Australia and the USA, their net benefits from the adoption of CIMMYT wheat varieties should accordingly be reduced by 10–20 per cent of the value of their wheat exports in the current year, and by corresponding proportions in previous years. Applying price reductions of this order to Australian and USA wheat exports will substantially offset and could even reverse the finding that these countries have received net benefits from CIMMYT wheat research, depending on other aspects of the analysis. For instance, with USA wheat exports worth about US$3 billion in 2000, this adjustment would reduce the USA benefits from CIMMYT wheat varieties by $300–600 million in that year alone.

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[18] Brennan (1986, 1989) noted this point but did not adjust his measures of benefits to Australia from CIMMYT. Most of the studies of this type have not accounted for the CG-induced changes in world prices. Notable exceptions are the studies by Brennan and Bantilan (1999) and Brennan *et al.* (2002) of the impacts on Australian agriculture of research from two other CG centres: ICRISAT and ICARDA. The main effects of these research-induced changes in prices are on the distribution of benefits between producers and consumers and thus among countries. They have little impact on the measures of global benefits.

[19] The relevant counterfactual might be one in which no country adopted any CIMMYT wheat (i.e., CIMMYT did not exist), or one in which the CIMMYT existed but on a smaller scale in the absence of USA or Australian support. And, in either of those cases there might be implied some different rates of varietal development from other research programs (or even different rates of donor support from other countries for CIMMYT).

[20] Pardey *et al.* (2002) have almost done it, though, for CIMMYT wheat and IRRI rice.

Brennan and Bantilan (1999) took explicit account of world price impacts in their assessment of Australia's benefits from ICRISAT research, and Brennan *et al.* (2002) made similar adjustments in their assessment of Australia's benefits from ICARDA research. In the case of ICRISAT research on sorghum, for instance, taking account of the price effect turned what would have been a producer (and national) benefit of A$4.7 million (at full adoption in 1996 dollars), holding prices constant, into a national benefit of A$3.6 million – representing the net effect of a producer loss of A$1.7 million and a consumer gain of A$5.3 million. Similarly, for ICRISAT research on chickpeas, taking account of the price effect turned what would have been an Australian producer (and national) benefit of A$5.2 million (at full adoption), holding prices constant, into a national benefit of A$1.2 million – the net effect of a producer loss of A$2.6 million and a consumer gain of A$3.8 million. These examples show how adjusting for price effects might have very serious implications for the distribution of spillover benefits from the CG system both between producers and consumers within countries, and among countries; hence, on the benefits relative to the costs for particular countries, depending on their trade status and their ability to exploit the technology.

The methods used to partition credit for the benefits from varietal improvement between the domestic national agricultural research system (NARS) and international agricultural research centres (IARC) can also be used to partition credit between the domestic NARS and other NARS. For instance, Pardey and Chan-Kang (2002) quantified the benefits from crop improvement research in Brazil and attributed them between the Brazilian national agricultural research agency (Embrapa) and other public and private agencies operating in Brazil, and spillovers from the CGIAR and the USA. Like Pardey *et al.* (1996) and the other studies mentioned above, the authors used genetic attribution rules combined with actual adoption patterns and experimental yields of individual varieties.[21] This study also raised some additional attribution issues. One issue concerned the addition of overhead costs, such as a share of headquarters administration costs and the costs of pre-technology (say, biotechnology) research incurred in the capital city, Brazilia in support of Embrapa's crop improvement research undertaken at individual regional research centres. Another was how to partition credit for Embrapa releases in proportion to shares of funding support between Embrapa and its public- and private-sector partners in joint-venture projects. Using a geometric attribution rule, the authors found that, of the total

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[21] Other studies that used genetic attribution rules to measure country-to-country spillovers of varietal technologies include Flores-Moya *et al.* (1978), Evenson (1994), Brennan *et al.* (1997), Maredia and Byerlee (2000), and Jin *et al.* (2002), for example.

benefits from varietal improvement for upland rice in Brazil (which had a present value of US$1683 million in 1999 dollars over 1984–2003), non-Embrapa sources were responsible for 64 per cent. Likewise, of the total benefits from varietal improvement research for edible beans (which had a present value of US$677 million in 1999 dollars over 1985–2003) non-Embrapa sources, mostly within Brazil, were responsible for 67 per cent. Similarly, of the total benefits from varietal improvement research for soybeans (which had a present value of US$12 473 million in 1999 dollars over 1981–2003), non-Embrapa sources were responsible for 77 per cent of the total, with 22 per cent of the benefits attributable to spill-ins from the USA.

## 6. Overview of the evidence on international agricultural R&D spillovers

While it is hard to generalise too much from such a large and diverse literature, two points are clear. First, estimation of these state, national, or multinational impacts is data intensive and difficult. The case-study approach, either ex-ante or ex-post, rests on having good estimates of the adoption patterns and the performance of the technological alternatives in farmers' fields (both of which are hard to measure) and a reasonable definition of the relevant counterfactual alternative.[22] If world prices are affected by the technology, as with CIMMYT wheat, then representing the relevant counterfactual may be difficult and demanding of data. Many studies have assumed this element away, with potentially serious implications for the interpretation of their findings. Perhaps most difficult of all is the problem of apportioning credit among the various participants in the global agricultural R&D complex.

A part of this attribution problem in the case-study setting is to determine what part of the total public agricultural R&D budget should be levelled against the particular element of research output being evaluated (and what to do about overhead costs, for instance). This aspect of the attribution problem might be eliminated by studying the impacts of the total system in aggregate, but there are other problems with regression-based estimates. 'While the production function approach is more general than the case study approach, it is much coarser and suffers from all the problems that beset attempts to infer causality from behavioural data on the basis of correlational techniques.' (Griliches 1979, p. 93). In particular, it is necessary to impose many untested restrictions as maintained hypotheses in order to be able to obtain estimates of relationships between research investments and productivity, and then these have to be combined with other assumptions to

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[22] McAfee (1983) provides a memorable treatment of the issue.

derive estimates of benefits. In his Presidential address to the American Finance Association, Black (1986, p. 535) stated 'Sometimes I wonder if we can draw any conclusions at all from the results of regression studies.' While we might not all go that far, there are certainly grounds for skepticism about the potential bias and fragility of many of the published estimates of returns to agricultural R&D, including our own, skepticism that can be extended to estimates of returns to research more generally.

The second main point to emerge from the literature is, however, that even when we view the evidence sceptically there can be little doubt that agricultural R&D generates very large benefits, and that a very large share of those benefits comes through spillovers. Every study cited here found evidence of substantial international spillovers of agricultural R&D. In many cases, spillovers accounted for half or more of the total research benefits in studies of individual countries. This indicates that substantial international market failures in agricultural R&D are likely, given the current institutions. Studies of the impacts of varietal improvement R&D from the international centres of the CGIAR reinforce this idea, showing very large benefits both to individual countries and globally from CG programs.

## 7. Policy responses

Spillovers of results from public agricultural R&D across geopolitical boundaries are positive externalities that give rise to distortions in incentives to undertake certain types of research. An innovating state will not count the benefits to other states that are able to adopt its research results, and will do less such research than would be collectively optimal for the nation, taking into account all of the benefits and costs to all states. This is true when prices can be regarded as unaffected, and may be exacerbated if prices are affected.

Prices might be affected either in the absence of technology spillovers, when the innovating country is a large-country exporter, say, or through technology spillovers, even in the small-country case, if the interstate (or international) adoption of one state's research results gives rise to reductions in world prices. In these two cases, spillovers mean lower benefits to the innovating country as well as innovator benefits being less than global benefits.[23] For example, innovations in the California almond industry might well give rise to a lower world price of almonds, which diminishes the benefits

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[23] If the innovating country were an importer, it would *benefit* from any price reduction arising from the overseas adoption of the new technology (the increase in domestic consumer benefits would exceed the reduction in domestic producer benefits) – see Edwards and Freebairn (1984). A related issue is the role of imperfect competition in input or output markets, which will influence the extent to which changes in costs are translated into changes in prices, and thus the distribution of benefits, see Alston *et al.* (1997).

to California from its innovations (redistributing them towards interstate or international consumers). This effect is even greater if other countries such as Australia and Spain also can adopt the new technology, exacerbating the price-depressing effect.[24] As California does not count the benefits (or costs) to overseas (or even interstate) producers and consumers, it will underinvest in almond research from a global standpoint.

More generally speaking, a geopolitical mismatching of the incidence of the benefits and costs of different types of agricultural research, arising from technological spillovers as well as research-induced price changes, gives rise to distortions from the aggregate viewpoint in the total amount of research undertaken, and the mixture of research projects. Specifically, there will be a greater collective underinvestment by individual states (from a national viewpoint) or individual countries (from a global viewpoint) in research projects for which a larger share of the benefits will accrue elsewhere either because the innovating state (or nation) is a large exporter, or because of large potential interstate or international spillovers of the technology. For such types of research, policies are required that reach beyond the individual state (or nation) to reflect the relevant set of broader interests.

Actual domestic policies adopted by the USA and Australia, for instance, indicate the possibilities for policies that might be adopted to address agricultural R&D spillovers within nations. One such possibility, adopted in both these countries, is federation – where a federal or central government is established to provide national public goods that extend across multiple states.[25] Federation gives rise to the possibility of national or regional programs devised nationally, or the federal provision of incentives to individual states to make more-nearly nationally optimal research investments individually or in cooperation with one another. Included here is the development of national institutions for intellectual property protection that might be employed to manage some aspects of the spillover problem. Another possibility is bilateral or multilateral cooperation among states without the intervention of federal authorities. In both Australia and the USA we can observe elements of these ideas in practice, with important differences between the agricultural research institutions in the two countries (see Alston *et al.* 1998, for instance). How well the various elements work is

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[24] A parallel can be drawn with Leahy and Neary (1997) analysis of public policy towards R&D in oligopolistic industries. Here, the individual states (or nations) can be thought of as playing the role of Leahy and Neary's oligopolistic firms, subject to policy imposed by the federal (or world) government to correct the distortions in their incentives. See, also Leahy and Neary (1999).

[25] Other geographically and economically large countries that have a national-state (or provincial) structure for agricultural research (among other things) include Brazil, Canada, and India.

affected by the number and diversity of the states, and their agricultural sectors, as well as the constitutional division of powers between the states and the federal government.

An important policy innovation in Australia that has no real parallel in the USA has been the development of levy-based funding through Research and Development Corporations (RDCs), supported with matching grants from the federal government. This innovation appears to have led to a substantial increase in the total funds available for public agricultural R&D (at least compared with the likely situation without the RDCs); it may also have had significant impacts on the nature of the research undertaken. Levy-based funding for commodity-orientated agricultural R&D within a nation renders state borders irrelevant and thus resolves the issue of interstate spillovers. Compared with funding from general revenues of the federal (or state) governments it has another virtue in that it gives rise to a closer matching of the incidence of benefits and the incidence of costs. It might also be a more-efficient source of funding once we give consideration to the excess burden of taxation associated with general government revenues, and the potential relative efficiency of commodity taxes.

Nevertheless, geopolitical incidence problems can arise even with levy-based funding of national RDCs – paradoxically, problems that are greater when agroecological variation is greater. While the potential for agricultural R&D spillovers (and spillover problems) is greater when different geopolitical regions are more agroecologically similar (i.e., when the states of a nation are more homogeneous), the political problems with national approaches to financing research are greater when the nation is more agroecologically heterogeneous. Heterogeneity gives rise to competing research agendas within the industry, with different groups preferring research related to different particular agroecologies, making cooperative or collective solutions more difficult to reach and sustain. For certain types of research, however, levy-based approaches might be fair and efficient, and an effective national policy approach for addressing research applicable in more than one state within the nation. This will be most-clearly so for research that is more-nearly uniformly applicable among different production regions. For other types of research, applicable less uniformly, other approaches might be more useful for addressing spillovers – such as federal funding, or cooperative federal–state or state-to-state arrangements. A variety of such approaches have been employed in the USA, and a large share of the total agricultural research effort is either federally funded or influenced by federal funding, or has some multistate elements. Nevertheless, if the AJPZ results are to be believed, it seems likely that there are still substantial distortions in research resource allocation – in terms of both the total investment in agricultural R&D and its allocation among federal intramural R&D, state research and extension, and among states, and probably also in the allocation within states, among fields of science and commodity orientations–associated with interstate spillovers of public agricultural R&D and technology in the USA.

The same types of policy responses, while conceivable in principle, are less clearly feasible for dealing with international spillovers. In the absence of a 'world government' and the corresponding coercive powers, only voluntary and cooperative options remain. Several recent studies have discussed the general issue of multinational or global public goods (e.g., Kindelberger 1986; Sachs 2000; Dalrymple 2001) – topics ranging from global warming to HIV/AIDS to world hunger – and the general failure of institutions to address them. Others have addressed agricultural R&D specifically as an example of a global public good, including Anderson (1998), Sachs (1999), Pinstrup-Andersen (2000), Dalrymple (2001), and Gardner (2002), for the most part relating to the CGIAR, a 'new' perspective that might give new insights.

The policy implications of substantial international spillovers of results from public agricultural research have been discussed elsewhere as well. For example, Pray and Fuglie (2000) discuss harmonising food and agricultural regulations, reducing global trade barriers, and strengthening intellectual property rights, which can be seen as potential policy complements to national and international agricultural science policy. The same authors also discuss the actual past and potential future gains from collaboration among NARSs, and between NARSs and the IARCs, taking advantage of their different comparative advantages in things such as basic biological sciences and more labour-intensive plant breeding activities. This line of argument complements that of Maredia and Byerlee (2000), promoting the idea that as well as gaining economies from specialisation and the division of labour among NARS, there are potential economies of size and scope to be garnered by a more efficient organisation of the global agricultural research system. An earlier discussion of these ideas may be found in Pardey *et al.* (1991).

What is lacking, however, is an institutional design (and perhaps the political wherewithal to implement it) that will address the free-rider problems and information and transactions costs that have so far prevented the emergence of substantial cooperative solutions to the international agricultural R&D spillovers problem. Perhaps the most important innovation along these lines has been the CGIAR system (as well as the other IARCs), and most of the literature in this area ends up arguing for greater international support of the CG system as a way of addressing the spillovers problem. A weakness of the CG system to date has been the fact that it has been implemented not as an element of (agricultural) science policy, or agricultural policy; rather it has been implemented (at least, for the most part) through the international economic development aid programs of the donor nations. In the early days, the mandate of the system was clear and simple – to build a bigger pile of grain – and not inconsistent with a policy of addressing international market failures in agricultural science. With time, and the evolution of the system and its mandates, however, things have changed. The current philosophy and priorities of the donors and the CG leadership, may be consistent with addressing international market failures in agricultural research only insofar as they coincide with income distributional problems – poverty, malnutrition, and the like – to which the CG system explicitly targets much of its activity.

The CG system might well be the appropriate agency within which to conduct agricultural R&D funded cooperatively by multiple nations, but the use of donor funds through aid agencies might not be the best way to fund research with a view to addressing spillovers and their implications – any more than we would expect domestic welfare agencies to do a good job of financing, managing, and setting priorities for agricultural research among states within a country. As national agricultural research does among states, international agricultural research might make use of collaborative arrangements among NARS, possibly funded with a mix of general revenues, hypothecated taxes, or both, from the member states. If, for instance, all nations of the OECD were to collect a tax equal to one-tenth of 1 per cent of the value of all of their agricultural production (worth, say, US$800 billion per year), to be used to fund a pool to finance international agricultural research, this would generate US$800 million per year, which might not solve the spillovers problem entirely, but would make a huge difference nevertheless. Even if these funds were to become available, there would remain the practical political problem of devising institutions for spending the money to greatest effect to counter the existing international market failures in public agricultural R&D.

## 8. Conclusion

Agricultural productivity gains as a result of public agricultural research investment have been and will continue to be critical to global economic growth and food security, allowing rising standards of living for a still rapidly growing population in spite of a shrinking natural resource base. This is not disputed by anyone; nor is the idea that international or interstate spillovers are important, although they are often not taken into account in empirical analysis.

Spillovers across geopolitical borders are important enough to cause significant biases in studies that ignore them. The omission or mismeasurement of spillover effects may have contributed to a tendency to overestimate rates of return to agricultural R&D in some instances. At the same time, however, spillovers might help account for why the actual rates of return are as high as they are and why; nevertheless, funding support for public agricultural R&D is waning. Studies typically find that in the range of half of the research benefits in any state or nation may be attributable to spill-ins from other places, and that benefits to other places from spillouts might be of similar magnitudes to their own benefits from research conducted by a state or nation. When the research is directed at multiple locations – such as USDA research benefiting many states or CGIAR research benefiting many nations – the 'spillover' aspect becomes quantitatively even more important. Given such substantial differences between total 'social' and 'private' benefits, we should not be surprised to find distortions in research investments undertaken by state governments from the point of view of the nation, or national governments from the global perspective.

Spillovers add to the measurement problems in evaluating research impacts. Accounting for spillovers in ex-ante analysis of particular technologies requires anticipating the research results and the resulting adoption patterns. More recent studies have been adding refinements in terms of the use of agroecological information to predict adoption patterns, mapping across geopolitical boundaries, but it remains difficult to define and quantify meaningful hypothetical technological alternatives and the work is information (and time) intensive. Nevertheless, work of this type is potentially very productive in research-management contexts where spill-overs are relevant. In studies of particular cropping technologies, recent studies have been using increasingly detailed data on varietal adoption, on genetic history of varieties, and on experimental and commercial yield performance, but it is still necessary to use arbitrary rules to attribute credit for genetic gains among generations.

More-recent work has illuminated the issue of apportioning credit, and has shown the potential magnitude of benefits in particular from CG centres to particular countries, including donors, but there remains room for improvement in the methods and for the development of data and results. In the context of aggregative studies, using econometric methods, spillovers add to the number of explanatory variables to be considered in a setting where multicollinearity and other statistical problems are already serious. The necessary response is to impose additional restrictions on the estimation, but this tends to reduce confidence in the robustness of the results. Fortunately, the phenomenon we are dealing with is so large that, while choices made by the analyst might affect the particular results, they cannot change the key point: agricultural productivity is very important and valuable, and interstate and international R&D and technology spillovers have contributed a substantial share – perhaps half or more – of the total gains.

Within a country, interstate spillovers can be addressed by federal action, or by multi-state cooperation. Among countries, international spillovers are harder to resolve with existing institutional frameworks, but knowing better the nature and extent of these spillovers will surely help, and an investment in such knowledge is a useful first step. There is room for much more bilateral cooperation. A truly multinational approach could be developed, and the CGIAR could play a significant role in implementing it. A significant impediment, however, might be the fact that the CG system is seen by several key donors as a vehicle for implementing international humanitarian development aid, rather than as a vehicle for providing international public goods to address a global market failure in agricultural R&D arising from international spillovers.

It has been my purpose to demonstrate that agricultural R&D spillovers are important and interesting but not well understood, and that they are a worthy subject for further study. More work is needed both to develop better methods of measurement and better measures, and to develop better institutions and policies. A lot of good work has already been done on this subject, and a disproportionate amount of that by Australians. I hope this may continue.

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## Appendix

### List of acronyms and abbreviations

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| IDB | Inter-American Development Bank |
| CG | CGIAR |
| CGIAR | Consultative Group on International Agricultural Research |
| CIAT | Centro Internacional de Agricultura Tropical |
| CIMMYT | Centro Internacional de Mejoramiento de Maiz y Trigo |
| CIP | Centro Internacional de la Papa |
| EU | European Union |
| FAO | Food and Agriculture Organisation of the United Nations |
| GATT | General Agreement on Tariffs and Trade |
| GDP | gross domestic product |
| IARC | International Agricultural Research Centre |
| ICARDA | International Centre for Agricultural Research in the Dry Areas |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| IFPRI | International Food Policy Research Institute |
| IRRI | International Rice Research Institute |
| LDC | less-developed country |
| NARS | national agricultural research system |
| OECD | Organisation for Economic Cooperation and Development |
| R&D | research and development |
| SAES | State Agricultural Experiment Station |
| USDA | United States Department of Agriculture |