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Beyond semi-dwarf wheat yield increases: impacts on the Australian wheat industry of on-going spillovers from the International Maize and Wheat Improvement Center

John P. Brennan†

Wheat genetic materials developed from research at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico for developing countries have provided spillover benefits to Australia. Varieties developed from those genetic materials have resulted in yield increases in Australia. While the initial impact came through the introduction of higher-yielding semi-dwarf wheat crops, those impacts have continued in the post-semidwarf period. CIMMYT's success in developing countries has also reduced the world price for wheat. While the lower prices affect returns in Australia, the increased yields in Australia from the CIMMYT spillovers from both the semi-dwarfs and the post-semidwarf phases have provided benefits to Australia averaging A$30 million per year.

Key words: R&D evaluation, R&D policy, spillovers, technology adoption.

1. Introduction

1.1 Background

Wide-ranging impacts on crop productivity have occurred through the crop variety improvement activities of the international agricultural research centres (Evenson and Gollin 2003a,b). The wheat breeding program at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico has led to large increases in wheat yields in many developing countries throughout the world, particularly through the development and widespread use of semi-dwarf varieties (for example, see Lantican *et al.* 2005). Even though CIMMYT's breeding program has been directed at developing countries, Australia has benefited from it (Brennan 1989; Brennan and Fox 1995).

The impacts of the semi-dwarf wheat crops and the Green Revolution have been reviewed extensively, but there is now increasing evidence that global impacts on wheat productivity have continued in the post-Green Revolution period (Byerlee and Moya 1993; Byerlee and Traxler 1995). Gollin *et al.* (2005) have highlighted a number of the key issues related to technological change in developing countries in that period. While there have been several

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studies of CIMMYT impacts on developed countries (Brennan and Fox 1995; Pardey *et al.* 1996; Thomas 1996), the post-Green Revolution impacts on developed countries have not been closely documented. The aim in this paper is to assess the spillover benefits from CIMMYT to Australia, with particular emphasis on the post-semidwarf impacts.

Australia has contributed regularly to CIMMYT's core funding since its inception, and has also developed a range of project-based funding with CIMMYT. As a result, there have been a number of successful collaborations between CIMMYT and Australian scientists. These arrangements have ensured that Australia has been in a position to take advantage of any potential spillover benefits that might result from CIMMYT's work.

Studies of the impact of research at Consultative Group on International Agricultural Research centres such as International Crops Research Institute for the Semi-Arid Tropics (Brennan and Bantilan 1999, 2003) and International Center for Agricultural Research in the Dry Areas (ICARDA) (Brennan *et al.* 2002, 2003) have shown the importance of the price effects in assessing not only the total net benefits to Australia but also in the distribution of those benefits globally. Where these centres have achieved major productivity gains at the global level, the world price is likely to be lower for all producers (including Australia) than if they had not achieved that success.

1.2 Attribution of gains to CIMMYT in this study

Alston and Pardey (2001) have highlighted the significant issues relating to the attribution of research outcomes to particular sources. CIMMYT has to some extent been a clearing-house for wheat genetic resources from around the world, and as a result the countries from which those genetic resources originated have a claim on some of the benefits of CIMMYT's work. For convenience, the benefits of any such genetic materials are attributed in this study to CIMMYT, rather than to any country making a prior contribution.

At the same time, the main strength of CIMMYT has been to enhance and further develop genetic materials, rather than to act simply as a clearing-house. The crosses made at CIMMYT have meant that most of the CIMMYT material has been changed substantially from the original genetic resources introduced into CIMMYT's germplasm collection. In particular, CIMMYT has: (i) used shuttle breeding to speed up genetic improvement; (ii) developed wide adaptation of semi-dwarf materials through testing of segregating material under a wide range of disease pressures; (iii) developed crosses between spring and winter wheat crops; (iv) incorporated genetic translocations from rye into wheat; (v) developed durable rust resistance; and (vi) developed synthetic wheat developed from wide crosses with wild relatives of wheat (Brennan and Quade 2004). As Alston and Pardey (2001) noted, the attribution difficulties for these developments remain complex, but it is clear that CIMMYT has added considerable value to the genetic material from around the world. In this study, we label the outcomes from that research as

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'CIMMYT-derived varieties', 'CIMMYT varieties' or 'CIMMYT materials', whilst noting the vital prior contributions of other countries.

1.3 Outline of the paper

In the next section, the nature of CIMMYT's impact on Australia is discussed, along with the impact of CIMMYT's semi-dwarfs on wheat yields in Australia and the yield impacts of CIMMYT beyond the semi-dwarfs. The economic value of these yield increases is estimated in section 3 in a market framework that incorporates price impacts and determines the distribution of those benefits. In the final section, the results are discussed and some implications are highlighted.

2. Impacts of CIMMYT in Australia

2.1 Nature of CIMMYT impacts in Australia

Following Byerlee and Moya (1993) and Byerlee and Traxler (1995), there have been two phases to the impacts of CIMMYT's wheat breeding program:

- Initial introduction and usage of semi-dwarf wheat varieties derived from CIMMYT (Phase 1)
- Replacement of the earlier semi-dwarfs by higher-yielding varieties through the continuing use of CIMMYT materials in breeding programs (Phase 2)

The initial adoption of semi-dwarf wheat (Phase 1) led to yield improvements around the world. The level of improvement varied with the production environment, but generally there were significant yield improvements associated with the change from older tall wheat crops to semi-dwarf wheat varieties. While CIMMYT's research has been targeted at developing countries (for example, see Lantican *et al*. 2005), the varieties developed have been grown in many areas apart from the target regions, and spillover benefits to developed countries such as Australia have resulted. As outlined in Brennan and Fox (1995), the semi-dwarf varieties have greatly modified the nature of Australian wheat crops, and have brought about improvements in plant structure and productivity.

Few of the lines that Australia has been importing from CIMMYT since the 1960s have been suitable for direct release for commercial production in Australia. In most cases, the CIMMYT lines have been used as parent lines in Australian wheat breeding programs, and Australian breeders have combined them with other Australian varieties to develop improved varieties adapted to the Australian environment (Brennan and Quade 2006). Thus the strength of the Australian wheat breeding programs has enabled Australia to obtain the gains provided through germplasm from CIMMYT.

Since the release of the first semi-dwarf varieties in Australia in 1973, until 2003, 216 wheat varieties have been released in Australia for commercial production. Of those, 192 varieties (89 per cent) have had at least one CIMMYT line in their pedigree. In developing those varieties, the Australian breeders have used a range of strategies, including directly releasing a variety developed

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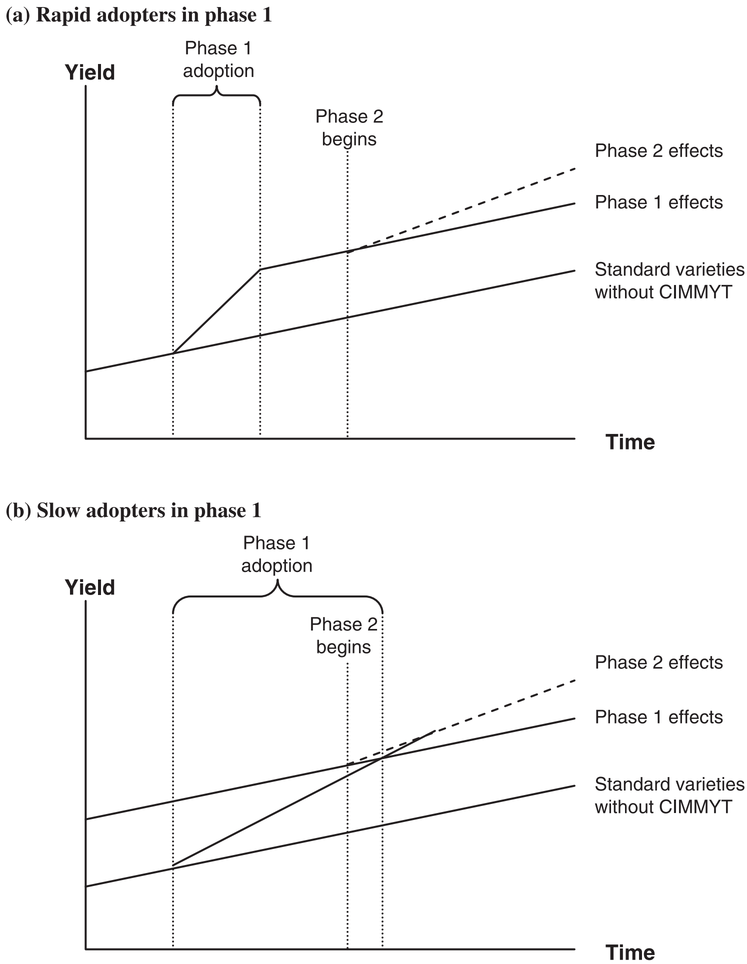

Figure 1 Effect of CIMMYT germplasm on rate of yield increase. (a) Rapid adopters in Phase 1. (b) Slow adopters in Phase 1.

by CIMMYT (3 per cent), using CIMMYT varieties as a parent in a crossing program (23 per cent) or using CIMMYT-derived lines as parents in the crossing program (63 per cent). An analysis of the evolving usage of CIMMYT materials in the development of Australian wheat varieties reveals a trend away from direct use of CIMMYT lines for release or for use as parents, and an increasing trend towards the release of varieties with CIMMYT in earlier stages of the pedigree (Brennan and Quade 2006).

Following adoption of the semi-dwarfs, subsequent CIMMYT research has led to further yield improvements; in Phase 2, the yield gains achieved with the use of semi-dwarfs were consolidated and enhanced. CIMMYT's research has continued to contribute to yield gains around the world, even in those regions where semi-dwarfs have long been adopted. Australia is now in this second phase.

The analysis of the impact of CIMMYT's spillovers is based on the two phases operating together (Figure 1). The initial adoption of semi-dwarfs is

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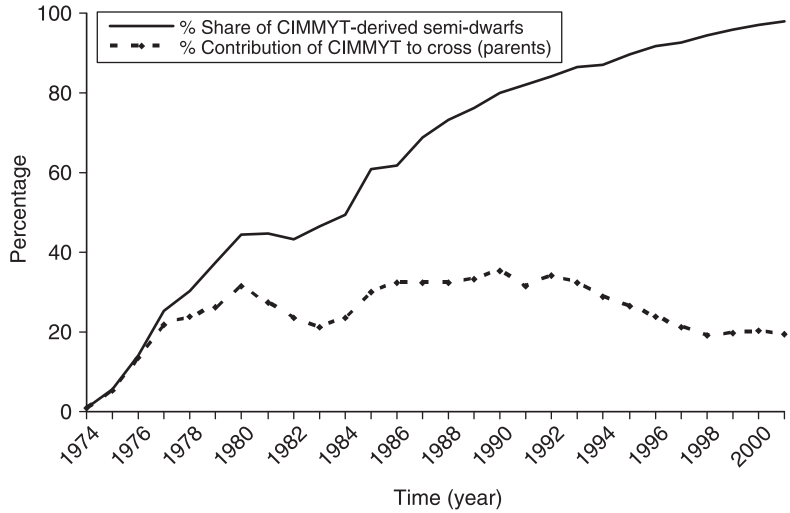

Figure 2 Contribution of CIMMYT to gains from CIMMYT-derived varieties (based on origin of parents used in cross).

seen as a permanent upward shift in yields, and as adoption of the semi-dwarfs approaches 100 per cent in each state, these gains are fully realised. Because the germplasm from CIMMYT is the same for each state, the technology for the start of Phase 2 is common to all states. As a result, all states are assumed to have the same starting-year for Phase 2, whether or not Phase 1 has been completed in that state. For the states with rapid adoption of semi-dwarfs, the situation is illustrated in Figure 1a; Phase 1 is completed before Phase 2 begins. For the states with slower adoption of semi-dwarfs (Figure 1b), Phase 2 begins before Phase 1 is completed.

2.2 Impact of Phase 1: CIMMYT's semi-dwarf wheat varieties in Australia

Analysis indicates that, with the adoption of the semi-dwarf wheat varieties, the yield increases attributable directly to CIMMYT by 2001 (Table 1) ranged from 4.1 per cent in Queensland to 0.1 per cent in Western Australia (Brennan and Quade 2006). At their peak in the mid-1980s, the direct contribution of CIMMYT was markedly higher in each state, but the trend has been for an increasing use of second-, third- and subsequent-generation lines from Australia as parents rather than the original CIMMYT semi-dwarfs. As a result, the direct CIMMYT contribution to those varietal gains has declined in the past 15 years or so (Fig. 2). At the national level, CIMMYT's contributions to the first phase increases have been as high as 2.5 per cent in 1990, but were only 1.3 per cent in 2001. Thus, although the CIMMYT-derived semi-dwarf wheat varieties led to varietal yield increases as high as 9.2 per cent in Queensland, the majority of those gains (based on contribution to pedigree) were attributable to the Australian breeders and their already-adapted materials, rather than directly to the CIMMYT contribution.

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Table 1 Yield increases from semi-dwarfs attributable to CIMMYT (per cent increases due to CIMMYT)

Year	New South Wales	Victoria	Queensland	South Australia	Western Australia	Australia
1973	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.2	0.0	0.0	0.0	0.0	0.1
1975	1.2	0.1	0.6	0.1	0.0	0.4
1976	2.4	1.1	2.3	0.7	0.0	1.0
1977	3.7	2.4	3.2	0.9	0.0	1.5
1978	4.2	2.6	2.8	1.1	0.1	1.7
1979	4.4	3.1	2.3	1.5	0.1	1.9
1980	5.5	3.7	1.7	1.8	0.2	2.2
1981	4.3	4.4	1.3	1.8	0.2	2.0
1982	3.4	4.1	1.1	2.0	0.2	1.7
1983	2.0	4.8	1.3	1.8	0.2	1.5
1984	1.8	5.6	1.9	2.2	0.2	1.7
1985	2.0	6.5	2.9	2.1	0.4	2.1
1986	2.7	6.3	2.8	1.8	0.6	2.3
1987	2.9	5.0	3.6	1.7	0.6	2.3
1988	3.2	4.7	4.0	1.6	0.6	2.3
1989	3.3	4.8	4.8	1.4	0.6	2.4
1990	3.6	4.8	5.5	1.4	0.6	2.5
1991	3.4	5.0	4.5	1.4	0.6	2.2
1992	3.4	4.9	5.9	1.4	0.7	2.4
1993	3.6	5.2	4.1	1.1	0.7	2.3
1994	3.4	4.8	7.0	0.8	0.5	2.1
1995	3.3	4.8	4.0	0.6	0.5	1.9
1996	2.9	3.3	3.9	0.5	0.4	1.7
1997	2.5	2.6	4.3	0.4	0.4	1.5
1998	2.3	1.9	4.4	0.3	0.3	1.4
1999	3.0	1.7	4.7	0.4	0.2	1.4
2000	3.6	1.8	5.1	0.4	0.1	1.4
2001	3.5	1.8	4.1	0.4	0.1	1.3

2.3 Impact of Phase 2: post-semidwarf impacts in Australia

Adoption of semi-dwarfs varies across the states. The first semi-dwarfs were released in 1973, and began production in 1974 in New South Wales and Queensland. Other states were slower to begin adoption. Once adoption started, it proceeded rapidly in the eastern states, and more steadily in South Australia and Western Australia (Brennan and Quade 2004).

The second phase of CIMMYT impacts occurs where the original semi-dwarf varieties were being replaced by improved semi-dwarfs with higher productivity. Because the germplasm from CIMMYT was the same for each state, the technology available for Phase 2 is common to all states. As a result, all states are assumed to have started Phase 2 in 1988, whether or not Phase 1 was completed in that state.

The CIMMYT technologies involved in the post-semidwarf period (Phase 2) have generally related to improved disease resistance, particularly rust

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Table 2 Yield increases attributable to CIMMYT from post-semidwarfs gains (per cent increases due to CIMMYT)

Year	New South Wales	Victoria	Queensland	South Australia	Western Australia	Australia
1988	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.3	0.5	0.5	0.2	0.2	0.3
1990	0.7	1.1	1.0	0.4	0.4	0.6
1991	1.1	1.7	1.5	0.6	0.7	0.9
1992	1.4	2.2	2.1	0.8	0.9	1.2
1993	1.8	2.8	2.5	1.0	1.1	1.5
1994	2.2	3.4	3.2	1.1	1.3	1.8
1995	2.5	4.0	3.7	1.2	1.5	2.1
1996	2.8	4.4	4.1	1.3	1.6	2.3
1997	3.1	4.7	4.5	1.4	1.7	2.5
1998	3.3	4.9	5.0	1.4	1.8	2.7
1999	3.6	5.1	5.5	1.5	1.9	2.9
2000	4.0	5.3	6.0	1.6	1.9	3.1
2001	4.4	5.6	6.4	1.6	2.0	3.2

resistance; improved tolerance to abiotic stresses such as soil acidity; and other more general improvements in yield potential since the development of the initial semi-dwarfs. These improvements resulted in yield increases in addition to those associated with the initial shift to semi-dwarf varieties. The extent of those further increases from Phase 2 is more difficult to determine from the available data.

From 1983 to 2001, Australian wheat yields increased by an average of 1.86 per cent per year. Brennan and Bialowas (2001) found that 50 per cent of yield increases in New South Wales were attributable to varieties and 50 per cent to other farm management factors. Thus the varietal increase that has taken place nationally in the period in which CIMMYT's Phase 2 has been operating is taken as 50 per cent of total yield increases, or 0.93 per cent per year. CIMMYT's share of those increases was determined by its contribution to the pedigrees of those varieties. Thus, where CIMMYT contributed 30 per cent to the pedigrees of the varieties in one state in a particular year, it is taken as contributing 30 per cent of the 0.93 per cent gain in yield in that year, on top of the gains from the Phase 1 increase in yield level from the initial adoption of semi-dwarfs (Brennan and Quade 2004).

By 2001, Queensland and Victoria had both received yield gains from CIMMYT in excess of 5 per cent, with New South Wales at 4.4 per cent (Table 2). South Australia and Western Australia both had received 2.0 per cent or less by 2001 through post-semidwarf yield gains. On average, the yield gains were 3.2 per cent for Australia by 2001, in addition to the gains from the semi-dwarfs.

From both the Phase 1 semi-dwarfs and the Phase 2 post-semidwarfs, the varietal yield gains for Australia attributable directly to CIMMYT averaged 4.6 per cent for Australia by 2001 (Table 3). For South Australia and Western

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Table 3 Total yield increases attributable to CIMMYT from Phases 1 and 2 (per cent increases due to CIMMYT)

Year	New South Wales	Victoria	Queensland	South Australia	Western Australia	Australia
1973	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.2	0.0	0.0	0.0	0.0	0.1
1975	1.2	0.1	0.6	0.1	0.0	0.4
1976	2.4	1.1	2.3	0.7	0.0	1.0
1977	3.7	2.4	3.2	0.9	0.0	1.5
1978	4.2	2.6	2.8	1.1	0.1	1.7
1979	4.4	3.1	2.3	1.5	0.1	1.9
1980	5.5	3.7	1.7	1.8	0.2	2.2
1981	4.3	4.4	1.3	1.8	0.2	2.0
1982	3.4	4.1	1.1	2.0	0.2	1.7
1983	2.0	4.8	1.3	1.8	0.2	1.5
1984	1.8	5.6	1.9	2.2	0.2	1.7
1985	2.0	6.5	2.9	2.1	0.4	2.1
1986	2.7	6.3	2.8	1.8	0.6	2.3
1987	2.9	5.0	3.6	1.7	0.6	2.3
1988	3.2	4.7	4.0	1.6	0.6	2.3
1989	3.6	5.3	5.3	1.6	0.8	2.7
1990	4.3	5.9	6.5	1.8	1.1	3.1
1991	4.5	6.7	6.0	2.0	1.3	3.2
1992	4.8	7.1	8.0	2.2	1.5	3.7
1993	5.4	8.0	6.6	2.1	1.8	3.8
1994	5.6	8.2	10.3	2.0	1.8	3.9
1995	5.8	8.8	7.6	1.9	1.9	4.0
1996	5.7	7.7	8.0	1.8	2.0	4.0
1997	5.5	7.3	8.8	1.8	2.1	4.0
1998	5.7	6.8	9.3	1.8	2.1	4.1
1999	6.6	6.8	10.2	1.9	2.1	4.3
2000	7.6	7.1	11.1	2.0	2.0	4.5
2001	7.9	7.4	10.5	2.0	2.0	4.6

Australia, these gains were 2.0 per cent in 2001, while for Queensland (10.5 per cent), New South Wales (7.9 per cent) and Victoria (7.4 per cent) they were higher.

3. Economic analysis of impacts

3.1 Framework for analysis of spillover impacts

In economic terms, the yield-increasing effects of a new variety result in a shift of the supply curve (Lindner and Jarrett 1978; Norton and Davis 1981; Edwards and Freebairn 1984). The increase in productivity is defined as a parallel downward shift in the supply curve through a lowering of the production costs per tonne (Edwards and Freebairn 1984). The benefits that are measured are changes in the producer and consumer surpluses. The analysis aims to measure the difference between the producer and consumer surpluses

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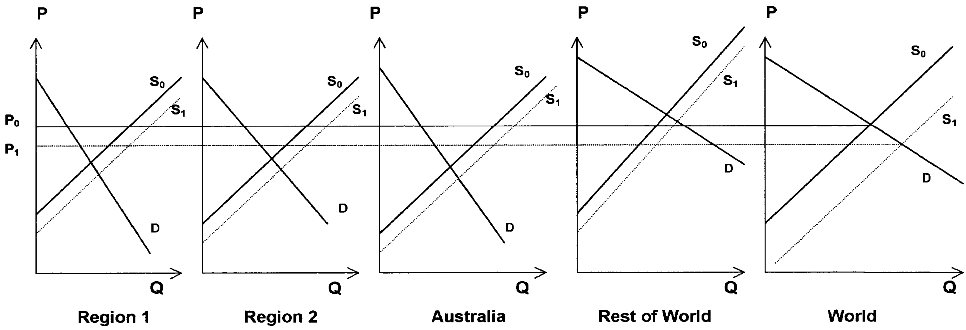

Figure 3 Spillover framework. Reproduced from Brennan and Bantilan (2003).

with the CIMMYT contribution and the surpluses that would apply if there were no impact from CIMMYT.

The net benefits of agricultural research in a tradable commodity in a particular region are influenced by the spillover of the effects of that research to other producing regions with which the target region competes for a share of the world market (Edwards and Freebairn 1984). It is likely that the increased supply resulting from the increased productivity in developing countries obtained through CIMMYT material (Evenson and Rosegrant 2003) has affected the prices received for Australia's wheat production, so that the net gains to Australian producers indicated by this analysis are lower than if the assumption of perfect elasticity had been maintained. As a result, these price effects are likely to reduce the benefits for Australian producers of those crops, while at the same time producing benefits for Australian consumers. While a large proportion of production in some of the crops analysed is not traded, the simplifying assumption of a single world price applying to all production is a practical means of allowing us to assess the impacts on Australia, which is the main objective of the study.

The framework used in this analysis of spillovers is based on Edwards and Freebairn (1984). The world market for wheat is disaggregated into two major component regions, namely Australia and the Rest of the World (ROW). Australia is further disaggregated into five wheat-producing states. The empirical analysis was carried out using the Dynamic Research Evaluation Model (DREAM) evaluation model (Alston *et al.* 1995, appendix A5.1.2). For each of the crops, the data were used in DREAM, run as a horizontal multimarket to provide analysis of the spillovers from CIMMYT to Australia (and in states within Australia).

The framework is illustrated in Figure 3, where P is price and Q is the quantity supplied or demanded. CIMMYT research leads to a shift in supply curves for each region from S_0 to S_1. Direct shifts are obtained in the ROW (the 'target' region for that research), with spillovers impacting on Australia. For simplicity in this analysis, the impacts on developed countries other than Australia are incorporated with the ROW. Results for the ROW are provided

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Table 4 Elasticities† of supply and demand used in analysis

	Supply elasticity	Demand elasticity
Australia	0.25	−0.20
Rest of World	0.30	−0.20

† Elasticity = (ΔQ/Q)/(ΔP/P).
Source: ACIAR spillover model (D. Templeton, pers. comm.).

in this report for completeness, but they do not reflect the impact on individual countries.

The shifts in supply in the ROW and regions within Australia lead to a shift in the aggregate supply curve for the World. The shift in the world supply leads to a price fall from P_0 to P_1, given that there has been no change in the demand curve. The lower price feeds back to each region, so that each region faces a changed equilibrium price as well as the shift in the supply curve. The resultant welfare gains are measured as changes in producer and consumer surpluses for each of the regions.

In estimates of supply shifts, the technological impact of CIMMYT is expressed as a percentage yield gain. Following the way in which the Alston *et al.* (1995) analysis has been incorporated into the DREAM analytical model, a simplifying assumption is that the world price represents an equilibrium at which the total cost of production equals the price. On that basis, the world price is a proxy for the total costs per tonne without the CIMMYT technology. Increases in yield due to CIMMYT lead to a reduction in costs, which measures the downward shift in the supply curve. The calculation of the shift is determined by the yield increase and the demand and supply elasticities, as outlined in Alston *et al.* (1995).

For the empirical analysis, the data on area, yield and production in Australia for wheat in recent years were obtained from ABARE (2004a,b). World area, yield, production and trade data were obtained from FAO statistics (FAO 2004). The prices used in the analysis were also obtained from ABARE. Average prices are taken as A$216 per tonne, based on the average unit value of production in the three years to 2002–03. The supply and demand elasticities used in the analysis were derived from elasticities obtained from ACIAR (Table 4). Details of the parameters used in the empirical analysis are outlined in Brennan and Quade (2004).

In a static analysis such as this, a number of simplifications are made. One such simplification is the lack of dynamic aspects such as second-round impacts on demand or supply of other commodities as a result of an increase in yields, and therefore income. As in Brennan *et al.* (2002), a further simplification is that demand is assumed to remain static. Consequently, an increase in productivity leading to a downward shift of the supply curve means that the price falls. However, it is likely that in the time period used in this analysis, increases in world population and income are likely to lead to

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Table 5 Global impact of CIMMYT on wheat, 1965–2001

Region	Production 1995–1997 (million tonnes)	Yield increase from CIMMYT (per cent)
Developing countries	271.6	22.6
Other developed countries without Australia	291.9	3.0
Rest of World	563.4	12.5
Australia†	24.8	4.6
World total	584.2	12.2

† Weighted average yield increase, from Table 4.

an upward or outward shift in the demand curve, so that the actual price may not fall over the period of the analysis. Nevertheless, since the welfare analysis measures the difference between the with- and the without-CIMMYT scenarios, the results would be similar whether or not the demand curve shifts out over time.

3.2 Economic analysis of CIMMYT's impact on Australian wheat industry

The yield increases attributable directly to CIMMYT (Table 4), from both Phases 1 and 2, are used in the analysis of CIMMYT's impact. Estimation of the extent to which CIMMYT's research has affected wheat productivity in the ROW is complex. There have been many studies, including Byerlee and Moya (1993), Byerlee and Traxler (1995) and Heisey *et al.* (2002), which have addressed this issue, culminating with the very detailed work described in Evenson and Gollin (2003a). However, even within each of those studies, there is no clearly defined estimate published that can be readily utilised. Instead, an estimate had to be developed from the information provided in those papers, as follows (Table 5):

1. Heisey *et al.* (2002) suggest that CIMMYT has led to yield increases in developing countries between 0.2 and 0.4 t/ha; we use their mid-point estimate, 0.3 t/ha.[1] Given that wheat yields in those countries averaged 1.33 t/ha in 1965–67, the assumed increase in production in yield in developing countries is 22.6 per cent over the period 1965–97.
2. Following the work of Pardey *et al.* (1996) and Thomas (1996), the impact on some developed countries has been significant, while it is unclear how much CIMMYT has influenced yields in Europe or much of the former Soviet Union in the period up to the late 1990s. However, the overall impact is clearly less than for the developing countries targeted by CIMMYT. We attribute to CIMMYT a 3.0 per cent increase for all countries other

[1] In a more recent study of the impact on developing countries by 2002, Lantican *et al.* (2005) identified a range of 0.15–0.45 t/ha, also with a mid-point of 0.30 t/ha.

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Table 6 Welfare impacts of spillovers from CIMMYT to Australia 1965–2020 (present value, 2003 Australian dollars)

	Producer surplus (A$ million)	Consumer surplus (A$ million)	Total welfare (A$ million)	Price (A$/t)
CIMMYT spillover benefits to Australia				
Australia	–1239	566	–673	
Rest of World	53 661	78 340	132 001	
Total	52 422	78 906	131 328	200.10
No spillover benefits to Australia				
Australia	–2659	560	–2099	
Rest of World	54 375	77 606	131 982	
Total	51 717	78 167	129 883	200.30
Net gains from spillovers to Australia				
Australia	1420	5	1425	
Rest of World	–714	734	20	
Total	706	739	1445	–0.20

than developing countries and Australia over the period 1965–97, based on an arbitrary assessment of the available data.

3. Using average world wheat production data for 1995–97, the weighted average yield increase for the ROW is 12.5 per cent.
4. These increases were assumed to occur at a regular linear rate between 1965 and 2001, and were projected to 2020.

In this analysis, the value to Australia of CIMMYT's existence is not addressed directly, but rather the value of the spillovers from CIMMYT is assessed. The broader question of the value of CIMMYT's existence is addressed more directly in Evenson and Rosegrant (2003) for the entire CGIAR system. However, an estimate of the impact of CIMMYT itself on Australia is a by-product of the analysis undertaken. With or without Australia's involvement in CIMMYT and spillovers from CIMMYT to Australia, CIMMYT wheat varieties would have increased production in the ROW. Therefore, the large price effects likely to result from CIMMYT's success in that task would have been felt by Australian producers in any case. Given that Australia has been able to capture some spillover benefits through collaborative research, those effects have been mitigated. Thus, the counterfactual for this analysis is the absence of any spillover yield benefits to Australia from CIMMYT.

Initially, the analysis was run for the current situation in which CIMMYT provides benefits to the ROW and the observed spillovers to Australia. In that situation, the substantial gains from CIMMYT in developing countries lead to large supply shifts, and a fall in price from the initial A$216.00 to A$200.10. That fall (7.4 per cent) in price results in loss of producer surplus in Australia of A$1239 million over the period 1965–2020, that is partly offset by gains of A$566 million for Australian consumers (Table 6). Thus, while the ROW has net gains (shared by both producers and consumers) of

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A$132 billion over that period,[2] Australia as an exporter suffers a net loss of welfare of A$673 million from the successful work of CIMMYT.

When the analysis was re-run excluding the observed spillovers to Australia, the world price fall is slightly less (7.3 per cent). The results indicate that Australian producers would be considerably larger net losers of welfare from CIMMYT (A$2659 million), with gains to Australian consumers of A$560 million. The position for Australia, if there were no spillovers from CIMMYT, is a net loss of welfare of A$2099 million over the period 1965–2020.

Thus, the results of the analysis (Table 6) show that spillovers from CIMMYT to Australia lead to welfare benefits totalling A$1425 million over the period 1965–2020. As found in Brennan *et al.* (2003) for ICARDA, the spillovers also enhance the benefits to the ROW, through inducing a further price fall of A$0.20 per tonne. That price fall leads to a transfer of welfare from the ROW producers to ROW consumers, and increases overall welfare by A$20 million. Global benefits of the spillovers (including those to Australia) are estimated at A$1445 million over the period.

These results are sensitive to the assumptions made in the analysis (Brennan and Quade 2004). Across the range chosen for the possible values of the main parameters, none change the overall result that Australia obtains a significant net gain of welfare from the impact of the spillovers from CIMMYT's work. The estimated aggregate impacts for Australia vary with the wheat price used and (inversely) with the discount rate, though less than proportionately to the change in parameter value. The benefits are proportional to the yield gains in Australia. In addition, because the yield changes in the ROW impact on the price, the impacts for Australia are also sensitive to the value for those yield gains. However, Australian welfare impacts are largely insensitive to a variation in the elasticity of demand and supply in Australia, though similar changes in the elasticity of demand and supply for the ROW lead to greater changes in the aggregate Australian welfare. In particular, Australian benefits are sensitive to changes in the elasticity of supply for the ROW, and increase when the supply elasticity is lower.

4. Discussion of results

4.1 Value of CIMMYT spillovers to Australia

The analysis shows that Australia has been affected in two ways by CIMMYT's wheat breeding program. First, via the spillovers of the genetic materials from CIMMYT, Australia's wheat yields have increased gradually, being for example 4.6 per cent higher in 2001. Second, at the same time, CIMMYT's global success has resulted in 7.4 per cent lower world prices, including those for Australian wheat. The analysis indicates that the price fall has been

[2] This estimate is consistent with the annual estimate of Byerlee and Traxler (1995) of benefits of US$2.5 billion (A$3.4 billion) per year in developing countries in the late 1980s.

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Table 7 Average annual welfare benefits for Australia 1973–2020 (average present value per year, 2003 Australian dollars)

	Producer surplus (A$ million)	Consumer surplus (A$ million)	Total welfare (A$ million)
With spillover benefits to Australia	–26.4	12.0	–14.3
Without spillover benefits to Australia	–56.6	11.9	–44.6
Net gains from spillovers to Australia	30.2	0.1	30.3

greater than the average yield increase, so overall Australian wheat producers have suffered a reduction in welfare from CIMMYT's activities.

Those impacts are essentially the outcome of genetic improvement worldwide. However, collaboration with CIMMYT has enabled Australia to draw on the potential spillovers from the CIMMYT research aimed at developing countries and to obtain significant benefits from the spillovers that have flowed from that collaboration.

The analysis indicates that spillovers from CIMMYT to Australia lead to welfare benefits totalling A$1425 million over the period 1965–2020. As previously shown in Brennan *et al.* (2003) for ICARDA, the spillovers to Australia also enhance the benefits to the ROW marginally.

Almost all of the benefits of the spillovers from CIMMYT to Australia are received by Australian wheat producers. For the period since 1973, when those spillovers were first received in Australia, the net welfare gains for Australia from the CIMMYT spillovers has averaged A$30 million per year (Table 7). Given that Australia's investment in CIMMYT has averaged close to A$1 million per year, Australia has received a high return on the funds invested in developing, enhancing and capturing those spillovers from CIMMYT. Without this investment, it is likely that Australia would have had less access to CIMMYT materials.

It is apparent from Tables 1 and 2 that the post-semidwarf yield gains for Australia have been greater than those from the semi-dwarfs in more recent years. Of the total discounted benefits to Australia from spillovers since 1965, approximately 61 per cent came from Phase 1 (semi-dwarfs) and 39 per cent from Phase 2 (post-semidwarfs).

4.2 Implications of results

It is clear that Australia has received a significant dividend from the efforts in Australia to develop and enhance the spillovers from CIMMYT. While CIMMYT's success in other countries has resulted in price reductions and a consequent loss of welfare for Australian producers, the benefits obtained from the spillovers have mitigated those effects to a substantial extent. Given that CIMMYT's global impact will be similar whether or not Australia supports the work at CIMMYT, the most appropriate strategy (from the

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point of view of economic benefits) for Australia is to continue to fund research at CIMMYT, particularly research that can develop and enhance spillovers to Australia. Australia's collaborative and funding ties and extent of research cooperation with CIMMYT enable spillover benefits to flow back to Australia.

From CIMMYT's point of view, increased spillovers to Australia have not been associated with any trade-off in terms of benefits to developing countries. Indeed, the spillovers to Australia have resulted in marginal increases in the benefits flowing to the ROW, through a shift in welfare from producers to consumers. As discussed in Brennan *et al.* (2003), where increasing supplies of cheaper food are a priority for food security, such spillovers are a positive outcome. Where increasing production and the welfare of the farmers producing such crops in developing countries is considered more important than cheaper food, the spillovers to countries such as Australia can be seen as a negative (albeit a small one) for CIMMYT. Thus, while in aggregate terms the spillovers represent a win–win situation for both Australia and the ROW, whether the small shift in welfare gains from producers to consumers in the ROW is seen as desirable by CIMMYT is not clear.

In all studies such as this, there are significant issues relating to attribution of research outcomes (Alston and Pardey 2001). In thus study, we have not evaluated whether CIMMYT's existence can be justified, but rather we have evaluated the impact of materials that have emanated from CIMMYT. There has been no attempt to attribute to particular prior sources the gains that have come through CIMMYT. Thus, the gains attributable to the genetic materials from CIMMYT in this study may in fact have been derived in whole or in part from other countries or research programs around the world.

As Brennan *et al.* (2003) found for ICARDA, the results of this study also provide clear support for the role of national agricultural research systems such as that in Australia, as international research does not replace nationally funded research. Very few CIMMYT wheat varieties have been released without further development and breeding in Australia. The incorporation of genetic material from CIMMYT into Australian varieties has been carried out through nationally funded research, which has been necessary to capture the potential benefits available from the CIMMYT genetic materials.

An interesting question arises as to whether Australia would be better off diverting its CIMMYT contribution to Australian wheat breeding programs, and effectively free-riding on CIMMYT. There is no hard evidence from this study to address that question directly. However, the issue turns on whether the additional marginal resources for the Australian wheat program would increase yields and quality to a greater extent than the marginal decline in CIMMYT's impact on Australia from its reduced funding. Given the leverage that Australia's funding provides in terms of cooperative access to CIMMYT's lines at an early stage and the increased associated information, it seems likely that the benefits to Australia from CIMMYT would decline, perhaps markedly in the medium to long term, without the Australian funding. In

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that case, the additional funds in the Australian programs would have to be extremely productive to lead to an improved outcome for Australia in the long-term, although there are possibly some gains in the short-term.

Overall, the yield increases that the CIMMYT wheat breeding program in Mexico has generated around the world have affected Australia by lowering the price for wheat. However, the Australian wheat industry has received extremely valuable spillover yield benefits from CIMMYT to partly counter those price effects. Given on-going collaboration, it seems likely that Australian breeders will continue to obtain spillover benefits for some time to come, and efforts to enhance the relationship between CIMMYT and Australia are likely to provide substantial returns for Australia.

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