The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

Australian Journal of Agricultural and Resource Economics, 58, pp. 409–429

Payoffs from research and development along the Australian food value chain: a general equilibrium analysis*

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The payoffs and distribution of payoffs from research and development (R&D) along the food value chain depend on many interacting economic factors. To quantify these, we have developed a general equilibrium model of the Australian economy with detailed farming, processing and marketing information. We use the model to assess potential payoffs and distributions from various R&D scenarios that lead to demand expansion and productivity improvement. We find that productivity improvement caused by R&D is unambiguously beneficial to the whole economy while the benefits of export or domestic market demand expansion mainly accrue to the primary producers and processing industry, when the economy is at full employment. Also, productivity improvement from R&D on-farm may benefit processors while improvements postfarm may benefit farmers.

Key words: food processing, general equilibrium, R&D, value chain.

1. Introduction

Heady (1952) demonstrated the complex, often counterintuitive but important, economy-wide, value chain and distributional effects of technological change and innovation in agricultural industries.

> 'Technological change is one of the more important forces which alters the structure of the agricultural production process. ... It is one of the forces which may cause economic decay in one region while other regions bloom and prosper. Each specific innovation calls for readjustments of resources ... while technical change in aggregate calls for changes in the total amount of resources employed in agriculture relative to other industries.' (page 794) ... 'the marginal physical rates of substitution (the elasticity of substitution) are always altered in favour of one factor by specific innovations ... the entire production surface is altered. (page 805) ...innovations ... may have varied effects on the

* The authors acknowledge the funding of the work reported here by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia) and the Department of Primary Industries, Victoria (DPI, Victoria, Australia).

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doi: 10.1111/1467-8489.12062

value productivity and returns to particular resources (page 812) . . . and may conceivably increase or decrease absolute rents depending upon whether the demand for the product is elastic or inelastic (page 817). . . and the nature of the . . . supply function for individual factors of production' (page 819).

More recent contributions to the literature also demonstrate that, the payoffs and distribution of payoffs from research and development (R&D) along the food value chain depend critically on the economic nature of the value chain (Freebairn *et al*. 1982, 1983; Alston and Scobie 1983; Edwards and Freebairn 1984; Holloway 1989; Alston *et al*. 1995; Wohlgenant 1997).[1] The distribution of payoffs can shift up and down the chain depending on many economic variables. In particular, payoffs will depend on:

- the nature of the technological or other change caused by successful R&D;
- where it occurs along the chain (on-farm or postfarm) and rate of uptake;
- the elasticities of supply and demand and substitution between inputs and substitution between final products; and
- relative sizes of gross value of production at each point along the chain.

This means that successful R&D for the food processing sector can provide payoffs to farmers and successful on-farm R&D can pass benefits along to processors. Given the often large size of the food processing sector, relative to agriculture, R&D in the processing sector may be an important source of benefit to the farming sector. R&D that is adopted both on- and off-farm can also pass benefits to consumers and other sectors of the economy.

To efficiently allocate R&D funds requires a close understanding of these complex interactions within a particular value chain and their interactions with the rest of the economy. Much of the previous work conducted has been done using simple models to uncover the theoretical principles. Much has been undertaken using restrictive assumptions such as parallel supply shifts where in reality these tend to be the exception rather than the rule.[2] Alston

[1] A number of Australian studies have reported applications in specific industries or about specific technologies. For example, Mullen *et al*. (1989) on the impact of farm and processing research on the Australian wool industry; Freebairn (1992) on distribution of benefits from the dairy industry research; Zhao *et al*. (2000) on the probability distribution of benefits from technical change in the wool industry; Wittwer *et al*. (2005a) on the impact of plant disease incursion; Wittwer *et al*. (2005a,b) on regional benefits of weed management in Australia; Zhao *et al*. (2003) on the distribution of gains from generic promotion and R&D in the grapes and wine industry.

[2] Some exceptions include studies by Duncan and Tisdell (1971), which diagrammatically showed that the distribution of research benefits between producers and consumers does depend on the nature of the shift in the supply curve and on the elasticity of demand for the product, and by Jarrett and Lindner (1977) and Sarhangi *et al*. (1977) that developed some generalised formulae for measuring the benefits from agricultural research. However, these studies are about one market and thus of partial equilibrium nature. They also do not explicitly explore the distribution of benefits along the value chain.

et al. (1995) points out, at length, the many measurement difficulties of disentangling the multiproduct, multifactor, multistaged, multimarket and economy-wide welfare distributional effects of R&D and technological change. Alston *et al*. (1995) also highlight the theoretical advantages of using economy-wide (general equilibrium) models to track such complex interactions but bemoan the vast quantities of information, the management complexity and expense of developing and using such models. Moreover, Alston *et al*. (1995) correctly note that a full general equilibrium treatment allows measurement of the full welfare consequences (p. 234) — an important issue when considering the efficient allocation of R&D funds.

Over the past 25 years, The Centre for International Economics (TheCIE) has been involved in building detailed economic value chain models of the Australian food and agricultural industry and has built up vast data bases on each of these. These have been used to assess the potential magnitude and distribution of payoffs from successful R&D along the value chain. Results of this work have been used to help guide R&D allocations for most of Australia's agricultural primary industries.

Also over this period, TheCIE has built and maintained many general equilibrium models of the Australian, other country and global economies. With the detailed data we have amassed, it has become feasible to overcome the difficulties outlined by Alston *et al*. (1995) and build a highly detailed representation of the Australian food value chain into our 53 sector, eight region model of the Australian economy[3] for the specific purpose of evaluating the impacts of successful R&D and technological change on the industry.

In this paper, we seek to extend the general understanding provided by the authors cited above and apply this in particular to the postfarm processing sector. We aim to draw out findings about the magnitude and distribution of payoffs along Australia's highly variable food value chains resulting from successful postfarm-focussed food research.

This paper contributes to the existing literature in two aspects. Our new general equilibrium model allows considerably more detailed exploration of the impact of a very wide variety of economic changes that may be induced by agricultural and processing R&D or other economic changes. It is based on actual Australian data (2005–06) that captures the individual nature of each value chain. The model captures market behaviour about supply and demand between farm, processor and the consumers for fresh and processed products

[3] The model includes all important linkages to the wider economy and economy-wide constraints such as the supply of labour and household and government incomes. There are potentially around 15,000 variables explaining the supply side and another 15,000 explaining the demand side. All variables are calibrated to official or published data but not all are unique. Some variables are generic, but where there are known individual differences relating to quantities, prices and behaviour, these are incorporated. The model assumes perfect competition, constant returns to capital and is run to assess long-term adjustments to change.

Table 1 Food products

Agricultural	Processed
Cattle	Beef
Sheep	Sheepmeat
Raw milk	Dairy products — milk
Wheat	Flour, confectionary, bakery
Oilseed	Oil and fat
Vegetables	Juice
Other crops	Other food manufacturing
Other grains	Beverage and tobacco
Other animals (pigs, poultry, etc.)	Dairy products — other
Fruit and nuts	Fruit products
	Vegetable products

Source: TheCIE Food Processing Model.

and so includes farming, transport, handling, wholesaling, manufacturing, marketing, retailing, taxes and trading (imports and exports).

Second, a systematic investigation is carried out to evaluate the benefits and distribution of benefits from different types of R&D in different stages of the food value chain using the model. Unlike previous studies which tend to analyse a single industry often with a partial equilibrium framework, this paper investigates the impact of R&D in every farm and food processing industry. With a stylised one per cent shock to relevant variables, it also enables comparison and prioritisation of different R&D options. The impacts of a specific R&D event may be derived by calibrating these one per cent shocks.

2. The model and the Australian food value chain

The model was developed by TheCIE based on the publicly available MMRF-NRA model developed by the Australian government's Productivity Commission (2006).

Considerable effort has been put into restructuring the commodities and sectors in the original model to disaggregate the on-farm and off-farm sectors (Table 1) and to aggregate other manufacturing and services sectors. As a result, the existing version of the food processing model identifies 38 sectors.[4]

The aggregate data lying behind the Australian food value chain is as represented in Figure 1, but the value chain can be disaggregated by the products set out in Table 1. A schematic illustration of the value chains for four of Australia's main agricultural and food industries is shown in Figure 4.

[4] The base data in this model has been drawn from the 2005–06 Input-Output tables compiled by the Australian Bureau of Statistics (2009). The data has been adjusted in order to be consistent with TheCIE's more detailed value chain databases and with the requirement to balance input-output tables in a general equilibrium model. Also, all margins such as transportation, marketing and taxes have been added.

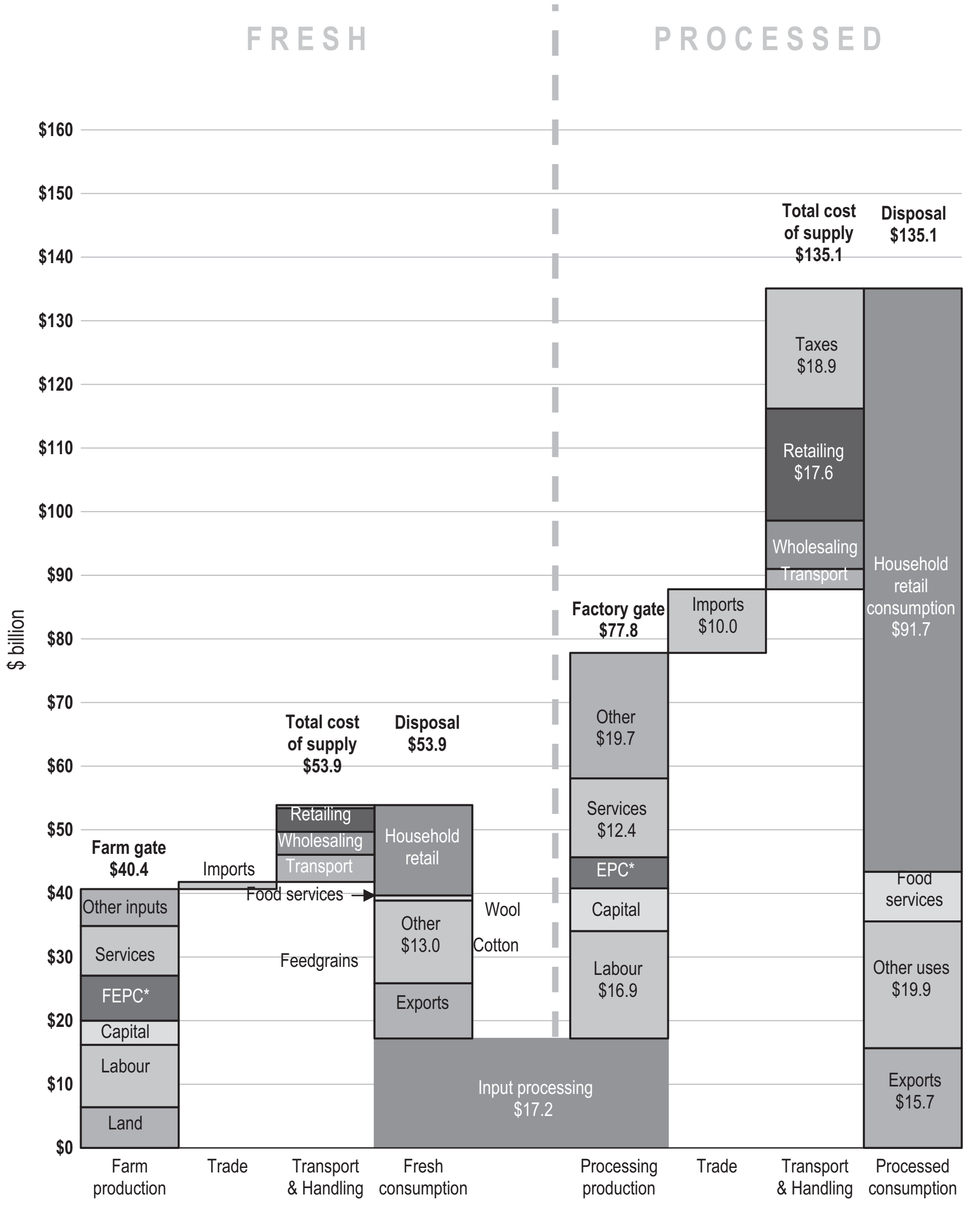

Figure 1 Aggregate value chain for Australian agriculture and food processing 2005–06. *Feed, energy, packaging and chemicals. [a]Exports valued at free-on-board (fob) basis and imports on a cost insurance freight (cif) basis. Source: TheCIE estimates based on Australian Bureau of Statistics.

In Figure 1, the farm gate value of production is $40.4 billion representing the value of primary factors, plus 38 intermediate inputs as shown in the ‘farm production’ column. In the model, production functions explain the demand for inputs, given the costs of input, prices of outputs and the level of relative technical efficiency between inputs.

Imports and margin activities (retailing, wholesaling, transport and taxes) are added to the farm gate value to provide a wholesale and/or retail value of fresh produce worth around \$53.9 billion a year. Margin activities also use inputs and are represented by relevant production functions.

Some of the \$53.9 billion of agricultural output[5] shown in Figure 1 ('fresh consumption' column) are consumed directly as fresh produce by Australian households, particularly fruit and vegetables. Household demand for each fresh agricultural product is represented as a function of prices, income and population. Some such as feed grains is recycled back to agriculture, and some is nonfood, such as wool. About 20 per cent is exported unprocessed, such as wheat, determined by the domestic and world prices. And the rest, about 32 per cent, is used as inputs into food processing.

In addition to the fresh inputs, inputs from other industries as well as primary factors generate a factory gate value of \$77.8 billion of processed food products a year ('processed production' column).

Imports and other margin activities of transport, wholesaling, retailing and taxes are added to the \$77.8 billion to provide a retail and/or wholesale value of processed products of \$135.1 billion ('processed consumption' column).

About \$99.5 billion is purchased by households and food service outlets and restaurants in Australia. Some \$19.9 billion is recycled within the food processing sector, such as meat going into meat pies and cheese into prepacked pizzas and other nonfood sectors. And the rest (about 12 per cent) is exported.

The gross value of the Australian agricultural food chain is around \$172 billion per year with about 30 per cent of value originating from farming production and 70 per cent of value arising from the manufacturing and distribution processes. Processing uses many other inputs than agricultural ones. Around 32 per cent of the value of agricultural outputs are used in the processing, which account for only 22 per cent of the factory gate value of processed food. Household and food services consumption of food is predominantly in processed form; and Australia exports more processed (\$15.7 billion) than unprocessed agricultural products (\$8.7 billion).

3. Aggregate gains from R&D along the chain

In an economic sense, R&D and technological progress may impact and change the value chain through expanding demand and/or shifting supply.

Demand expansion may be achieved by improving the quality, features or information about a product either domestically or internationally and either at the farm level or through processing and marketing; reducing barriers to trade or other impediments such as the peril of distance that existed before the invention of refrigerated shipping or through using other preserving techniques such as canning, clever packaging, new ripening techniques or

[5] For the 10 products on the left-hand side of Table 1.

nonthermal processing (domestically or internationally) or finding a new use for an existing product or by-product.

Supply shifts may be achieved by increasing the productivity or reducing the cost of resource use, or by decreasing waste of agricultural input use in processing.

It should be noted that, because productivity gains are focused on particular inputs or parts of markets, most changes caused by technological change when translated into the linear approximations of demand and supply curves are likely to be pivotal in general equilibrium models (not uniform or parallel as is often assumed in simpler partial models). Explicit and detailed representation of the technological change has advantages over implicit representation of change as a uniform or parallel shift in the supply curve of simpler models. Representing pivot shifts as parallel is likely to be inaccurate.

In a general equilibrium model, the slope of the supply curve is not a parameter, but a consequence of the underlying optimisation problem. It can easily be shown that the slope of supply in a given equilibrium is a function of the proportion of various factors in the production function, and the substitutability between them. The slope of the new supply curve in the new equilibrium depends on the nature of the technological change caused by R&D. The general equilibrium model represents all changes as direct, explicit, changes in underlying technology and preference parameters. These are likely to correspond to pivotal changes although in the general equilibrium context the choice is not made *ex ante*, but results as a consequence of the nature of the change applied to the relevant parameter.

3.1. Application of the model

Each technological or preference changes can have different economic impacts along the value chain. Here, we formulate seven scenarios of changes that might arise from R&D (Table 2) and use the model to estimate the impacts of these changes.

In the model, these changes are applied as uniform one per cent perturbations across the entire food value chains. The one per cent shock is chosen because of two considerations. Frist, the same magnitude of 1 per cent change makes the results comparable. Second, it allows easy calibration of specific R&D outcomes.

The results presented here are based on a time frame long enough to allow all adjustments to take place and assuming a situation of strong competition between farmers and processors. As such, they measure the long-term gains to the nation from R&D and the distribution of benefits ultimately expected. Competition for agricultural supplies by processors is strong in the long-term. In the short-term, some processors or farmers may gain individual advantage due to having an earlier mover advantage or have brands or patents in place

Table 2 Scenarios

	Scenario	Note
1	Export demand	1% increase in export price to represent an increase in export demand for Australia's exports
2	Domestic demand	1% increase in quantity* demanded domestically to represent R&D activity aimed solely at increasing domestic demand
3	Processing production productivity	1% increase in processing productivity for all processing factors excluding agricultural inputs used in processing
4	Transport and handling efficiency of processed products	1% increase in productivity for transport, wholesaling, marketing and retailing for processed products
5	Waste reduction in processing	1% increase in productivity of the use of agricultural inputs in processing
6	Farm production efficiency	1% on-farm productivity increase for all on-farm variable factors
7	Transport and handling efficiency of farm products	1% increase in productivity in transport, wholesaling, marketing and retailing of agricultural output

Source: CIE formulation.
*Domestic demand increases are expressed in quantity terms because sustaining any price increase is difficult as product from the export market is redirected to the domestic market with any domestic demand increase.

to protect their intellectual property. If true, gains to individuals holding the intellectual property may be higher than indicated here, but gains to society are likely to be lower as the new technology is less freely dispersed through the economy. Through time however, retaining any short-term advantage may be more difficult. Others will copy and follow and the technology will be more fully taken up.

If necessary, the model can be run to represent short-term outcomes.

Another important setup relating to the one per cent change scenarios is that they occur separately. In reality, successful productivity increases may simultaneously induce increased marketing effort to ensure export markets expand to absorb the increase. The purpose of this setup is to dissect and compare the benefits of different R&D outcomes.

The one per cent change scenarios deal with the R&D benefits solely and do not consider the cost of any particular R&D development. That is, it is not a complete benefit–cost analysis. The specific results presented here are illustrative only to demonstrate the above-mentioned general principles that need to be understood for policy making and strategic planning relating to allocating R&D.[6]

[6] These principles are that the allocation of benefits from R&D is complex, sometimes counterintuitive in particular market situations and differs by commodity. The results should not be used as a basis for specific R&D allocation. To do this would require carefully running the model to assess the specific R&D under investigation.

3.2. Overall impacts

Table 3 sets out the payoffs in terms of changes in the real value of production, value added and returns to capital and land (an indicator closely related to profit) from each of the simulated R&D scenarios. The results show the magnitude and distribution of benefits of the perturbations between the farming sector and the processing sector.

The largest potential gains to the farming and processing/marketing sectors can be seen to come from increases in export demand. Gains from increases in productivity along the chain are generally significant, but in many cases initial gains from productivity increases get passed to others along the value chain and to other sectors of the economy.

Gains to the rest of the economy come from increases in the incomes of others in the economy either due to increased wages paid, increased profits to suppliers, marketers and other industries and from decreased prices to consumers. The increased income and decreased price allow Australians to consume more products and services.

Figure 2 shows the impact on household real consumption of the changes under each scenario. Household real consumption is a comprehensive economy-wide measure of the welfare impact. Usually, general equilibrium studies do not distinguish between consumer and producer surplus. They are concerned with the aggregate welfare change of households, which in general equilibrium is the ultimate place where welfare changes are meaningful. In contrast, partial equilibrium measures such as producer surplus and consumer surplus are used often as proxies of the appropriate general equilibrium welfare measure. Harberger (1971) shows the differences and similarities between partial and general equilibrium measures. Alston *et al.* (1995) discuss the measurement issues and errors attaching to using partial measures of welfare such as consumer and producer surplus and argue that a full general equilibrium treatment allows measurement of the full welfare consequences.

Table 3 Aggregate food value chain: changes in production, value added and returns to capital and land

	Change in real production $ million		Change in value added $ million		Change in returns to capital/land $ million	
	Farming	Processing	Farming	Processing	Farming	Processing
Scenario 1	558	1276	246	418	138	190
Scenario 2	137	409	69	131	37	59
Scenario 3	121	1101	55	376	32	64
Scenario 4	21	135	10	36	6	15
Scenario 5	−91	263	−41	62	−22	28
Scenario 6	210	107	81	23	46	10
Scenario 7	23	14	8	3	4	1

Source: TheCIE Food Processing Model.

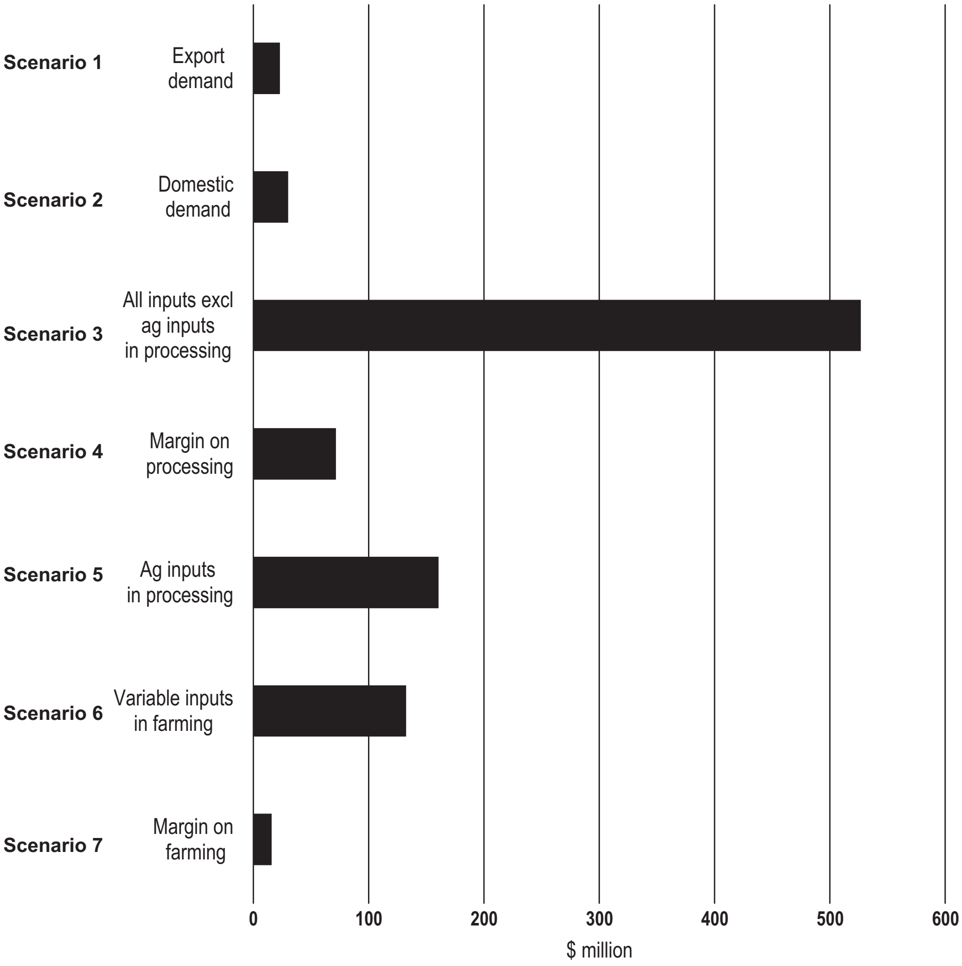

Figure 2 Aggregate food value chain: change in household real consumption. Source: The CIE Food Processing Model.

The figure shows that, unlike to the payoffs to farmers and processors, productivity improvement resulting from R&D generates higher welfare gains to the whole economy than market expansion.

3.3. Export and domestic demand increases

By far, the greatest value added gains to both the farming and processing sectors come from increasing export demand (scenario 1). Even though the value of exports is relatively low compared with the total value of agricultural and processed food production, expansion of export demand, if it can be achieved, has a far greater impact than increases in domestic demand. The reason being that, expansion in export demand causes product to be diverted from the domestic market to exports which raise prices domestically. By contrast, any success in raising domestic demand only (scenario 2), causes exports to be diverted to the domestic market (and possibly attracts imports) moderating the initial price rises domestically. Because Australia's market influence in international markets is less than on the domestic market, diverting product away from export markets has less influence in raising world prices as it does in lowering them at home.

The share of benefits to the food value chain is roughly in proportion to the gross value of production of each sector. That said, the farming sector receives around 40 per cent of the benefit with only a 30 per cent share of the total gross value of the whole food value chain. This reflects the fact that agricultural resources such as land and water are relatively scarcer than resources used in processing. That is, the supply of processed food products is more elastic than that of agricultural products. As a result, higher demand results in more benefits being accrued to farmers than to processers.

While an expansion in demand is unambiguously beneficial for the food value chain, the gains to the nation are not as great (Figure 2). This is because, with existing resources and technology, the expansion in agricultural and processing industries is achieved with the contraction in other industries such as mining. Figure 3 provides a state breakdown of the national results set out in Figure 2 for export and domestic demand scenarios.

The success in R&D in the food industry that helps boost export demand tends to help NSW, Victoria, South Australia and Tasmania to become more competitive by helping these states to retain and grow labour and capital that

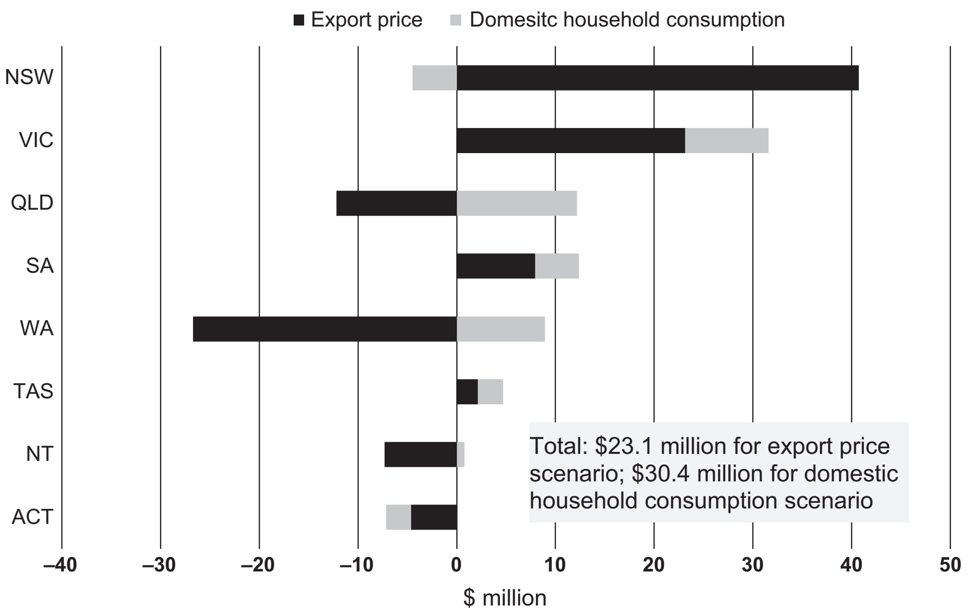

Figure 3 Aggregate food value chain: state breakdown of change in household real consumption. Source: TheCIE Food Processing Model.

might otherwise have gone to the mining industry in the boom states of Western Australia and Queensland. As a result, household income and consumption in these states increase. By contrast, household income will decrease in Western Australia and Queensland because the labour and capital are diverted from the mining sector to the expanding agriculture and food processing sectors in other states.

The state impacts of domestic market expansion are different again. NSW and the ACT as major domestic food importing states are negatively affected by higher prices, and these effects are not offset adequately by increases in production.

3.4. Increased productivity

From Table 3 it can be seen that the increased value added from productivity gains in processing (scenario 3) provide considerable gains ($376 million) for processing but it also provides considerable benefits to the farm sector ($55 million).

A productivity increase in processing lowers the marginal cost of supplying both the processing services and the final product, say cheese, and so it shifts both the supply schedules for processing services and cheese downward to the right. With more supplied at the same price, to induce consumers to absorb more product, the market price for cheese must decline, as it does for processing services, and a new equilibrium is established with an increase in quantity. However, because more milk is now required to meet the new market opportunity, the derived demand for milk shifts outward to the right. Without a productivity gain in milk production on-farm, to induce more supply, the price of milk on-farm must increase. This benefits the farming sector. The net gain to the processing sector is determined by the reduction in costs net of the change in milk price and higher production.

Throughout the history of Australian agriculture, productivity gains in processing have been important to raise the derived demand for raw agricultural products and provide benefits to the farming sector. Refrigerated transport of meat opened up big opportunities to expand the beef and lamb industries for export, for instance.

Although some benefits are captured by the processing sector from on-farm productivity gains (scenario 6), they are relatively small ($23 million) because agricultural inputs overall are a small proportion of total inputs in processing, so the effect on the derived demand for processing is not as great as when processing achieves an increase in productivity, and affects derived demand from agricultural inputs.

Although the farming sector benefits from productivity gains in terms of reduced costs, if processing capacity is at its limits and productivity gains are not achieved in processing, farmers must lower their farm gate prices to induce processors and consumers to absorb more product produced after the productivity gain. This can mean they pass some of the benefits of on-farm productivity up the value chain. This is particularly true when agricultural inputs are a small percentage of total processing costs, such as the case of dairy. It means that for the processors that are at maximum capacity (which they are likely to be in the long run situation) to absorb the increased farm output, they would need to expand their factories and employ more people and find more markets. This is costly and they will need to be induced to do so. For these reasons, productivity gains in processing are very important to farmers to ensure increasing derived demand for their products.

An exception to productivity improvement in processing being of benefit to the farming sector occurs if processors use agricultural inputs more efficiently, such as might occur if they can reduce waste or use less of the inputs to achieve the same output (scenario 5). Then, the derived demand for agricultural inputs decreases and returns to the farming sector fall. As shown in Table 3, this can cause declines in value added to the farming sector. That said, where a reduction in wastage occurs through the development of a new by-product, which simultaneously creates a new market opportunity, the outcome may be different. However, if there is no simultaneous increase in demand for the final product, the farming sector is likely to experience lower prices, while consumers will receive significant benefit.

As shown in Table 3, decreases in various marketing margins (scenarios 4 and 7) can also be of some benefit to the farming sector, but overall, because margins are smaller than processing costs, the benefits of productivity gains here are commensurately smaller.

Table 4 shows the total and state impacts of each scenario on the household real consumption. Benefits from increases in productivity (for example scenarios 3, 5 and 6) tend to provide considerably greater overall gains to the nation than increases in export demand. The reason for this is that the productivity gains let the nation produce more with the same amount of inputs. The overall benefits exceed those captured by the food industry.

Table 4 National and state impacts on real household consumption

Scenario	1 Export demand \$million	2 Domestic demand \$million	3 All but ag inputs in processing \$million	4 Margin for processing \$million	5 Ag inputs in processing \$million	6 Variable inputs in farming \$million	7 Margin for farming \$million
State							
NSW	40.7	−4.5	176.8	24.1	55.9	47.7	5.7
Vic	23.1	8.5	154.4	21.3	47.3	36.8	4.1
Qld	−12.2	12.2	80.9	10.9	26.2	18.4	2.5
SA	7.9	4.4	43.1	5.1	9.3	10.2	1.2
WA	−26.7	8.9	26.9	4.0	10.6	9.6	1.2
TAS	2.1	2.6	14.7	2.0	3.3	3.3	0.4
NT	−7.3	0.8	3.2	0.6	1.3	0.1	0.0
ACT	−4.6	−2.5	26.7	3.7	6.8	6.5	0.8
Total	23.1	30.4	526.8	71.6	160.7	132.6	16.1

Source: TheCIE Food Processing Model.

4. Difference between agricultural products

The value chain structure varies significantly across industries. Figure 4 shows the differences between value chains for four of Australia's main agricultural industries: beef, dairy, wheat, flour and bakery and horticulture. The figure is similar to Figure 1, except that the total use of processed products is scaled to 100.

It can be seen from the figure that beef meat represents the highest proportion in final processed products. By contrast, only a small proportion of wheat or fresh horticultural products are used in processing because a big proportion of fresh products are either exported directly (wheat) or consumed directly (horticulture).

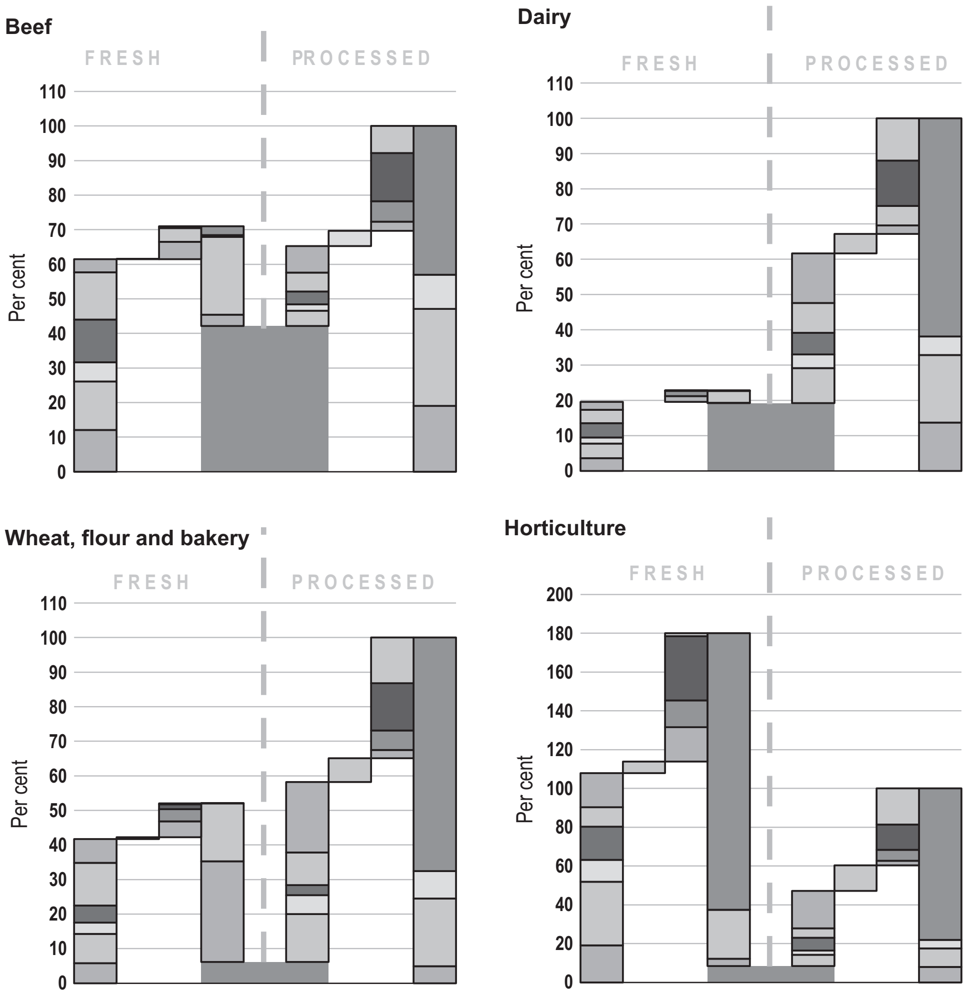

Figure 4 Schematic differences in value chains between agricultural products. Source: TheCIE. Colours and categories correspond to those in Figure 1. The magnitudes are scaled such that final uses and consumption of processed products total 100 per cent.

The differences in the value chain pattern help explain the differences in results of simulated changes for different products.

4.1. Export demand

Table 5 shows the effects on farming and processing sector value added from increases in export demand by commodity. Partly, these results reflect the differences in size and opportunities of each industry, but they also show considerable difference in the importance of processing to each industry, as illustrated in Figure 4. In the case of wheat, there are virtually no processed exports, so an increase in export demand transmits quite directly to farmers rather than processors. In the case of dairying, the gross value of processed production is nearly three times higher than for the farm gate value and no farm product is marketed without being processed. As a result, more benefits are attained by dairy processors than farmers.

4.2. Domestic demand

The pattern of payoffs from a successful increase in domestic demand is very different from that for export demand (Table 6). Because wheat has to be processed before it can be consumed, expansion in domestic demand leads to more benefits being accrued to processors. By contrast, horticulture produce can be consumed fresh. Higher domestic demand leads to more benefits being accrued to farmers.

The domestic market is relatively less important for wheat than the export market, whereas the domestic market is fairly important for horticulture. That said, the prospects for expanding the export market for horticulture (from its current low base) may greatly exceed that of the domestic market. Demand increases of one per cent a year may be possible on the domestic market, but anything more may be nearly impossible. On the other hand, the

Table 5 Impact of higher export demand (scenario 1)

	Change in real production ($million)		Change in value added ($million)		Change in returns to capital/land ($million)	
	Farming	Processing	Farming	Processing	Farming	Processing
Beef	65.1	64.9	33.2	6.8	19.5	3.2
Sheepmeat	19.0	10.9	10.1	0.6	6.1	0.3
Dairy	51.5	175.7	25.1	40.1	14.6	18.4
Wheat	199.5	53.6	85.4	17.9	46.9	8.2
Oilseed	25.6	16.1	11.0	2.2	6.0	1.0
Horticulture	44.0	55.7	24.7	9.3	13.5	4.3
Other	153.6	898.8	56.4	340.9	30.9	154.5

Source: TheCIE Food Processing Model.

Table 6 Impact of higher domestic demand (scenario 2)

	Change in real production ($million)		Change in value added ($million)		Change in returns to capital/land ($million)	
	Farming	Processing	Farming	Processing	Farming	Processing
Beef	27.6	33.8	14.0	3.2	8.0	1.5
Sheepmeat	5.2	6.4	2.5	0.3	1.4	0.1
Dairy	15.9	53.9	7.6	12.1	4.3	5.5
Wheat	7.7	44.7	2.8	14.9	1.5	6.7
Oilseed	1.2	7.7	0.5	1.1	0.2	0.5
Horticulture	53.2	18.2	31.3	3.2	15.8	1.4
Other	26.5	244.5	10.1	96.2	5.3	43.5

Source: TheCIE Food Processing Model.

world market for horticultural products expands each year by the total size of the Australian industry. New Zealand has been able to achieve 10 per cent growth a year in horticultural exports for over a decade.

4.3. Productivity changes

Tables 7 and 8 show the range of outcomes from productivity improvements in processing (scenario 3) and farm production (scenario 6), respectively.

Several observations may be made from Table 7.

Productivity improvements in beef processing make its capacity more abundant, driving up cattle prices due to increased competition for cattle. This benefits the farming sector but causes the meat processing sector to give away its initial gains to the farming sector, consumers and other sectors.

It is interesting to note that the impact on the return to beef processing capital is negative. This is because the demand for processing capital declines with the productivity improvement. Increased productivity in processing

Table 7 Impact of higher productivity of nonfarm inputs in processing (scenario 3)

	Change in real production ($million)		Change in value added ($million)		Change in returns to capital/land ($million)	
	Farming	Processing	Farming	Processing	Farming	Processing
Beef	16.2	18.6	8.3	2.6	5.1	−2.8
Sheepmeat	1.7	3.3	0.9	0.3	0.7	−0.3
Dairy	33.4	116.5	16.1	26.6	9.4	1.5
Wheat	5.8	59.8	1.6	19.5	1.0	−2.8
Oilseed	1.5	16.1	0.6	2.2	0.3	0.1
Horticulture	25.0	52.6	14.4	8.8	7.8	1.5
Other	37.6	834.3	13.1	315.6	7.4	66.5

Source: TheCIE Food Processing Model.

Table 8 Impact of higher productivity of variable inputs in farming (scenario 6)

	Change in real production ($million)		Change in value added ($million)		Change in returns to capital/land ($million)	
	Farming	Processing	Farming	Processing	Farming	Processing
Beef	26.2	23.0	12.0	1.8	7.4	0.7
Sheepmeat	9.5	4.1	4.4	0.1	2.7	0.0
Dairy	8.8	25.2	3.7	5.2	2.3	2.3
Wheat	89.3	5.9	34.0	1.7	18.3	0.7
Oilseed	11.3	1.7	4.5	0.2	2.4	0.1
Horticulture	12.3	4.1	5.8	0.7	3.3	0.3
Other	52.9	43.0	16.9	13.7	9.3	6.1

Source: TheCIE Food Processing Model.

means 1 per cent less capital and labour is needed in the sector than before to produce the same output. However, the output expands by only 0.2 per cent due to land and other constraints on farm and difficulties in expanding domestic and international markets to absorb the increased output. As a result, there is a 0.8 per cent reduction in capital needed to process beef than before (1 per cent minus 0.2 per cent).

It should be pointed out that lesser amount of capital, labour and other inputs required by the beef processing industry is beneficial to the whole society as it frees up these resources for other uses in the rest of the economy.

The sheepmeat industry is affected in a similar way to beef but to a lesser degree.

For similar reasons, domestic wheat processors' 'profit' declines with processing productivity improvement as less capital overall is required and the domestic market cannot be easily expanded and the export market for processed wheat products is virtually non-existent.

Dairy processing also gives a large share of the benefit back to farmers as increased processing efficiency and capacity leads to increased demand for more raw milk which drives up the milk price. However, dairy processing manages to retain some of the benefit, as milk has a lower share in the value of inputs used in processing than cattle and sheep do in meat processing, and, export markets for dairy products such as milk powders tend to be more absorptive than beef and easier to expand.

Productivity improvement in the horticultural processing sector benefits both farmers and processors because it is relatively easy to expand its markets and the supply of agricultural inputs is less constrained than for meat and dairy. Further, increased demand can be met by diverting product from the fresh market, which is not an option in the case of meat.

The 'other' processing section is very large in value terms but uses proportionally fewer agricultural inputs than the other sectors and so is relatively unconstrained to expand — its highly processed products such as frozen meals, ready to eat soups and beverages are fairly highly substitutable with imports. As a result, productivity improvements can help it expand to displace imports.

Table 8 shows that on-farm productivity improvements (scenario 6) can benefit both processors and farmers particularly where there are good export opportunities. This is especially true if there is less need to process the product before exporting (for example, in the case of wheat), so that increases in processing capability do not impose a constraint to expansion and do not hold back benefits of productivity in farming. This also implies that for the farming sector to benefit from on-farm productivity improvements, productivity improvements in processing are needed to ensure there is increased capacity to handle the increased farming output.

5. Conclusions and implications

The results of the model used in this paper confirm earlier theoretical work and indicate that the benefits and distribution of benefits from R&D are likely to be highly indirect and sometimes ‘counter-intuitive’ in particular market situations. Successful R&D has the capacity to greatly change supply and demand in complex ways. Market responses to these changes will ultimately determine who captures the benefits. The markets for Australia’s agricultural products vary greatly in nature and character and the results here show that this can have a large bearing on the payoffs.

While some of the results presented here are consistent with the general findings from earlier theoretical or simple partial models, the huge variation in results between products using a highly detail general equilibrium model suggest an important implication. Applying the general principles alone (based on simplified assumptions and little empirical analysis) may not be helpful for R&D fund managers who must allocate R&D funds efficiently. Having a detailed empirical model of each value chain’s production function, product and factor markets (and other economy-wide constraints on supply, income and expenditure) is critical to understanding the relative payoffs from different forms of R&D along the value.

Although results vary widely by the nature of the market involved, we are confident to draw out some general conclusions.[7]

First, R&D that can successfully expand export demand is invariably and unambiguously adding economic value and is likely to provide the greatest benefits to the farming and processing sectors if it can be achieved. However,

[7] These general conclusions hold even with large changes to key parameters. To test this, we halved export demand elasticities, substitution elasticities between primary inputs, and substitution elasticities between export and domestic markets. The most sensitive parameter appears to be the export demand elasticity for the export expansion scenario which sees about 45 per cent reduction in the increase of some agricultural products and about 54 per cent increase in the growth of economy-wide welfare measure (aggregate household consumption) with halving the elasticity. However, the order of welfare gains from different scenarios still holds with varying parameters.

benefits to the whole economy are not as great as benefits to farmers and processors. This provides more meaningful results than those from some partial models. Partial equilibrium analysis points to similar benefits between production cost reduction and demand increase (for example Wohlgenant, 1993) or higher benefits from market innovation than from productivity (for example Zhao *et al*. 2003). Our general equilibrium results, while replicating some partial equilibrium findings of payoffs to individual sectors such as Zhao *et al*. (2003), show much greater economy-wide advantage from productivity than demand increases.

Almost invariably, expansion of the export market due to its significantly greater size will provide larger benefits for farmers and processors than for the same percentage expansion of the domestic market. Moreover, considering that expanding the domestic market is likely to be more limited unless large amounts of imports can be displaced, the export market and world demand opportunities are likely to be more open-ended if R&D provides a competitive advantage simply because the world market dwarfs the size of the domestic market.

Second, productivity gains anywhere along the value chain are invariably good for the whole economy. It means fewer resources are needed to produce the same amount of food. This either means more food can be produced or additional labour, capital and other inputs can be made available to other sectors where they can be productively and profitably employed. It typically also means consumers will benefit from lower prices.

Third, the farming sectors are likely to benefit from successful R&D that either expands demand or increases the productivity of processing and marketing as this will increase the derived demand for their products. This confirms the theoretical finding of Freebairn *et al*. (1982).

Fourth, the processing sector can benefit from successful R&D on-farm, as this will increase the availability of agricultural inputs at lower cost. The farming sector is likely to give away some gains from successful R&D if the productivity gains lead to increased supplies that exceed the existing capacity of processors to process farmers' additional output. To be induced to build new capacity and develop new markets, processors will require discounts on buying the input, which will transfer benefits to processors and probably consumers.

However, the ability of processors to benefit from the farming sector is less than the reverse. This is largely due to the fact that the value of agricultural inputs is only a small proportion of the value of all inputs used in processing.

Finally, farmers who do not depend on the processing industry to reach the final market, (wheat) are likely to retain a large proportion of benefits from successful on-farm oriented R&D. For those who do rely on processing to reach the market such as dairy and meat, it may be equally important that productivity gains are being achieved in processing as well as on-farm so that capacity in processing increases in line with their own ability to expand.

In making decisions about where to allocate R&D funds requires having a close knowledge of the economic features of each market and the interactions that take place in them. It also requires knowing how successful R&D at any point in the chain will affect relative payoffs. All players in the value chain are likely to benefit from successful R&D conducted at other points in the chain. Allocation of R&D funds needs to consider opportunities along the entire length of the chain, not just those in the sector where the R&D funds are raised.

References

Alston, J.M. and Scobie, G.M. (1983). Distribution of research gains in multistage production system: comment, *American Journal of Agricultural Economics* 65, 353–356.

Alston, J.M., Norton, G.W. and Pardey, P.G. (1995). *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Cornell University Press, Ithaca (reprinted in soft cover by CAB International 1998).

Australian Bureau of Statistics (2009). Australian National Accounts: Input-Output Tables — Electronic Publication, 2005-06 Financial, Cat. No. 5209.0.55.001.

Duncan, R. and Tisdell, C. (1971). Research and technical progress: the returns to producers, *The Economic Record* 47, 124–129.

Edwards, G.W. and Freebairn, J.W. (1984). The gains from research into tradable commodities, *American Journal of Agricultural Economics* 66 (1), 41–49.

Freebairn, J.W. (1992). Evaluating the level and distribution of benefits from dairy industry research, *Australian Journal of Agricultural and Resource Economics* 36 (2), 141–165.

Freebairn, J.W., Davis, J.S. and Edwards, G.W. (1982). Distribution of research gains in multistage production systems, *American Journal of Agricultural Economics* 64, 39–46.

Freebairn, J.W., Davis, J.S. and Edwards, G.W. (1983). Distribution of research gains in multistage production systems: reply, *American Journal of Agricultural Economics* 65, 357–359.

Harberger, A.C. (1971). Three basic postulates for applied welfare economics: an interpretive essay, *Journal of Economic Literature* 9 (3), 785–797.

Heady, E.O. (1952). *Economics of Agricultural Production and Resource Use*. Prentice-Hall Inc, Englewood Cliffs, NJ.

Holloway, G.J. (1989). Distribution of research gains in multistage production systems: further results, *American Journal of Agricultural Economics* 71 (2), 338–343.

Jarrett, F.G. and Lindner, R.K. (1977). Who benefits from agricultural research: comment, *Review of Marketing and Agricultural Economics* 45 (4), 167–178.

Mullen, J.D., Alston, J.M. and Wolhgenant, M.K. (1989). The impact of farm and processing research on the Australian wool industry, *Australian Journal of Agricultural and Resource Economics* 33 (1), 32–47.

Productivity Commission (2006). Potential Benefits of the National Reform Agenda. Report to the Council of Australian Governments. Available from URL: http://www.pc.gov.au/research/commissionresearch/nationalreformagenda [accessed 1 July 2011].

Sarhangi, R.F., Logan, J., Duncan, R.C. and Hagan, P. (1977). Who benefits from agricultural research: comment, *Review of Marketing and Agricultural Economics* 45 (4), 179–185.

Wittwer, G., McKirdy, S. and Wilson, R. (2005a). Regional economic impacts of a plant disease incursion using a general equilibrium approach, *Australian Journal of Agricultural and Resource Economics* 49 (1), 75–89.

Wittwer, G., Vere, D.T., Jones, R.E. and Griffith, G.R. (2005b). Dynamic general equilibrium analysis of improved weed management in Australia's winter cropping system, *Australian Journal of Agricultural and Resource Economics* 49 (4), 363–377.

Wohlgenant, M.K. (1993). Distribution of gains from research and promotion in multi-stage production systems: the case of the US beef and pork industries, *American Journal of Agricultural Economics*. 75(3), 642–651.
Wohlgenant, M.K. (1997). The nature of the research-induced supply shift, *Australian Journal of Agricultural and Resource Economics* 41 (3), 385–400.
Zhao, X., Griffiths, W.E., Griffith, G.R. and Mullen, J.D. (2000). Probability distributions for economic surplus change: the case of technical change in the Australian wool industry, *Australian Journal of Agricultural and Resource Economics* 44 (1), 83–106.
Zhao, X., Anderson, K. and Wittwer, G. (2003). Who gains from Australian generic wine promotion and R&D?, *Australian Journal of Agricultural and Resource Economics* 47 (2), 181–209.