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Issues in Measuring Returns from RD&E Investments in the Australian Grains Industry[1]

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Abstract

Governments and funding agencies are interested in demonstrating the economic impacts of research to justify their investments and to prioritise future research investments. The Grains Research and Development Corporation invests around $200 million annually in a varied portfolio of research in the Australian grains industry. The Corporation does not have access to an industry-wide equilibrium displacement model to help assess likely returns to investments in research, development and extension projects. In this paper the issues involved in developing an industry level model of the Australian grains industry are canvassed.

Key words: grains industry, RD&E, returns to research, equilibrium displacement model.

Introduction

Increases in the capacity of the agricultural sector to increase output comes from new technology and changes to farm systems. Investing in agricultural research, development and extension (RD&E) plays a significant role in increasing agricultural productivity. The Australian Grains Research and Development Corporation (GRDC) conducts RD&E to improve the welfare of domestic consumers, farmers and everyone else in the Australian grains value chain. The GRDC is principally supported by a grower levy and Australian Government contributions.

Allocating limited funds to grains RD&E poses challenges and trade-offs. The Grains Industry National Research, Development and Extension Strategy (Research and Innovation Committee, 2017, p.30) noted that 'the modest size of Australia's RD&E budget in the global context dictates that investment decisions must be strategic to achieve the best effect in industry innovation'. Governments and research organizations need to know and demonstrate the economic impacts of research programs, to justify investments and prioritise future research. Evaluating the merits of research investment involves finding out about the total benefits from the research as well as the distribution of these benefits through society. To these ends, estimating the net benefits of investments in agricultural RD&E is required, and this is challenging. Economic modelling is one way to estimate the size and

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distribution of the net benefits of agricultural RD&E. Equilibrium displacement models (EDMs) have been used to do this in various agricultural industries, but not the grains industry.

Though the Australian grains industry delivers around one quarter of agricultural export value (ABARES, 2018), EDM has been little used to analyse the size and distribution of the net benefits of grains RD&E. Partly, this is because of the complexity of the grains industry, with many complementary and competing activities in cropping and mixed farming systems. The objective of this paper is to canvass the key issues involved in developing a model for assessing the returns to investment and distribution of net benefits from Australian grain RD&E.

An overview of the Australian grains industry is presented that covers the various value-adding stages in the production and marketing of grains. Then follows background and motivation for agricultural research evaluation in the Australian grains industries. A brief review of modelling options is provided, describing their features and assumptions, as well as examples of where they have been used in other agricultural industries. The paper concludes with a discussion of the major issues that need to be addressed in developing an EDM for evaluating investment in RD&E in the Australian grains industries.

Grain Production in Australia

Overview

Grains are important staple foods used worldwide for human consumption and as inputs to livestock production. Grains are classified into cereal grains, oilseeds and pulses (grain legumes). In Australia, grains are a major group of agricultural commodities. In 2014-15, grains, oilseeds and pulses comprised Australia's largest category of food exports, contributing over $14 billion to the economy (ABARES, 2017).

Australian grain production occurs in three main cropping regions – northern, southern, and western, and two crop-growing periods – winter and summer (GRDC, 2018a; Australian Grain, 2013). The northern cropping region is in central to southern Queensland (Qld), through to northern New South Wales (NSW). Most of the rainfall in this region occurs over the summer months, with some rainfall also occurring during winter. The northern cropping region has high fertility soils with high moisture storing capacity. Rainfall over the summer makes it feasible to grow summer crops of maize, sorghum, and tropical pulses and the winter crops wheat, barley, winter-pulses and oilseeds.

The southern cropping region is in south-eastern Australia, including central and southern NSW, Victoria (Vic.), Tasmania (Tas.) and south-eastern South Australia (SA). This region encompasses Temperate (uniform) and Mediterranean climates. The rainfall patterns in NSW are generally uniform, while winter/spring rainfall dominates in Vic., and both Tas. and SA ares winter. Crop yields in the southern grain-producing region depend on seasonal rainfall. Soil fertility is low. The western cropping region is in Western Australia (WA). Winter cropping is the main activity, based on winter and spring rainfall. Soil fertility is low. Wheat, barley, canola, and lupins are the main grain crops. As shown in Tables 1 and 2, over 24 million hectares of crops were planted in 2016-17 across Australia, mostly as winter crops.

Wheat and barley

The major winter cereals in Australia are wheat and barley. Wheat is the major grain crop in Australia and is used to make breads, noodles and pastas. As shown in Table 1, close to 13 million hectares of wheat was sown in 2016-17, producing a crop of over 34 million tonnes (a record 2.6 tonnes/ha average yield). On average, around 25 million tonnes of wheat are produced in Australia each year.

WA has the highest production of wheat compared to other States, accounting for over one-third of wheat production. Production of wheat in each State is shown in Table 2.

Table 1. Australian winter crop production and area, 2014/15-2016/17

Crop	Area			Production		
	2014–15	2015–16	2016-17	2014–15	2015–16	2016-17
	'000 ha	'000 ha	'000 ha	kt	kt	kt
Wheat	12 155	11 282	12,191	23 076	22 275	31,819
Barley	3 912	4 108	4,834	8 173	8 992	13,506
Canola	2 824	2 091	2,681	3 447	2 775	4,313
Chickpeas	425	677	1 069	555	875	2 004
Faba beans	164	220	233	284	301	484
Field peas	237	238	230	290	205	415
Lentils	189	225	276	242	182	680
Lupins	443	534	515	549	652	1 031
Oats	869	821	1,028	1 184	1 300	2,266
Triticale	126	78	62	225	127	150

Source: Australian crop report, ABARES; Australian Bureau of Statistics; Pulse Australia

Table 2. Australian wheat production by State, average 2014-2017

State	Production ('000 tonnes)
Western Australia	9,078
New South Wales	7,317
South Australia	4,287
Victoria	3,096
Queensland	1,380
Tasmania	37
Total	**25,195**

Source: AEGIC (2018a)

Yields of wheat vary greatly each year from region to region due to variable rainfall (ABS, 2006). The average yield across Australia was 0.77 tonnes per hectare in the drought of 1982-83, and 2.11 tonnes per hectare in 2016 when exceptionally good seasonal conditions prevailed.

Australia produces around 3 per cent of the world's wheat output. It is a major wheat exporter, exporting to more than 40 countries and, in years when seasonal conditions are good, accounts for 10-15 per cent of annual global wheat exports (ABS, 2006; AEGIC, 2018a). In 2014-15, wheat exports contributed $5.5 billion to the Australia economy – half of the value of total grain exports (ABARES, 2015).

Barley for animal feed and brewing, and the feed grains oats and triticale, are the other major winter cereal crops in Australia. Barley is the second most important winter cereal in Australia after wheat, with around 9.5 million metric tonnes produced annually. WA is the leading producer of barley in Australia, producing over a third of total production. In Table 3 below is shown barley production for each state.

Barley exports were over $2.1 billion in 2014-15 (ABARES, 2015). Around 40 per cent of Australian barley went to malting for beer and the rest to animal consumption (PwC, 2011). Although barley is grown in most areas where wheat is grown, it has an average yield of around 2 tonnes per hectare which is slightly higher than wheat.

Table 3. Australian barley production by State, average 2014-2016

State	Production ('000 tonnes)
Western Australia	3,290
South Australia	2,069
New South Wales	1,973
Victoria	1,934
Queensland	255
Tasmania	18
Total	**9,539**

Source: AEGIC (2018b)

In WA 90 per cent of wheat and barley is exported, while in SA 70 per cent of cereal grain produced is exported. Cereals grown in Vic., NSW and Qld are used mainly to meet domestic uses, with around half of production exported in years of good production. In lower production years, nearly all the cereals grain grown in Vic., NSW and Qld is used for domestic human and animal consumption.

Canola

Oilseed crops are used for vegetable oils and livestock feed. Canola makes up around 90 per cent of oilseed production. Around 4 million hectares of canola is grown, producing over 4 million tonnes, making it the third largest winter crop behind wheat and barley. Canola is grown in WA, NSW, Vic. and SA (Table 4). Around 20 per cent of the Canola is genetically modified to be tolerant to non-residual, broad-spectrum herbicides.

Table 4. Australian canola production by State, average 2014-2017

State	Production ('000 tonnes)
Western Australia	1,685
New South Wales	1,025
Victoria	693
South Australia	376
Total	**3,779**

Source: AEGIC (2018c)

Pulses

Pulses are grain legumes used for human consumption and animal feed. The main pulses grown in Australia include lupins, field peas, and chickpeas; other pulses grown include faba beans, lentils, and vetch. Over 2 million tonnes of these pulses are produced each year, mainly in NSW, WA, and SA (Table 5) (AEGIC, 2018d). Pulses improve soil fertility by fixing nitrogen in the soil for the following crop in a rotation and providing a disease 'break crop' in cereal crop rotations.

Lupin varieties grown are the 'narrow leaf lupin' (*Lupinus angustifolius*) and the larger seeded and broader leaf *Lupinus albus* or 'white lupin'. The higher protein narrow leaf lupin is used for stock feed and the white lupin is generally used for human consumption. Field peas are grown in SA, Vic. and WA.

Field peas are an alternative to lupins in cereal rotations. They can be sown later than lupins and on a wider range of soils. Most of the pea crop is exported for human consumption in Asia and the Middle East, and for stock feed in Europe. Chickpeas are an alternative 'break crop' to peas and are produced mainly in NSW with smaller areas grown in Qld and Vic.

Table 5. Australian pulse production by State, average 2013-2017

State	Production ('000 tonnes)
New South Wales	580
Western Australia	479
South Australia	459
Queensland	295
Victoria	291
Total	**2,104**

Source: AEGIC (2018d)

Crop rotations

Grains are grown in sequences of various crops and pastures over time to maintain soil nutrients, and control weed, pest and disease problems. Typical sequences of crops grown in the south-eastern grains industry include several cereal crops, a pulse and an oilseed. Pulses and oilseeds in the cereal crop sequence provide benefits in nutrient supply, disease and weed control and soil health. Farmers do not adhere rigidly to a set rotation of activities but opportunistically adjust the length or nature of each phase of a rotation, depending on seasonal outlook, weed burdens and relative commodity prices.

Common crop sequences in the south-eastern grains industry are indicated by the rotations used in the Sustainable Cropping Rotations in a Mediterranean Environment (SCRIME), a research project established in 1998 on the Wimmera on the grey self-mulching clay of the Victorian Wimmera region, conducted by the Victorian Department of Primary Industries since 1990. The crop and pasture activity sequences of the SCRIME experiment, listed below, are 3-part or 6-part rotations, with standard fertiliser and chemical inputs, and with most activities sown using minimum tillage. The rotations analysed were:

Continuous Wheat across all years

Pea/Wheat/Barley across all years

Vetch/Wheat/Barley

Canola /Wheat/Pea

Canola/Wheat/Pea Conventional Tillage

Lucerne/ Lucerne/ Lucerne/Canola/Wheat/Pea

Vetch GM/Canola/Pea/Medic/ Wheat/Barley

Canola /Wheat/Pea with No Tillage

Fallow/Wheat/Chickpea until 2011, then changed to Fallow/Wheat/Lentil

Tables 6 and 7 below provide examples of farm cropping systems in the Western Region. Farms have varying soil types across paddocks with considerable variation in fertility, soil moisture holding capacity and cropping history. Different crop sequences are adopted depending on the soil type. The range and variation of crop rotations greatly complicates the development of an EDM for grains.

Table 6. Example of a farm cropping system in the Kwinana East Port Zone, WA

Soil Type		Year 1	Year 2	Year 3	Year 4	Year 5
Heavy	Crop	Wheat	Barley	Wheat	Barley	Fallow
	Yield (t/ha)	3	2.8	2.3	2.8	-
Medium	Crop	Wheat	Wheat	Barley	Fallow	Canola
	Yield (t/ha)	2.6	2.0	2.8	-	1.4
Light	Crop	Wheat	Oats	Pasture		
	Yield (t/ha)	2.6	1.89	-		

Source: GRDC (2017)

Table 7. Example of a farm cropping system in the Geraldton Port Zone, WA

Soil Type		Year 1	Year 2	Year 3	Year 4	Year 5
Heavy	Crop	Canola	Wheat	Wheat	Barley	
	Yield (t/ha)	0.82	1.73	1.73	2.24	-
Light	Crop	Canola	Wheat	Lupin	Wheat	Wheat
	Yield (t/ha)	0.82	1.73	1.48	1.73	1.73

Source: GRDC (2017)

Major Markets for Australian Grains

Wheat

Different classes of wheat are produced in Australia for a multiple number of end-uses for different markets. There are three categories of wheat: Premium Hard Wheats, Multi-Purpose Wheats and Speciality Wheats (Wheat Quality Australia, 2018). Premium Hard Wheats are the Australian Prime Hard and Australian Hard wheats. These have high protein with high milling qualities. Flour from Australian Prime Hard wheat suits high volume breads, artisan bread, yellow alkaline noodles, fresh ramen and dry white salted noodles. Flour from Australian Hard wheat suits baked products, including pan and hearth breads, Middle Eastern-style flat breads, yellow alkaline noodles, white noodles and steamed breads.

The Australian Standard White and Australian Premium White wheats have multiple uses. These wheats make up the largest proportion of Australia’s wheat crop. Flour milled from Australian Standard White and Australian Premium White wheats are used to make a variety of breads and noodles (AEGIC, 2018a). Speciality Wheats are the Australian Noodle Wheat, Australian Premium White Noodle, Australian Soft, and Australian Premium Durum classes. These varieties make up a low proportion of the total Australian wheat crop, with unique characteristics that suit specific end uses.

Around 65 to 75 per cent of Australia’s total wheat production is exported each year (AEGIC, 2017). In Table 8 is a breakdown of Australia’s top 10 wheat export markets. Indonesia is Australia’s largest wheat export market, importing over 4 million tonnes annually, valued at $1.2 billion.

Barley

Over 50 per cent of Australia’s annual barley production is exported. In Table 9 are the top 10 export markets for barley. China is Australia’s largest barley export market, accounting for over 3 million tonnes with an export value of close to $1 billion annually. Australia is also the leading supplier of malting barley to China, supplying 60 per cent of Chinese demand annually (Department of Primary Industries and Regional Development, 2018).

Table 8. Major export markets for Australian wheat, average 2014-2017

Destination	Quantity ('000 tonnes)	Value (A$m)	Per cent of Total Value (%)
Indonesia	4,140	1,200	22
Vietnam	1,497	460	8
China	1,426	428	8
South Korea	1,034	328	6
Japan	898	301	5
Philippines	1,024	287	5
Malaysia	928	281	5
Yemen	901	272	5
India	786	224	4
New Zealand	489	155	3
Other Export Markets	4,873	1,600	29
Total	17,996	5,550	100

Source: AEGIC (2018a)

Table 9. Major export markets for Australian barley, average 2013-2016

Destination	Quantity ('000 tonnes)	Value (A$m)	Per cent of Total Value (%)
China	3,148	968	59
Saudi Arabia	1,064	290	18
Japan	638	187	11
U.A.E	201	56	3
Kuwait	156	41	2
South Africa	58	21	1
Korea	55	19	1
Taiwan	40	12	1
Oman	39	11	1
Vietnam	33	10	1
Other Markets	120	37	2
Total	5,552	1,652	100

Source: AEGIC (2018b)

Canola

Australia supplies annually 2.5 million metric tonnes of canola to international markets. In Table 10 are Australia's top 10 export markets for canola, which account for 99 per cent of the total value of canola exports. The European Union is the leading destination for Australian canola exports, taking over 70 per cent of the total, with these exports used mainly for biodiesel production (AEGIC, 2018c).

Pulses

Australia exports most of its pulse production to international markets. The Indian sub-continent is the leading destination for pulses with around two-thirds of exports shipped to India, Bangladesh, Pakistan, and Sri Lanka annually (Table 11).

Table 10. Major export markets for Australian canola, average 2014-2017

Destination	Quantity ('000 tonnes)	Value (A$m)	Per cent of Total Value (%)
Germany	635	366	25
Belgium	634	359	25
France	288	163	11
China	253	147	10
Japan	174	103	7
Netherlands	180	99	7
Pakistan	102	63	4
U.A.E	110	61	4
Denmark	95	59	4
Vietnam	36	22	2
Other Markets	21	13	1
Total	2,528	1,455	100

Source: AEGIC (2018c)

Table 11. Major export markets for Australian pulses, average 2013-2016

Destination	Quantity ('000 tonnes)	Value (A$m)	Per cent of Total Value (%)
India	723	619	38
Bangladesh	307	239	15
Pakistan	170	145	9
Egypt	242	135	8
Sri Lanka	94	81	5
U.A.E	88	68	4
South Korea	126	49	3
Netherlands	92	37	2
Saudi Arabia	44	29	2
Malaysia	26	17	1
Other Markets	212	225	14
Total	2,124	1,644	100

Source: AEGIC (2018d)

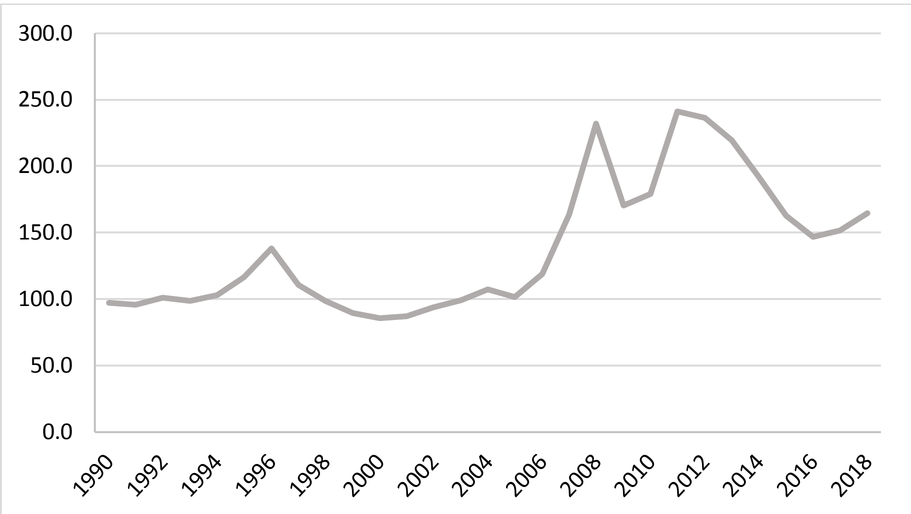
Prices for Australian Grains

The price of grain is determined mainly on international markets. Fluctuations in global grain prices and supplies cause volatile incomes for producers. Grain prices are volatile for grain exporting countries like Australia because only a small share of total global production enters world trade, and increases and decreases in national production of countries can significantly add to or subtract from grain available for trade, causing significant swings in aggregate trade volumes and associated swings in prices. World market conditions have varied dramatically over the past 10 years.

During the 2007-08 global food crisis, world food prices rose to very high levels. Between 2006 and 2008, average world prices for grains increased sharply – rice rose by 217 per cent, wheat by 136 per cent, maize by 125 per cent, and soybeans by 107 per cent (FAO International Commodity Price Database, as cited by Haugh *et. al.* (n.d)). Low world grain stocks were a main cause, with stock levels in 2006-07 falling to their lowest levels in almost 20 years (FAO, 2009). A combination of other interrelated factors included production shortfalls, increasing oil prices, collapse of share markets, greater demand for biofuels, a depreciating US dollar and growing incomes in emerging economies (FAO, 2009). The successive droughts in Australia prior to 2005-06 contributed to the upwards pressure on prices of various grains, in particular, wheat prices. Domestic wheat prices in Australia rose by 38 per cent in 2012-13 when low annual rainfall reduced national wheat production (IBISWorld, 2017).

Food prices have been very volatile since the global food crisis, with food prices falling after 2007-08 only to then rise again during 2011-12. Cereal grain prices subsequently dropped again below 2009-10 levels as shown in Figure 1. This was caused by a global grains glut with grain stocks reaching their highest levels in 30 years (Ruitenberg, 2015). Drought in south-eastern Australia in 2018 saw little grain going to export markets. Domestic wheat prices rose sharply from the medium-term average of $280/t to over $400/tonne. Future grain price instability will derive from (i) increasingly volatile weather and severe weather events; (ii) a growing world population; (iii) barriers to trade; (v) oil price fluctuations; and (v) changes in the use of biofuels.

Figure 1. Cereal grains price index, 1990-2018



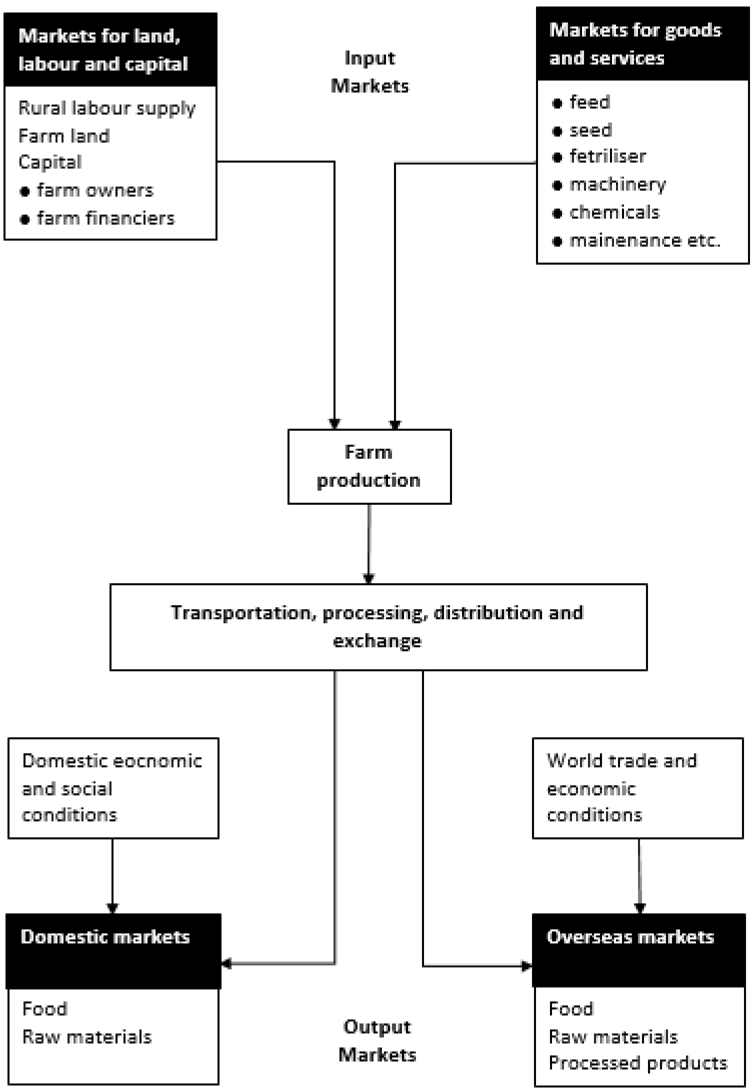
Source: FAO Food Price Index

Supply and Value Chains

Producing grain on the farm and the marketing of grains to users involves many stages. A supply chain describes the network of processes and activities necessary to bring a farm product through different stages of production and marketing to delivery to the final consumer.

The various input and output stages in the production and marketing (processing, distribution and exchange) of agricultural commodities is illustrated in Figure 2. Here, farm production of grains requires the use of various farm inputs including factors of production (land, labour and capital) and other intermediate inputs (e.g. seed, fertiliser, machinery, chemicals, transport, fuel and equipment etc.). Farm products are then transported, processed, distributed and sold to either the domestic or export markets for use in food, raw materials and other processed products. Marketers play an important role in the supply chain through linking growers with other market participants. They typically purchase grain from growers, identify buyers, and coordinate the logistics and delivery of grain to such customers from both the domestic and international markets.

Figure 2. Marketing channels for agricultural commodities



Source: Malcolm et al. (2009)

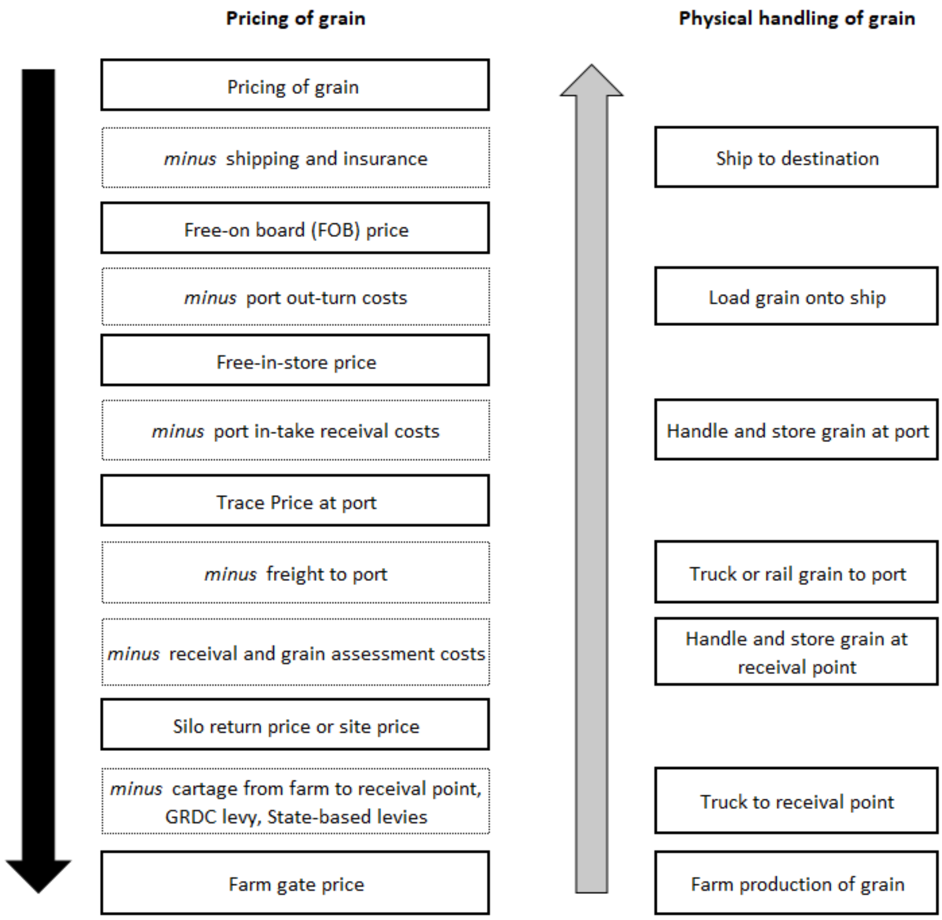
Relating to the concept of supply chains are value chains. Value chains comprise the same network of supply chain entities involved in the production and distribution of goods to end users. A value chain, however, places particular emphasis on the distribution of the final sales value of a commodity along the supply chain network. The focus lies on how value is sequentially added to a product as it is carried along the different stages of its supply chain. Both concepts are frequently used interchangeably as value chain maps will often encompass identical elements to supply chain maps.

An industry value chain map for an exported grain is shown in Figure 3 below. As depicted on the righthand side, the physical flow of grain moves from farm to its export destination. However, the pricing of grain (left hand side) is principally determined on international markets with supply chain costs being sequentially deducted to generate a farm gate price (Stretch et al., 2014). Value is added along each stage of the supply chain.

The performance of an agricultural value chain is measured by the chain economic surplus (total chain profitability) that it creates, captures and distributes among chain members. Chain surplus is the difference between aggregate willingness to pay by customers and the cost to the value chain of meeting their customers' requirements. All participants along value chains create value for consumers. Most do this by operating individually and collectively, in markets, in domestic and international economies.

Various determinants can affect the prices and costs of grains and grain products in domestic and overseas markets. The main factor that affects prices across the supply and value chain is the international price of flour-milling varieties of wheat (Spencer, 2016). As pointed out by Stretch et al. (2014), the pricing of grain at the farm-gate level is mainly determined on international by the prevailing world commodity prices with supply chain costs being sequentially deducted to generate a farm gate price.

Figure 3. Value chain for export grains



Source: Stretch et al. (2014)

In Table 12 below, a breakdown is provided for export grain supply chain costs by the main bulk handlers in each State for 2013-14 (Stretch et al., 2014). Wheat was the commodity used to illustrate the value chain costs, as it is the main grain grown and exported by Australian grain producers. It was assumed that wheat was delivered to a site 200 km from port, and that the FOB price of $320/t was used across all terminals in all states. Although the physical handling of grain starts at the farm level and moves to its export destination, the pricing of grain is primarily determined on international markets with the FOB price, with costs along the supply chain deducted to arrive at the farm gate price. Presuming the activities are profitable, the estimated export value chain costs in Table 12 indicate the 'net value add' process to grain commodities going from farm gate to the export markets. As shown, in 2013-14, export value chain costs for producers was least for WA at $58.93/t, whereas Qld had the highest export supply chain costs of $72.64/t.

Table 12. Australian grain export supply chain costs (2013-14)

2013/14	**WA (CBH)**	**NSW (GrainCorp)**	**SA (Viterra)**	**QLD (GrainCorp)**	**Vic (Emerald)**
			($/t)		
FOB price (assume same at all ports)	**320**	**320**	**320**	**320**	**320**
Port charges	21.90	20.99	21.78	24.11	21.11
FIS price	**298.10**	**299.01**	**298.23**	**295.89**	**298.89**
Up country receival and shrinkage	11.49	15.18	13.64	15.39	15.85
Storage for three months	-	4.50	3.30	4.50	4.80
Rail frieght - 200 km	19.00	23.00	27.20	23.00	23.40
GRDC levy	2.73	2.71	2.59	2.64	2.64
State researchand biosecurity levies	0.30	-	0.50	-	-
End point royalties	3.00	3.00	3.00	3.00	3.00
Other					
Total supply chain cost before rebates	**58.42**	**69.38**	**72.01**	**72.64**	**70.80**
Potential rebates from bulk handler	-1.75	-	-1.10	-	-
Supply chain cost after rebates	56.67	69.38	70.91	72.64	70.80
Farm gate price	**263.33**	**250.62**	**249.09**	**247.36**	**249.20**

Source: Stretch et al. (2014)

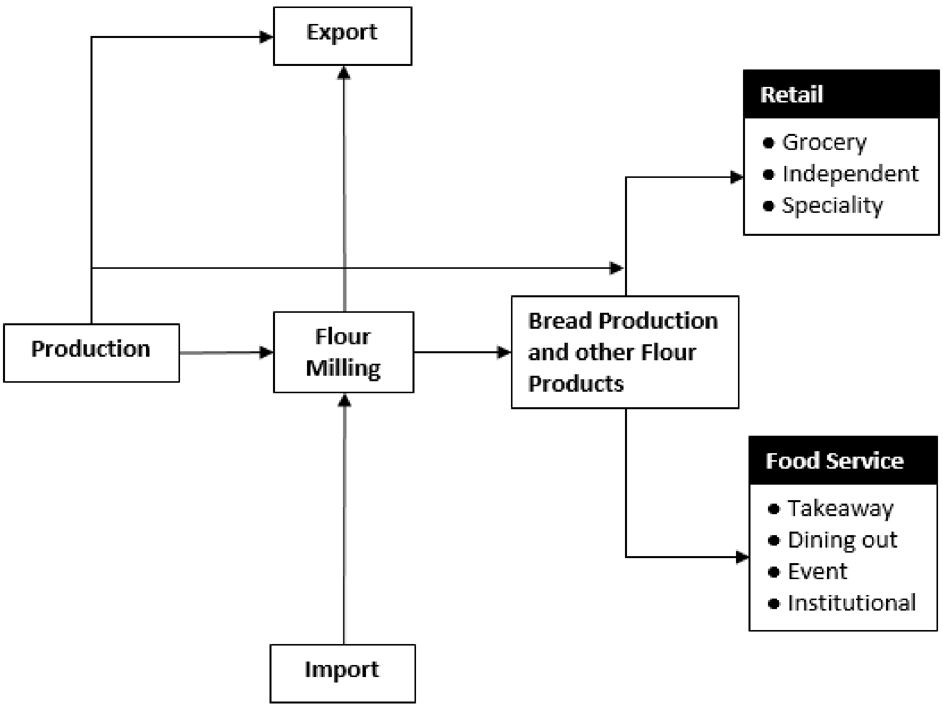
Stretch et al. (2014) highlighted that, in Australia, supply chains in WA and SA are structured to deliver grain to port, with around 85-95 per cent of the grain produced in these two states being exported. On the other hand, around 50 per cent of grain grown in eastern Australia is consumed locally, which results in grain going through a different supply chain and value-add process. In terms of wheat, the grains industry can process and market around 10-15 per cent of wheat production into domestic consumer markets in a variety of products (Spencer and Kneebone, 2012). Most food uses for wheat include wheat flour products such as bread and pastry products, and consumer and foodservice flour products. While it has been mentioned that the wheat industry is primarily export driven, with 85 per cent of raw wheat being exported, the flour industry is the opposite, with only around 10 per cent of flour production being exported overseas (Spencer, 2004). The supply and value chain for flour and other wheat products is more complex than for exported wheat. In Figure 4 below is a simple value chain map for grain and flour products.

The price of raw wheat and grains is a major cost in the production of flour. Spencer (2016) noted that the farm gate prices represented 34 per cent of the retail value of flour. As wheat and grains move along to be processed as flour at the wholesale level, costs are incurred. Finally, as flour is turned into bread and other flour products, further costs are incurred. Whether a further margin over cost is applied, depends on competition at each stage of the chain.

Major Competitors

Globally, Australia is a relatively small grain producer. An average of 25 million tonnes of wheat is produced per annum in Australia which accounts for only 3.6 per cent of world wheat production (see Table 13). An average of 18.5 million tonnes per annum is exported, accounting for over 70 per cent of the average annual production (Table 14). Annual global exports of wheat are around 200 million tonnes.

Figure 4. Grain and flour product supply chain map



Source: Spencer and Kneebone (2012)

South East Asia (SEA) is the largest market for Australian wheat, importing 42.9 million tonnes over the five years to 2017 valued at A$2.6 billion per annum (GRDC, 2018b). The competitive advantage of Australian wheat producers and sellers in the SEA market has been the close proximity to Australian grain ports, as well as some grain quality attributes. In recent years there has been a strong surge of competition from Russia and Ukraine in SEA markets, because of lower production and transport costs.

Between 2012-13 and 2016-17, Russia's wheat exports averaged 21 million tonnes per annum, a world share of over 13 per cent. The average growth rate in Russia's wheat exports was 27 per cent during this period (ABARES, 2017). This is in contrast to Australia's 7 per cent average growth rate in wheat exports. This rise in exports for Russia has come from a combination of factors, including exchange rate movements, the modernisation of agronomic practices, and increased investment in farm machinery and logistics infrastructure. It is projected that Russia's wheat exports will increase by 60 per cent between 2015 and 2030 (Kingwell et al., 2016a).

Ukraine averaged over 12 million tonnes of wheat exports per annum over 2013-2017, or 8 per cent of world production. Like Russia, the average annual growth rate in wheat exports was 28 per cent (ABARES, 2017), due to an exchange rate devaluation in 2014 boosting the export competitiveness of its grains. As noted by Kingwell et al. (2016b), there is significant scope for Ukraine to increase its international competitiveness by increasing the area sown to wheat, increasing investments in agricultural infrastructure, and adopting more modern farming methods.

Table 13. Top 10 wheat producing countries, average 2013-2017

Country	Production (Million Tonnes)	Per cent of World Share
China	125.6	17.5
India	91.4	12.7
United States	58.7	8.2
Russian Federation	56.5	7.9
France	37.4	5.2
Canada	30.7	4.3
Australia	25.8	3.6
Germany	25.2	3.5
Pakistan	24.9	3.5
Ukraine	23.4	3.3

Source: ABARES Agricultural Commodity Statistics

Table 14. Top 10 wheat exporting countries, average 2013-2017

Country	Exports (Million Tonnes)	Per cent of World Share (%)
European Union	30.9	19.6
United States	26.6	16.8
Canada	21.8	13.7
Russian Federation	21.1	13.3
Australia	18.5	11.7
Ukraine	12.7	8.0
Kazakhstan	7.2	4.4
Argentina	6.6	4.2
Turkey	5.2	3.3
India	3.5	2.2

Source: ABARES Agricultural Commodity Statistics

Policy Environment

Australia

The Australian grains industry has a long history of government regulation. Historically, the domestic and export sales for wheat were regulated under single-desk marketing arrangements: returns to growers were pooled nationally and the prices received by growers averaged. These marketing arrangements were carried out by the Australian Wheat Board (AWB) from 1939 to 1999, and later by its successor, AWB International, from 1999 to 2008 (Productivity Commission, 2010). The scope of single desk marketing arrangements was reduced in 1989 when the Commonwealth Government deregulated the domestic market for wheat sales. The export sales for wheat continued to operate under the single-desk monopoly until August 2007 when non-bulk exports were deregulated. In June 2008, the single-desk marketing arrangements were abolished when bulk wheat exports were deregulated. Subsequently, a significant number of new participants entered the bulk wheat exporting market, bringing greater competition and more marketing options for growers.

The momentum for change to the export marketing arrangements for wheat was partly the result of successful deregulation of the export of other grains (Productivity Commission, 2010). Prior to the 1990s, single-desk marketing arrangements also prevailed in the domestic and export markets for barley, sorghum, maize, oats, oilseeds, lupins and rice. The marketing arrangements were maintained by both (i) the various statutory marketing boards for each grain type and (ii) a single bulk handling authority in each state. Statutory marketing boards were provided with exclusive rights to acquire grain, whereas bulk handling authorities were given exclusive rights to receive grain. The 1990s and early 2000s saw consolidation in which a number of bulk handling companies and statutory marketing boards were privatised and merged, creating entities that performed dual functions. It was during this time that deregulation of the marketing arrangements for these grains also occurred.

Overseas

The wheat industries of other exporting countries exhibit similarities and differences in terms of their marketing and institutional arrangements.

By contrast to the Australian wheat industry, the US wheat industry has historically embraced a free enterprise approach in terms of agricultural marketing, protesting AWB's single-desk marketing arrangements during its existence (Watson et al., 2017). Another distinguishing feature of the US wheat industry is the utilisation of market intervention programs to counter adverse fluctuations in prices, revenues and production. These intervention programs lie in the form of federal subsidies for farm businesses and are substantial in magnitude—around $25 billion a year (Edwards, 2016).

The Canadian wheat industry, on the other hand, has a lot in common with the Australian wheat industry. Previously, the Canadian Wheat Board (CWB) operated as the sole marketing agency for Western Canadian wheat and barley. Deregulation of wheat exports occurred in 2012 as the CWB's single-desk monopoly position was removed. Since deregulation, two new agencies play a more prominent role in the market development and quality management functions: the Canadian Grains Commission (CGC) and the Canadian International Grains Institute (CIGI). The CGC is a federal government agency that regulates the grain handling industry, conducts scientific research into grain quality and safety, and provides technical advice and expertise to overseas customers (Watson et al., 2017). The CIGI, on the other hand, is a not-for-profit education and market-support organisation that serves to drive the market development of agricultural products. Unlike Australia, where the market development function was lost or transferred to the private interests of individual traders following export wheat deregulation, the market development function remained as a public function in the Canadian wheat industry (White et al., 2015).

Research Evaluation in Agriculture

Historical context

Technological changes have been prominent in shaping the evolution of agricultural production since the Industrial Revolution in the 17th to 19th centuries. Nowadays, agricultural production faces two main challenges: population growth and climate change. Over the past several hundred years, the world's population has grown rapidly, doubling from 1 billion people in 1800 to 2 billion people in 1930, before soaring to over 7 billion people by 2018. World population is estimated to reach over 9.5 billion people by 2050 (OECD, 2016) before stabilising. The implication of looming rapid world population growth is that food supply must increase by some 70 per cent to keep up with food demand which will grow with both increasing people and increasing incomes world-wide. Similarly, climate change will affect agricultural productivity through changes in key environmental factors such as temperature, rainfall, available irrigation water from run-off, increasing carbon dioxide concentrations, evaporation and plant water use, frost frequency, and extreme events such as cyclones and heavy rain, and increasing yield and price volatility

Modern progress in agriculture can be attributed to an increase in scientific research as a source of information in improving agricultural methods (Waite, 1915; Kingwell, Xayavong and Islam., n.d.). Successful agricultural research contributes, among other things, to the development of technologies, inputs and techniques of production that help to increase agricultural productivity (Maiangwa, 2010). Alston, Norton and Pardey (1995) point out that this is essential for improving welfare and overall economic development for many countries. For instance, agricultural productivity is important for less developed countries given its importance in helping to reduce income risk and improve national food security. In wealthy countries, growth in agricultural production is just as important in maintaining low food prices, generating foreign exchange, improving competitiveness in world markets, and improving animal welfare outcomes (Alston et al., 1998; Productivity Commission, 2011).

Gains from agricultural research

Agricultural productivity is measured as the ratio of agricultural outputs to agricultural inputs. Increases in agricultural productivity lead to either more output produced with the same level of measured inputs, or the same amount of output being produced with a smaller quantity of measured inputs (cost savings). Alston et al. (1995) pointed out that agricultural research is an investment in the production of knowledge. The benefits derived from changes in knowledge enable:

- more output (for a given expenditure on inputs),
- cost savings (for a given quantity on inputs),
- new and better products, and
- better organisation and quicker response to changing circumstances.

The Productivity Commission (2011) asserts that, in addition to higher productivity and competitiveness, agricultural research and development can deliver a wide range of other benefits. For instance:

- enhanced supply chain knowledge, management and efficiency,
- reduced impacts of pests and disease,
- better standards of living (through cheaper food and higher quality food), and
- contribute to better environmental and social outcomes.

Agricultural RD&E funding arrangements in Australia

The role of RD&E in enhancing growth and productivity in the agricultural sector was highlighted in the previous section. Globally, public sector agricultural research is a significant commercial activity. During the mid-1980s, around $9.2 billion (1980 dollars) was spent by agricultural research systems – around $4.4 billion in developing countries and $4.8 billion in developed countries (Anderson et al. as cited in Alston et al., 1995).

As noted by the Productivity Commission (2011), during the 2008-09 financial year, funding for rural RD&E and related activity was around $1.5 billion In Australia, with around three-quarters being provided by the Australian and State and Territory Governments (Table 15). A substantial part of the Australian Government funding for rural RD&E is provided to Rural Research and Development Corporations (RDCs) whereby the Australian government and primary producers co-invest in RD&E for industry and community benefits. There are currently 15 RDCs comprised of five Commonwealth statutory bodies and 10 industry-owned companies (IOCs).

Table 15. Source of agricultural RD&E in Australia, 2008-09

Organisation type	**Funding**	**Share**
	million	%
Australian Government		
Cooperative Research Centres	63	
Core funding for the CSIRO	193	
Core funding for the universities	118	
Research and Development Corporations (RDCs)	218	
Other departmental Programs	114	
Forgone tax receipts arising from RD&E tax concessions	9	
Total Australian Government	715	48
State and Territory Governments	348	
Project-related budget allocations	47	
Capital investment in RD&E facilities	21	
Payments to other funders and suppliers	416	
Total State and Territory Governments		28
Private/Industry		
Levy payments provided to RDCs	248	
Other (for which a tax concession is claimed)	116	
Total Private/Industry	364	24
Total	**1495**	**100**

Source: Productivity Commission (2011)

Grains RD&E funding arrangements

In the Australian grains industry, the Grains Research and Development Corporation (GRDC) is a statutory corporation, founded in 1990, under the Primary Industries Research and Development Act 1989. The GRDC is responsible for planning, investing in and overseeing grains RD&E to deliver improvements in production, sustainability and profitability for Australian grain growers, the grains industry and the wider community. The GRDC is principally supported by a grower levy and matching Australian Government contributions. The levy is based on the net farm gate value of the annual production of 25 crops: wheat; coarse grains (barley, oats, sorghum, maize, triticale, millets/panicums, cereal rye and canary seed); pulses (lupins, field peas, chickpeas, faba beans, vetch, peanuts, mung beans, navy beans, pigeon peas, cowpeas and lentils); and oilseeds (canola, sunflower, soybean, safflower and linseed). The current levy rate is 0.99 per cent of farm gate value for 24 grains and 0.693 per cent of farm gate value for maize. The Australian Government's matching payment is 0.5 per cent of the Gross Value of Production (GVP) calculated as a three-year rolling average of GVP of the 25 leviable crops. GRDC states 'Our investments must: deliver the highest impact; improve the profitability of Australia's grain growers; facilitate ways for research to be applied within the industry; provide the best return on investment; and align with our key areas of investment' (GRDC, 2018c).

The Australian grains industry has grown at an average of 1.9 per cent per annum over the past 30 years, due to market forces and increases in total factor productivity (Research and Innovation Committee, 2017). One of the key causes of this high growth rate has been successful RD&E generating knowledge: improved farm management; new plant varieties; improved crop rotations; better disease, weed and pest control; and advances in cropping technology. The Grains Industry Research, Development and Extension Strategy aimed to achieve total factor productivity growth of more than 2.5 per cent per annum by 2025 (Research and Innovation Committee, 2017), and the new Research and Development Plan currently continues pursuit of this aim.

The need for agricultural research evaluation

Agricultural research is an investment in the production of knowledge and, like any type of investment, involves the expenditure of scarce resources at the cost of other alternative consumption or investment choices forgone (Alston et al., 1995). This is a challenge faced by governments and funding agencies, as decisions must be made on how much limited public funding to allocate to specific research projects. Consequently, not all research problems can be addressed because of scarcity in research resources, including capital, skilled labour and other inputs (Alston et al., 1995). In periods of instability in revenues for research, agricultural research evaluation and priority setting become important. Hence, there is a need to measure the economic impacts of agricultural research to improve decision making and the effective management of public funds.

Evaluation of economic impacts in agricultural research

History shows that innovations in agriculture have usually came from research that led to advances in planting, growing, harvesting and processing. Innovations in agriculture often stem from breakthrough scientific knowledge (Sunding and Zilberman, 2001). There has been significant interest in agricultural innovation among economists and agricultural research funding agencies, as evident from the large number of studies examining payoffs to agricultural RD&E. Difficulties, however, have always arisen in attribution, determining research lags and in quantifying the overall net benefit distribution between producers and other participants in the value chain.

Methods for Assessing the Returns to Agricultural RD&E

The large body of literature dealing with evaluating agricultural research primarily covers two major methodologies. Some of the central concepts and techniques used in these methodologies are reviewed here.

Economic surplus methods

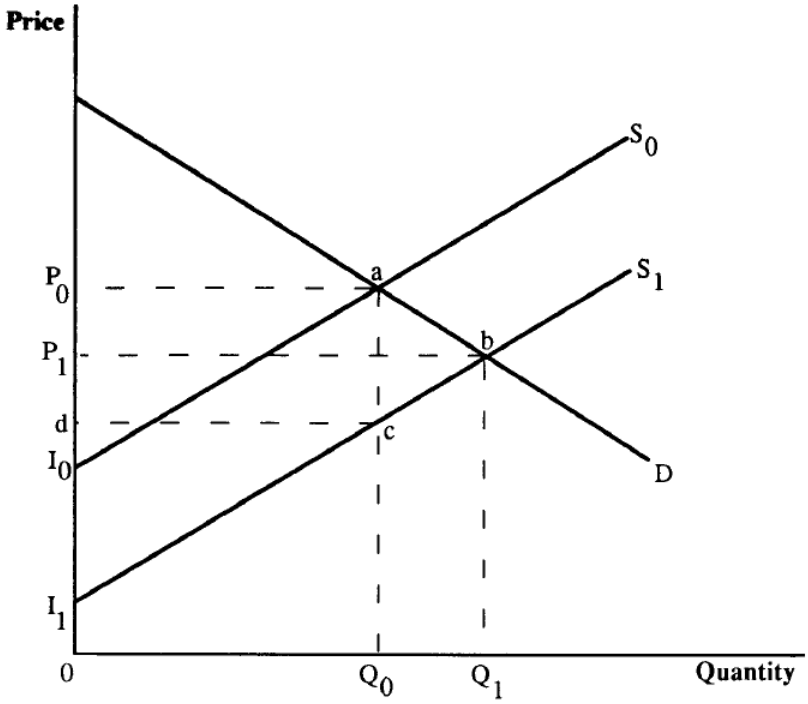
The most popular and successful approach used to assess the impacts of investments in agricultural research is the economic surplus approach (Alston et al., 1995). The economic surplus approach evaluates the benefits from shifts in supply due to changes in productivity brought about by the introduction of agricultural innovations. Changes in productivity will affect the relationship between inputs and outputs and this will change the relationship between production costs and output and thus between supply and price. Using this approach, the technological impacts from research can be assessed by looking at the relationship between research investments and a commodity's industry-level supply function.

The basic model (in a closed economy) for the economic surplus measure, as described by Alston et al. (1995), is illustrated in Figure 5. Here, S_0 is the supply curve under original technology, and S_1 is the supply curve after research-induced technical change. The initial equilibrium price and quantity are P_0 and Q_0, and the new equilibrium price and quantity after the supply shift are P_1 and Q_1. The total benefit and change in consumer surplus from the research induced supply shift is given by the area I_0abI_1. This net benefit can be decomposed into two parts: the cost saving on the original quantity (the area I_0acI_1); and the economic surplus because of the increment to production and consumption (area abc). Alternatively, the total benefit can also be broken down into the change in both consumer surplus (ΔCS= P_0abP_1), and producer surplus (ΔPS= P_1bI_1 - P_0aI_0). Mathematically, these effects can be expressed as follows:

ΔCS = $P_0Q_0Z(1+0.5Z\eta)$ (1)
ΔPS = $P_0Q_0(K-Z)(1+0.5Z\eta)$ (2)
ΔTS = $\Delta\text{CS}+\Delta\text{PS}=P_0Q_0K(1+0.5Z\eta)$ (3)

where K (also known as the K-factor) is a (research induced) shift of the supply function expressed as a proportion of the initial price, η is absolute value of price elasticity of demand, ε is the elasticity of supply, and Z=K ε/(ε+, η) is the proportional price reduction in the market relative to the initial base case (pre-research) scenario. The economic surplus formulae represented in equations (1), (2) and (3) are widely used in economic evaluations of agricultural research.

Figure 5. Consumer and producer surplus measurement



Source: Alston (1991)

Policy makers have an interest in knowing both the size of the economic benefits associated with research investment and its distribution among different industry groups. As such, the basic model in Figure 5 is often extended to consider various multimarket settings. As stated by Alston (1991), this firstly includes disaggregating the total benefits to answer questions relating to the distribution of benefits among stages of a multistage production system (vertical incidence), e.g. at the farm level, retail level, and some intermediate stage such as the marketing system. The measurement of the total benefits (consumer surplus plus producer surplus) will not be affected by the choice of where to measure benefits in the supply chain as it will be the same at all levels. The only thing that will be affected by the choice of measurement perspective will be the distribution of consumer surplus versus producer surplus. Secondly, the distribution of benefits can also be examined across different markets for the same product in different places or for different products (horizontal incidence). For example, at a given market level, suppliers and demanders can be disaggregated into subcategories according to geopolitical boundaries (e.g. domestic and foreign/export) or according to other characteristics (Alston, 1991).

Many past studies have examined the returns to agricultural investments using economic surplus approaches. Griliches (1958) provided one of the earliest examples of applying economic surplus concepts to *ex post* evaluation of agricultural research. In that work, Griliches focused on a successful agricultural venture, the introduction of hybrid corn in the USA, examining both the total research and development expenditures that led to its creation as well as the subsequent net increase in the value of the corn crop over the period from 1910 to 1955. The analysis provided evidence of the significant gains from research and development, with the net social returns estimated to be at least 700 per cent per year. Other early examples of economic surplus approaches to *ex post* agricultural evaluation include Peterson (1967) and Schmitz and Seckler (1970). Peterson's work focused on the returns to poultry research in the USA, estimating that past investments in poultry research yielded high returns of around 20 to 30 per cent per year. Schmitz and Seckler, on the other hand, studied the impacts of mechanised agriculture on social welfare, focusing on the development of the tomato harvester. They tested the impacts under two cost-saving scenarios, taking into consideration both the displacement effects of the innovation on tomato workers and the compensation needed to offset the impact of technological change for displaced workers (based on the Kaldor-Hicks criterion). Under the low cost-saving scenario, the net social rate of return varied between 929 and -8 per cent, and under the high cost-saving scenario, the net social rate of return varied between 1,288 and 345 per cent[2].

Many *ex ante* studies of agricultural research priorities using the economic surplus approach have also been conducted. Davis, Oram, and Ryan (1987) developed a multi-regional international trade model to derive *ex ante* measures of the relative economic benefits of alternative commodity and regional research portfolios as well as the distribution of these benefits among consumers, producers, importers and exporters. Norton *et al.* (1987) examined the benefits of agricultural research and extension using a consumer surplus framework for five commodities. In that study, attention was on the effects of demand shifts over time and government pricing policies on research and extension benefits.

The effects of the research-induced technological benefits may not simply be limited to just the consumers and producers of the commodity directly affected by the technological changes, but also impact the consumers and producers of other related commodities through cross-commodity feedback effects (Alston *et al.,* 1995). For instance, an improvement in technology in the pork industry will initially shift the supply of pork downwards and result in a reduction in its price. This may cause a reduction in the demand for beef (and reduction in its price) if pork and beef are substitutes in consumption. This may be complicated further if the reduction in the price of beef causes additional feedback to the pork market (and change the final equilibrium price and quantity in this market). This was first demonstrated by Buse (1958) who introduced the concept of 'total elasticity'. The total elasticity for demand and supply in an industry captured the total price sensitivity of a good in response to its own-price changes as well as feedback effects from price changes in related goods. This concept may be particularly relevant for the grains industry considering that the crops produced in a crop rotation system are 'joint products'; that is, outputs generated simultaneously using common inputs. This means that technical change that affects one crop (e.g. wheat) may also affect another crop in the cropping sequence (e.g. barley) through its effects on soil structure, fertility, pest and diseases. Many of these grains are also substitutes in consumption (Alston, 1995).

Econometric and statistical methods

[2] The internal rate of return metric that was much used in early research evaluation is flawed. The modified internal rate of return is the correct measure. See Hurley, Rao & Pardey (2014) for a discussion on this.

Econometric models have been used to estimate the relationship between past investments in agricultural RD&E and agricultural production and productivity. The ability of econometric models to account for a variety of changes simultaneously makes them highly useful (Heisey et al., 2010). In addition, econometric estimation allows for dynamic relationships such as seasonality and time effects to be captured within the model, and it allows researchers to test hypotheses about the parameters (Ludlow, 2013; Mounter et al., 2008). This is especially relevant from an agricultural perspective as seasonality conditions influence the yields of crops and other products (Griffith *et al.,* n.d.).

Econometric models include both parametric and non-parametric approaches. Parametric approaches involve specifying an explicit functional form that links inputs to outputs (Alston et al., 1995). This can include direct estimation of production functions, which model agricultural output quantities as a function of inputs; response functions, which model the factors that influence an important variable such as crop yield; or productivity functions, which estimate output per unit of input (Heisey et al., 2010).

Conventional approaches to modelling production functions involve estimating a parametric model and evaluating the properties of the estimated model. For example, as presented and explained by Alston et al. (1995), an econometric approach can be used to estimate an agricultural production function, which is the most common econometric method used to estimate the economic benefits of agricultural research:

$$Q_t = q(X_t, W_t, H_t, P_t, Z_t, R_{t-r}, E_{t-e}) \quad (4)$$

where q(.) is a production function that link inputs to agricultural output in time t, Q_t.
X_t – a vector of conventional inputs
W_t – uncontrolled factors such as weather in this instance
Z_t – various infrastructural variables (such as public investment in roads, communications, irrigation and education)
H_t – stock of human capital in agriculture
P_t – relative factor prices
R_{t-r} – past (lagged) investments in research
E_{t-e} – past (lagged) expenditure in extension services

By estimating equation (4), one can then determine the economic benefits from research by calculating the value of the additional output attributable to the lagged research expenditures (holding other inputs constant) or the value of the savings in inputs because of the lagged research expenditures (holding output constant). Lagged values for research investment and expenditure in extension services are used because research does not affect agricultural production directly or instantaneously; that is, time elapses before usable technologies can be generated from research investments (Alston et al., 1995).

An obvious drawback of the parametric approach is that different results will be obtained depending on the functional form q(.) chosen for the model. Non-parametric approaches are an alternative way to assess the effects of past agricultural research investments. Non-parametric approaches completely avoid the use of functional forms. This indirect approach involves treating the sector being analysed as a firm and using models of the firm and producer behaviour to incorporate changes in economic data (Heisey *et al*., 2010).

Econometric techniques can also be used directly to model the market described in Figure 5. Time series data on the variables in the model are used to estimate parameter values. This subsequently enables the estimated equations in the model to be simulated to predict changes in prices and quantities from a specified K shift, and hence can be used to measure economic surplus. Although potent in their abilities, econometric models are heavily data-intensive. As pointed out by Mounter et al. (2008), the data-intensive nature of econometric models makes them difficult to maintain and update in cases when data gets collected and reported infrequently.

Equilibrium displacement modelling

Thus, economic surplus approaches are the most widely used approach because of reasons such as their versatility in analysing specific rather than aggregate effects of research, and also because these methods are not 'data intensive' (Masters, 1996). In estimating economic surplus, researchers must first decide on a modelling strategy. This involves deciding on the type of functions (e.g. linear or non-linear) and the type of supply and demand shift (e.g. parallel vs pivotal) (Ludlow et al., 2013). The modelling strategy and scope of the study defines the data requirements (Alston et al., 1995). Researchers must choose from different techniques in measuring economic surplus.

An equilibrium displacement model (EDM) is an economic surplus approach used to estimate the net benefits from agricultural RD&E and the distribution of benefits between producers and other participants in the value chain. Such models are an increasingly popular economic surplus approach because of their strong theoretical basis and non-data intensive requirements. Rather than requiring extensive time series data, EDMs only require base equilibrium price and quantity data for a representative or average year, along with estimated Marshallian elasticity values taken from published work or expert opinion (Vere, Griffith, and Silvester, 2005). First coined by Piggott (1992), EDMs are a distinctive kind of comparative static approach that expresses the system of equations in the model in elasticity form. One advantage of the EDM construct is that it enables researchers to obtain information on partial elasticities, quantity, and expenditure shares in order to calculate the importance of various supply and demand shift parameters on market outcomes (Wohlgenant, 2011). As mentioned above, a drawback of parametric approaches in econometric modelling is that they rely on a functional form to be specified. By contrast, an EDM does not rely on a functional form since the system of equations are expressed in terms of relative changes/elasticities, and are linear in nature. Estimates obtained this way will yield good approximations for small equilibrium shifts. Some important concepts for EDMs are briefly reviewed in the following section.

As outlined by Piggott (1992), the general process of an EDM involves firstly having a market characterised by a set of supply and demand equations – consistent with economic surplus methods described previously, as in Figure 5. No functional forms are assumed for these equations. Next, the market is 'shocked' by a change in the value of an exogenous variable in the system. The impacts of the shock or disturbance are then approximated by functions that are linear in elasticity. EDM differs from other comparative static approaches in that it is underpinned by the concept of elasticity; changes in endogenous and exogenous variables are measured in proportionate terms or as ratios of proportionate changes (i.e. elasticities).

The EDM approach is sometimes known as 'Muth modelling', in reference to Muth (1964). The modified version of Muth's (1964) model by Alston et al. (1995) is shown below. Here, the market is characterised by a competitive industry producing a single homogeneous product using two factors of production. Following the notation used in both Alston et al. (1995) and Muth (1964), we have:

Consumer demand: $$Q = f(P) \tag{5}$$

Production: $$Q = q(X_1, X_2) \tag{6}$$

Factor demand: $$W_1 = Pq_1 \tag{7}$$

$$W_2 = Pq_2 \quad (8)$$

Factor supply:

$$X_1 = g(W_1) \quad (9)$$

$$X_2 = h(W_2) \quad (10)$$

Where Q is the quantity of product, P is the price of product, X_1 and X_2 are the quantities of factors 1 and 2, W_1 and W_2 are the prices of factors 1 and 2, and q_1 and q_2 are the marginal products of factors 1 and 2 respectively ($q_i = \mathrm{d}q(.)/dX_i$ for factor *i*).

Equation 5 shows the demand for the industry's output, equation 6 is the production function, equations 7 and 8 are factor demand equations with each factor being paid at the value of its marginal product, and equations 9 and 10 are the factor supply equations. Constant returns to scale are assumed at the industry level.

Equations 5 to 10 are differentiated, converting them to elasticity form. Exogenous shocks are introduced to yield the following equations expressed in terms of relative changes and elasticities:

$$E(Q) = -\eta[E(P) - \alpha] \quad (5')$$

$$E(Q) = s_1E(X_1) + s_2E(X_2) + \delta \quad (6')$$

$$E(W_1) = E(P) - (s_2/\sigma)E(X_1) + (s_2/\sigma)E(X_2) + \delta + \gamma \quad (7')$$

$$E(W_1) = E(P) - (s_1/\sigma)E(X_1) + (s_1/\sigma)E(X_2) + \delta - (s_1/s_2)\gamma \quad (8')$$

$$E(X_1) = \varepsilon_1[E(W_1) + \beta_1] \quad (9')$$

$$E(X_2) = \varepsilon_2[E(W_2) + \beta_2] \quad (10')$$

Where E denotes relative changes (e.g., E(Q)=ΔQ/Q ≅ Δlog(Q)), η is the absolute value of the elasticity of demand, α is a vertical shift in the demand function reflecting an increase in demand, s_i is the cost share of factor i ($s_i = W_iX_i/PQ$), σ is the elasticity of substitution between X_1 and X_2, ε_i is the elasticity of supply of factor i, and β_i is a vertical shift down in the supply of factor i reflecting an increase in its supply.

α, β_1, $\beta_{2,}$, δ, and γ are exogenous shift parameters, expressing equilibrium displacements relative to an initial equilibrium.

Equations 5' to 10' form a simple EDM. They do not have any assumptions concerning the functional forms of supply and demand, being a local approximation to unknown functions (Alston et al., 1995). The size and total distribution of total benefit from research can then be approximated using equations 1 to 3 above, where ΔPS_i is defined for each factor of production.

Dynamics

An EDM is a form of comparative static analysis comparing two different equilibrium states: before and after a change in an underlying exogenous parameter (representing the impacts of new innovations and technologies) in the model. It does not study the dynamic path of adjustment towards equilibrium, nor the process of change itself.

In practice, the research investment cycle takes time. Research and its output does not affect agricultural production directly or instantaneously. Time elapses before usable technologies can be generated from research investments, commercialised and adopted. Furthermore, as with any other form of capital, the knowledge generated through agricultural research becomes obsolete or depreciates over time. Therefore, time lags exist between the commencement of research, full adoption and eventual dis-adoption of an innovation or technology. A limitation of EDM is that it does not account for these dynamic responses within the framework. Exogenous shifts in the model that represent the impacts of new technologies or promotions are assumed to be instantaneous and the benefits are indicative of the returns assuming full adoption and complete market adjustment over some particular time frame as determined by the nature of the elasticity values used (Mounter *et al.,* 2008, p.80).

An implication of incorporating dynamics in the analysis is that the elasticities of demand and supply (denoted by η and σ respectively) can no longer be treated as constants. They will change and become more elastic over the adjustment process. This is because the more time consumers and producers have to respond to price changes, the more elastic are their demand and supply curves. Piggott (1992) highlighted that this phenomenon could be tackled by repeated applications of EDM using elasticities corresponding to different time periods.

As described previously, the K factor represents the size of the research-induced supply shift. In a dynamic setting, the K factor will also vary over time (i.e. K_t) as typically, the flow of benefits begins once the adoption phase commences and gradually increases over time until full adoption is reached. As such, the K factor becomes the most crucial variable in the system, as different approaches for estimating K_t can yield significantly different results (Alston et al., 1995; Norton, 2015). Various approaches for estimating K_t include (i) the use of expert opinions of scientists and other research experts, (ii) the incorporation of input and yield data from biological field experiments into budgets combined with adoption data from surveys, (iii) the use of survey data at the farm-household or plot level in regression-based analyses, and (iv) randomised controlled trials. Just, Hueth and Schmitz (1982, as cited in Zhao *et al.,* 2000) presented an approach to measuring the welfare impacts for the years after the initial exogenous shock and before reaching the new equilibrium, using different supply curves of different time durations.

Applications of Equilibrium Displacement Modelling in Various Agricultural Industries to Facilitate R,D&E Decisions

EDMs have been used extensively to determine the impacts of new technologies in many agricultural settings in Australia, particularly in the livestock industries. EDMs have been developed for the beef industry (Zhao *et al*., 2000), the sheep and wool industry (Mounter *et al.,* 2008), the pig industry (Mounter, Griffith and Piggott, 2004), and the dairy industry (Liu *et al.,* 2012; Ludemann *et al*., n.d.). In addition, there have been EDMs developed for the wine grapes and wine industry (e.g. Zhao, Anderson and Wittwer, 2002).

Many of the research questions posed have been about how the total benefits associated with research investments are distributed among different stages of the value chain. Thus, developing EDMs requires an understanding of the value chain structure of the industry being examined.

As highlighted by Borrell et al. (2014), the benefits and distribution of benefits from RD&E along the value chain depends on the economic assumptions and market characteristics of the value chain. As emphasised by Borrell et al. (2014), the payoffs particularly depend on: the type and nature of the change caused by successful RD&E; where change occurs along the supply chain; the elasticities of supply and demand and substitution between inputs and substitution between final products; and the relative sizes of gross value of production at each point along the value chain.

A Preliminary EDM for the WA Grains Industry

As outlined above, the Australian grains industry is vast in scope, comprising many grain types and qualities produced across three broad agro-ecological regions, with a range of different intermediate sectors and end uses along the supply chain. Constructing a comprehensive EDM of the entire grains industry in Australia is a complex activity.

As a starting point, a simplified EDM for the WA grains industry was constructed and tested by Li *et al*. (2017), as a precursor to the development of an Australia-wide model. This preliminary model provided a stylised representation of only two industries, wheat and barley, and only three industry sectors, farm production, storage and port. Even so, this simple specification resulted in a 50 equation EDM which represented the supply, demand and equilibrium conditions for each of the three industry sectors. The study modelled and tested the effects from two hypothetical scenarios: (i) new technologies or practices adopted from RD&E that reduce the costs of production and (ii) improvements in the quality of wheat that increase the overseas consumers' willingness to pay. Appendices 1 to 7 provide a summary of the model specification details along with the modelling results (the results have been updated slightly from those presented in the source paper).

In Scenario 1, a 1 per cent downward shift of the supply curve for other purchased farm inputs was imposed to simulate the effects of any research-induced technical change that reduces the cost of producing these inputs. The total surplus gain for the combined industry is estimated to be $15.49 million per year. All industry groups experience gains in welfare. In terms of the distribution of benefits, the farm sector is the main beneficiary of the technology shock with a total producer surplus of $10.95 million, equalling 59 per cent of the total surplus gain. Domestic consumers receive $1.98 million or 13 per cent of the total benefits, and the grain handlers and port operators share 8 and 4 per cent of the total benefits respectively. The prices for export grains are largely unaffected by the technological shock because of the high own-price elasticity of export demand for grains (-5). In this instance, the total benefits accruing to overseas consumers are $2.58 million or 17 per cent of the total benefits.

In Scenario 2, a 1 per cent upward shift of the demand curve for export wheat was imposed to simulate the effects of either (a) quality enhancing research that increases the willingness to pay by overseas consumers or (b) investments in advertising and promotion in overseas markets. The total returns here are comparable to those in Scenario 1, with the total surplus gain estimated to be $22.32 million per year. The economic benefit to the farm sector is significant at $13.97 million or 63 per cent of the total benefits. The grain handlers and port operators gain 8 and 5 per cent of the total benefits respectively, while domestic consumers gain 9 per cent and overseas consumers receive 15 per cent.

It is the calculation of these types of results across each of the major grains and production regions that is the objective of the more detailed EDM under construction.

Summary

Measuring the economic impacts of agricultural research can help improve decision making and the effective management of public funds. Economists have traditionally used two different methods in evaluating agricultural research investments. The economic surplus methods are the most popular and common approach to assess the impacts of investments in agricultural research. Economic surplus methods explicitly draw upon welfare economic concepts using consumer and producer surplus. Economic surplus methods have advantages over econometrics methods including their ability to measure the distribution of research benefits among the various components of the value chain and across different regions (through vertical and horizontal disaggregation respectively), their ability to be used for both *ex-ante* analysis and *ex-post* analysis, and their relatively low data requirements.

EDM is one way that economic surplus methods are implemented; thus, it is an increasingly popular approach because of its strong theoretical basis and relatively low data requirements. It is a comparative static approach that expresses the system of equations in the model in elasticity form.

The benefits of research investments are measured by specifying exogenous shifts in the supply and demand curves and tracing the subsequent changes in consumer and producer surplus among different industry groups.

EDMs have been used in many different industries in the Australian agricultural sector, with the grains industry being the only major industry without an EDM. This is partly because of the complex nature of the grains industry. The grains industry in Australia consists of different commodity types classified broadly into three main categories: cereal grains, oilseeds, and pulses. Geographically, there are three broad cropping regions in Australia: northern, southern, and western. Production of grains importantly requires the practice of crop rotation in helping reduce soil erosion and increasing soil fertility and crop yield, often including a pasture phase so livestock activities are an important consideration too. The grains supply chain consists of multiple stages and end phases including: production, up-country storage and transport, marketing, processing and exports. Cross-product effects between different grains in crop rotations, as well as distinctive supply chains across the three different production regions, add large degrees of scale and complexity to the evaluation of benefits to RD&E in the grains industry. As well, some grains are substitutes in consumption, as alternate animal feeds or as processed flours and the like. Finally, previous empirical studies show evidence of imperfectly competitive market structures for the grains industries, and this has implications for the specification of models designed to evaluate the benefits from RD&E investments.

However, once constructed, a complete EDM for the Australian grains industry will be able to reveal the overall benefits of grains RD&E as well as the distribution of these benefits along the value chain and across regions, resulting in better informed investment decisions.

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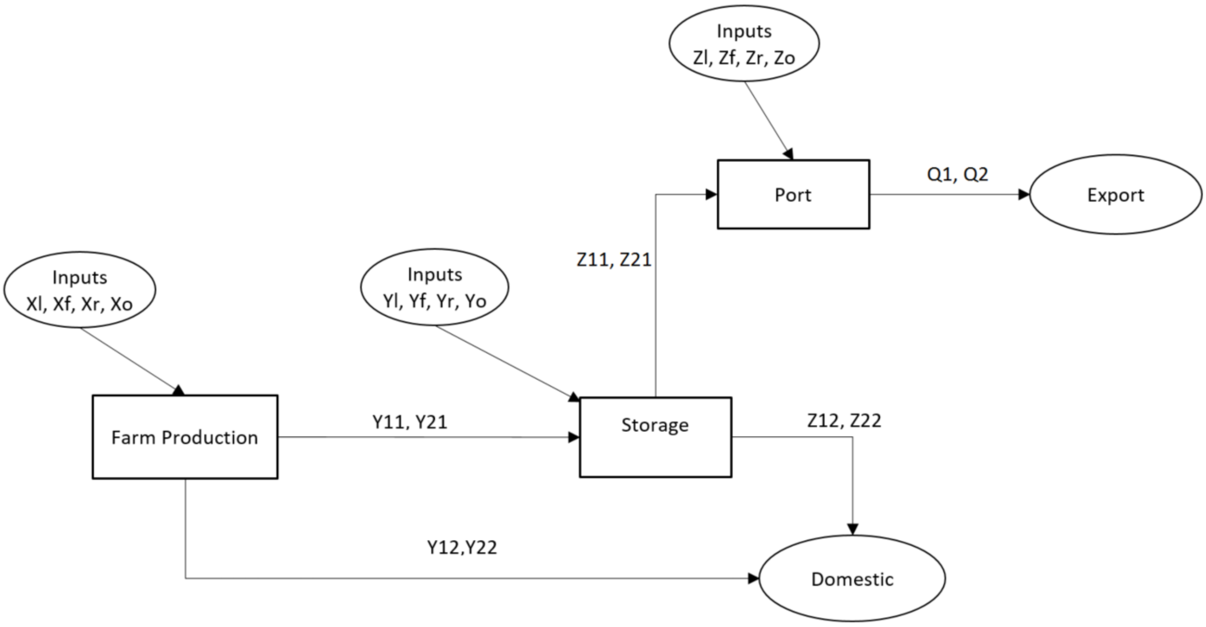
Appendix 1. Schematic for the simplified EDM of the WA grains industry



Appendix 2. Definition of variables and parameters for this simplified model

Endogenous Variables	
X_l, X_f, X_r, X_o	Quantity of factor inputs (labour, capital, land, other) used in farm sector
w_l, w_f, w_r, w_o	Price of factor inputs (labour, capital, land, other) used in farm sector
X	Aggregate input index of farm sector
Y_l, Y_f, Y_r, Y_o	Quantity of factor inputs used in storage sector
v_l, v_f, v_r, v_o	Prices of factor inputs used in the storage sector
Y_{11}	Quantity of wheat to the storage sector
Y_{21}	Quantity of barley to the storage sector
v_{11}	Price of wheat to the storage sector
v_{21}	Price of barley to the storage sector
Y_{12}	Quantity of wheat from farm to the domestic processing sector
Y_{22}	Quantity of barley from farm to the domestic processing sector
v_{12}	Prices of wheat from farm to the domestic processing sector
v_{22}	Prices of barley from farm to the domestic processing sector
Y	Aggregate output index of farm sector
Z_{12}	Quantity of wheat from storage to the domestic processing sector
Z_{22}	Quantity of barley from storage to the domestic processing sector
u_{12}	Price of wheat from storage to the domestic processing sector
u_{22}	Price of barley from storage to the domestic processing sector
Z_l, Z_f, Z_r, Z_o	Quantity of factor inputs input used in port sector
u_l, u_f, u_r, u_o	Prices of factor inputs used in port sector
Z_{11}	Quantity of wheat to port sector
Z_{21}	Quantity of barley to port sector
u_{11}	Price of wheat to port sector

u_{21}	Price of barley to port sector
Y^{s}	Aggregate input index of storage sector
Z	Aggregate output index of storage sector
Q_1	Quantity of wheat to the export market
Q_2	Quantity of barley to the export market
p_1	Prices of wheat to the export market
p_2	Prices of barley to the export market
Z^{p}	Aggregate input index of port sector
Q	Aggregate output index of port sector
Exogenous Variables	
TX_l, TX_f, TX_r, TX_o	Shift in supply for inputs used in farm sector
TY_l, TY_f, TY_r, TY_o	Shift in supply for inputs used in storage sector
TZ_l, TZ_f, TZ_r, TZ_o	Shift in supply for inputs used in port sector
$t_{xl}, t_{xf}, t_{xr}, t_{xo}$	Amount of shift in supply for farm sector inputs as a percentage of prices
$t_{yl}, t_{yf}, t_{yr}, t_{yo}$	Amount of shift in supply for storage sector inputs as a percentage of prices
$t_{zl}, t_{zf}, t_{zr}, t_{zo}$	Amount of shift in supply for port sector inputs as a percentage of prices
NY_{12}	Shift in demand for wheat from farm in the processing sector
NY_{22}	Shift in demand for barley from farm in the processing sector
NZ_{12}	Shift in demand for wheat from storage in the processing sector
NZ_{22}	Shift in demand for barley from storage in the processing sector
NQ_1	Shift in demand for wheat from port in the export markets
NQ_2	Shift in demand for barley from port in the export markets
n_{y12}	Amount of shift in demand for NY_{12} as a percentage of price of Y_{12}
n_{y22}	Amount of shift in demand for NY_{22} as a percentage of price of Y_{22}
n_{z12}	Amount of shift in demand for NZ_{12} as a percentage of price of Z_{12}
n_{z22}	Amount of shift in demand for NZ_{22} as a percentage of price of Z_{22}
n_{Q1}	Amount of shift in demand for NQ_1 as a percentage of price of Q_1
n_{Q2}	Amount of shift in demand for NQ_2 as a percentage of price of Q_2
Parameters	
$\eta_{i,j}$	Supply elasticity of commodity i with respect to price j
$\varepsilon_{i,j}$	Demand elasticity of commodity i with respect to price j
$\sigma_{i,j}$	Elasticity of substitution between inputs i and j
$\tau_{i,j}$	Elasticity of transformation between outputs i and j
κ_i	Cost share of input i
λ_i	Revenue share of output j

Appendix 3. EDM for the WA Grains Industry

1. Farm

1.1 Input Supply to farm enterprises

(A.1) $EX_l=\varepsilon_{xl,wl}*(Ew_l - t_{xl})$

(A.2) $EX_f=\varepsilon_{xf,wf}*(Ew_f - t_{xf})$

(A.3) $EX_r=\varepsilon_{xr,wr}*(Ew_r - t_{xr})$

(A.4) $EX_o=\varepsilon_{xo,wo}*(Ew_o - t_{xo})$

1.2 Output constrained input demands of farm enterprises

(A.5) $EX_l = -(\kappa_{xf} * \sigma_{xl,xf} + \kappa_{xr} * \sigma_{xl,xr} + \kappa_{xo} * \sigma_{xl,xo}) * Ew_l + \kappa_{xf} * \sigma_{xl,xf} * Ew_f + \kappa_{xr} * \sigma_{xl,xr} * Ew_r + \kappa_{xo} * \sigma_{xl,xo} * Ew_o + EY$

(A.6) $\mathrm{EX}_f = -(\kappa_{xl} * \sigma_{xf,xl} + \kappa_{xr} * \sigma_{xf,xr} + \kappa_{xo} * \sigma_{xf,xo}) * \mathrm{Ew}_f + \kappa_{xf} * \sigma_{xf,xl} * \mathrm{Ew}_l + \kappa_{xr} * \sigma_{xf,xr} * \mathrm{Ew}_r + \kappa_{xo} * \sigma_{xf,xo} * \mathrm{Ew}_o + \mathrm{EY}$

(A.7) $\mathrm{EX}_r = -(\kappa_{xl} * \sigma_{xr,xl} + \kappa_{xf} * \sigma_{xr,xf} + \kappa_{xo} * \sigma_{xr,xo}) * \mathrm{Ew}_r + \kappa_{xl} * \sigma_{xr,xf} * \mathrm{Ew}_f + \kappa_{xo} * \sigma_{xf,xo} * \mathrm{Ew}_o + \kappa_{xo} * \sigma_{xr,xo} * \mathrm{Ew}_o + \mathrm{EY}$

(A.8) $\mathrm{EX}_o = -(\kappa_{xl} * \sigma_{xo,xl} + \kappa_{xf} * \sigma_{xo,xf} + \kappa_{xr} * \sigma_{xo,xr}) * \mathrm{Ew}_o + \kappa_{xl} * \sigma_{xo,xl} * \mathrm{Ew}_l + \kappa_{xf} * \sigma_{xo,xf} * \mathrm{Ew}_f + \kappa_{xr} * \sigma_{xo,xr} * \mathrm{Ew}_r + \mathrm{EY}$

1.3 Input constraints output supplies of farm enterprises

(A.9) $\mathrm{EY}_{12} = -(\lambda_{y22} * \tau_{y12,y22} + \lambda_{y11} * \tau_{y12,y11} + \lambda_{y21} * \tau_{y12,y21}) * \mathrm{Ev}_{12} + \lambda_{y22} * \tau_{y12,y22} * \mathrm{Ev}_{22} + \lambda_{y11} * \tau_{y12,y11} * \mathrm{Ev}_{11} + \lambda_{y21} * \tau_{y12,y21} * \mathrm{Ev}_{21} + \mathrm{EX}$

(A.10) $\mathrm{EY}_{22} = -(\lambda_{y12} * \tau_{y22,y12} + \lambda_{y11} * \tau_{y22,y11} + \lambda_{y21} * \tau_{y22,y21}) * \mathrm{Ev}_{22} + \lambda_{y12} * \tau_{y22,y12} * \mathrm{Ev}_{12} + \lambda_{y11} * \tau_{y22,y11} * \mathrm{Ev}_{11} + \lambda_{y21} * \tau_{y22,y21} * \mathrm{Ev}_{21} + \mathrm{EX}$

(A.11) $\mathrm{EY}_{11} = -(\lambda_{y12} * \tau_{y11,y12} + \lambda_{y22} * \tau_{y11,y22} + \lambda_{y21} * \tau_{y11,y21}) * \mathrm{Ev}_{11} + \lambda_{y12} * \tau_{y11,y12} * \mathrm{Ev}_{12} + \lambda_{y22} * \tau_{y11,y22} * \mathrm{Ev}_{22} + \lambda_{y21} * \tau_{y11,y21} * \mathrm{Ev}_{21} + \mathrm{EX}$

(A.12) $\mathrm{EY}_{21} = -(\lambda_{y12} * \tau_{y21,y12} + \lambda_{y22} * \tau_{y21,y22} + \lambda_{y11} * \tau_{y21,y11}) * \mathrm{Ev}_{21} + \lambda_{y12} * \tau_{y21,y12} * \mathrm{Ev}_{12} + \lambda_{y22} * \tau_{y21,y22} * \mathrm{Ev}_{22} + \lambda_{y11} * \tau_{y21,y11} * \mathrm{Ev}_{11} + \mathrm{EX}$

1.4 Equilibrium conditions

(A.13) $\kappa_{xl} * \mathrm{EX}_l + \kappa_{xf} * \mathrm{EX}_f + \kappa_{xr} * \mathrm{EX}_r + \kappa_{xo} * \mathrm{EX}_o = \lambda_{y12} * \mathrm{EY}_{12} + \lambda_{y22} * \mathrm{EY}_{22} + \lambda_{y11} * \mathrm{EY}_{11} + \lambda_{y21} * \mathrm{EY}_{21}$

(A.14) $\kappa_{xl} * \mathrm{Ew}_l + \kappa_{xf} * \mathrm{Ew}_f + \kappa_{xr} * \mathrm{Ew}_r + \kappa_{xo} * \mathrm{Ew}_o = \lambda_{y12} * \mathrm{Ev}_{12} + \lambda_{y22} * \mathrm{Ev}_{22} + \lambda_{y11} * \mathrm{Ev}_{11} + \lambda_{y21} * \mathrm{Ev}_{21}$

1.5 Demands from domestic processing sector

(A.15) $\mathrm{EY}_{12} = \eta_{y12,v12}*(\mathrm{Ev}_{12} - n_{y12}) + \eta_{y12,v22} * (\mathrm{Ev}_{22} - n_{y22})$

(A.16) $\mathrm{EY}_{22} = \eta_{y22,v12}*(\mathrm{Ev}_{12} - n_{y12}) + \eta_{y22,v22} * (\mathrm{Ev}_{22} - n_{y22})$

2. <u>Storage</u>

2.2 Input supplies to storage sector

(A.17) $\mathrm{EY}_l = \varepsilon_{yl,vl}*(\mathrm{Ev}_l - t_{yl})$

(A.18) $\mathrm{EY}_f = \varepsilon_{yf,vf}*(\mathrm{Ev}_f - t_{yf})$

(A.19) $\mathrm{EY}_r = \varepsilon_{yr,vr}*(\mathrm{Ev}_r - t_{yr})$

(A.20) $\mathrm{EY}_o = \varepsilon_{yo,vo}*(\mathrm{Ev}_o - t_{yo})$

2.1 Output constraints input demands of storage sector

(A.21) $\mathrm{EY}_{11} = -(\kappa_{y21} * \sigma_{y11,y21} + \kappa_{yl} * \sigma_{y11,yl} + \kappa_{yf} * \sigma_{y11,yf} + \kappa_{yr} * \sigma_{y11,yr} + \kappa_{yo} * \sigma_{y11,yo}) * \mathrm{Ev}_{11} + \kappa_{y21} * \sigma_{y11,y21} * \mathrm{Ev}_{21} + \kappa_{yl} * \sigma_{y11,yl} * \mathrm{Ev}_l + \kappa_{yf} * \sigma_{y11,yf} * \mathrm{Ev}_f + \kappa_{yr} * \sigma_{y11,yr} * \mathrm{Ev}_r + \kappa_{yo} * \sigma_{y11,yo} * \mathrm{Ev}_o + \mathrm{EZ}$

(A.22) $\mathrm{EY}_{21} = -(\kappa_{y11} * \sigma_{y21,y11} + \kappa_{yl} * \sigma_{y21,yl} + \kappa_{yf} * \sigma_{y21,yf} + \kappa_{yr} * \sigma_{y21,yr} + \kappa_{yo} * \sigma_{y21,yo}) * \mathrm{Ev}_{21} + \kappa_{y11} * \sigma_{y21,y11} * \mathrm{Ev}_{11} + \kappa_{yl} * \sigma_{y21,yl} * \mathrm{Ev}_l + \kappa_{yf} * \sigma_{y21,yf} * \mathrm{Ev}_f + \kappa_{yr} * \sigma_{y21,yr} * \mathrm{Ev}_r + \kappa_{yo} * \sigma_{y21,yo} * \mathrm{Ev}_o + \mathrm{EZ}$

(A.23) $\mathrm{EY}_l = -(\kappa_{y11} * \sigma_{Yl,Y11} + \kappa_{Y21} * \sigma_{Yl,Y21} + \kappa_{Yf} * \sigma_{Yl,yf} + \kappa_{yr} * \sigma_{yl,yr} + \kappa_{yo} * \sigma_{yl,yo}) * \mathrm{Ev}_l + \kappa_{y11} * \sigma_{y1,y11} * \mathrm{Ev}_{11} + \kappa_{y21} * \sigma_{yl,y21} * \mathrm{Ev}_{21} + \kappa_{yf} * \sigma_{yl,yf} * \mathrm{Ev}_f + \kappa_{yr} * \sigma_{yl,yr} * \mathrm{Ev}_r + \kappa_{yo} * \sigma_{yl,yo} * \mathrm{Ev}_o + \mathrm{EZ}$

(A.24) $\mathrm{EY}_f = -(\kappa_{y11} * \sigma_{Yf,Y11} + \kappa_{Y21} * \sigma_{Yf,Y21} + \kappa_{Yl} * \sigma_{Yf,yl} + \kappa_{yr} * \sigma_{yf,yr} + \kappa_{yo} * \sigma_{yf,yo}) * \mathrm{Ev}_f + \kappa_{y11} * \sigma_{yf,y11} * \mathrm{Ev}_{11} + \kappa_{y21} * \sigma_{yf,y21} * \mathrm{Ev}_{21} + \kappa_{yl} * \sigma_{yf,yl} * \mathrm{Ev}_l + \kappa_{yr} * \sigma_{yf,yr} * \mathrm{Ev}_r + \kappa_{yo} * \sigma_{yf,yo} * \mathrm{Ev}_o + \mathrm{EZ}$

(A.25) $\mathrm{EY}_r = -(\kappa_{y11} * \sigma_{Yr,Y11} + \kappa_{Y21} * \sigma_{Yr,Y21} + \kappa_{Yl} * \sigma_{Yr,yl} + \kappa_{yf} * \sigma_{yr,yf} + \kappa_{yo} * \sigma_{yr,yo}) * \mathrm{Ev}_r + \kappa_{y11} * \sigma_{yr,y11} * \mathrm{Ev}_{11} + \kappa_{y21} * \sigma_{yr,y21} * \mathrm{Ev}_{21} + \kappa_{yl} * \sigma_{yr,yl} * \mathrm{Ev}_l + \kappa_{yf} * \sigma_{yr,yf} * \mathrm{Ev}_r + \kappa_{yo} * \sigma_{yr,yo} * \mathrm{Ev}_o + \mathrm{EZ}$

(A.26) $\mathrm{EY}_o = -(\kappa_{y11} * \sigma_{Yo,Y11} + \kappa_{Y21} * \sigma_{Yo,Y21} + \kappa_{Yl} * \sigma_{Yo,yl} + \kappa_{yf} * \sigma_{yo,yf} + \kappa_{yr} * \sigma_{yo,yr}) * \mathrm{Ev}_o + \kappa_{y11} * \sigma_{yo,y11} * \mathrm{Ev}_{11} + \kappa_{y21} * \sigma_{yo,y21} * \mathrm{Ev}_{21} + \kappa_{yl} * \sigma_{yo,yl} * \mathrm{Ev}_l + \kappa_{yf} * \sigma_{yo,yf} * \mathrm{Ev}_r + \kappa_{yr} * \sigma_{yo,yr} * \mathrm{Ev}_r + \mathrm{EZ}$

2.2 Input constrained output supply of storage sector

(A.27) $\mathrm{EZ}_{12} = -(\lambda_{z22} * \tau_{z12,z22} + \lambda_{z11} * \tau_{z12,z11} + \lambda_{z21} * \tau_{z12,z21}) * \mathrm{Eu}_{12} + \lambda_{z22} * \tau_{z12,z22} * \mathrm{Eu}_{22} + \lambda_{z11} * \tau_{z12,z11} * \mathrm{Eu}_{11} + \lambda_{z21} * \tau_{z12,z21} * \mathrm{Eu}_{21} + \mathrm{E}Y^s$

(A.28) $\mathrm{EZ}_{22} = -(\lambda_{z12} * \tau_{z22,z12} + \lambda_{z11} * \tau_{z22,z11} + \lambda_{z21} * \tau_{z22,z21}) * \mathrm{Eu}_{22} + \lambda_{z12} * \tau_{z22,z12} * \mathrm{Eu}_{12} + \lambda_{z11} * \tau_{z22,z11} * \mathrm{Eu}_{11} + \lambda_{z21} * \tau_{z22,z21} * \mathrm{Eu}_{21} + \mathrm{E}Y^s$

(A.29) $EZ_{11} = -(\lambda_{z12} * \tau_{z11,z12} + \lambda_{z22} * \tau_{z11,z22} + \lambda_{z21} * \tau_{z11,z21}) * Eu_{11} + \lambda_{z12} * \tau_{z11,z12} * Eu_{12} + \lambda_{z22} * \tau_{z11,z22} * Eu_{22} + \lambda_{z21} * \tau_{z11,z21} * Eu_{21} + EY^{s}$

(A.30) $EZ_{21} = -(\lambda_{z12} * \tau_{z21,z12} + \lambda_{z22} * \tau_{z21,z22} + \lambda_{z11} * \tau_{z21,z11}) * Eu_{21} + \lambda_{z12} * \tau_{z21,z12} * Eu_{12} + \lambda_{z22} * \tau_{z21,z22} * Eu_{22} + \lambda_{z11} * \tau_{z21,z11} * Eu_{11} + EY^{s}$

2.3 Equilibrium conditions

(A.31) $\kappa_{y11} * EY_{11} + \kappa_{y21} * EY_{21} + \kappa_{yl} * EY_{l} + \kappa_{yf} * EY_{f} + \kappa_{yr} * EY_{r} + \kappa_{yo} * EY_{o} = \lambda_{z12} * EZ_{12} + \lambda_{z22} * EZ_{22} + \lambda_{z11} * EZ_{11} + \lambda_{z21} * EZ_{21}$

(A.32) $\kappa_{y11} * Ev_{11} + \kappa_{y21} * Ev_{21} + \kappa_{yl} * Ev_{l} + \kappa_{yf} * Ev_{f} + \kappa_{yr} * Ev_{r} + \kappa_{yo} * Ev_{o} = \lambda_{z12} * Eu_{12} + \lambda_{z22} * Eu_{22} + \lambda_{z11} * Eu_{11} + \lambda_{z21} * Eu_{21}$

2.4 Demands from domestic processing sector

(A.33) $EZ_{12} = \eta_{z12,u12} * (Eu_{12} - n_{z12}) + \eta_{z12,u22} * (Eu_{22} - n_{z22})$

(A.34) $EZ_{22} = \eta_{z22,u12} * (Eu_{12} - n_{z12}) + \eta_{z22,u22} * (Eu_{22} - n_{z22})$

3. <u>Port</u>

3.1 Input supplies to port

(A.35) $EZ_{l} = \varepsilon_{zl,ul} * (Eu_{l} - t_{zl})$

(A.36) $EZ_{f} = \varepsilon_{zf,uf} * (Eu_{f} - t_{zf})$

(A.37) $EZ_{r} = \varepsilon_{zr,ur} * (Eu_{r} - t_{zr})$

(A.38) $EZ_{o} = \varepsilon_{zo,uo} * (Eu_{o} - t_{zo})$

3.2 Output constrained input demand of ports

(A.39) $EZ_{11} = -(\kappa_{Z21} * \sigma_{Z11,Z21} + \kappa_{Zl} * \sigma_{Z11,Zl} + \kappa_{Zf} * \sigma_{Z11,Zf} + \kappa_{Zr} * \sigma_{Z11,Zr} + \kappa_{Zo} * \sigma_{Z11,Zo}) * Eu_{11} + \kappa_{Z21} * \sigma_{Z11,Z21} * Eu_{21} + \kappa_{Zl} * \sigma_{Z11,Zl} * Eu_{l} + \kappa_{Zf} * \sigma_{Z11,yf} * Eu_{f} + \kappa_{Zr} * \sigma_{Z11,Zr} * Eu_{r} + \kappa_{Zo} * \sigma_{Z11,Zo} * Eu_{o} + EQ$

(A.40) $EZ_{21} = -(\kappa_{Z11} * \sigma_{Z21,Z11} + \kappa_{Zl} * \sigma_{Z21,Zl} + \kappa_{Zf} * \sigma_{Z21,Zf} + \kappa_{Zr} * \sigma_{Z21,Zr} + \kappa_{Zo} * \sigma_{Z21,Zo}) * Eu_{21} + \kappa_{Z11} * \sigma_{Z21,Z11} * Eu_{11} + \kappa_{Zl} * \sigma_{Z21,Zl} * Eu_{l} + \kappa_{Zf} * \sigma_{Z21,Zf} * Eu_{f} + \kappa_{Zr} * \sigma_{Z21,Zr} * Eu_{r} + \kappa_{Zo} * \sigma_{Z21,Zo} * Ev_{o} + EQ$

(A.41) $EZ_{l} = -(\kappa_{Z11} * \sigma_{Zl,Z11} + \kappa_{Z21} * \sigma_{Zl,Z21} + \kappa_{Zf} * \sigma_{Zl,Zf} + \kappa_{Zr} * \sigma_{Zl,Zr} + \kappa_{Zo} * \sigma_{Zl,Zo}) * Eu_{l} + \kappa_{Z11} * \sigma_{Z1,Z11} * Eu_{11} + \kappa_{Z21} * \sigma_{Zl,Z21} * Eu_{21} + \kappa_{Zf} * \sigma_{Zl,Zf} * Eu_{f} + \kappa_{Zr} * \sigma_{Zl,Zr} * Eu_{r} + \kappa_{Zo} * \sigma_{Zl,Zo} * Eu_{o} + EQ$

(A.42) $EZ_{f} = -(\kappa_{Z11} * \sigma_{Zf,Z11} + \kappa_{Z21} * \sigma_{Zf,Z21} + \kappa_{Zl} * \sigma_{Zf,Zl} + \kappa_{Zr} * \sigma_{Zf,Zr} + \kappa_{Zo} * \sigma_{Zf,Zo}) * Eu_{f} + \kappa_{Z11} * \sigma_{Zf,Z11} * Eu_{11} + \kappa_{Z21} * \sigma_{Zf,Z21} * Eu_{21} + \kappa_{Zl} * \sigma_{Zf,Zl} * Eu_{l} + \kappa_{Zr} * \sigma_{Zf,Zr} * Eu_{r} + \kappa_{Zo} * \sigma_{Zf,Zo} * Eu_{o} + EQ$

(A.43) $EZ_{r} = -(\kappa_{Z11} * \sigma_{Zr,Z11} + \kappa_{Z21} * \sigma_{Zr,Z21} + \kappa_{Zl} * \sigma_{Zr,Zl} + \kappa_{Zf} * \sigma_{Zr,Zf} + \kappa_{Zo} * \sigma_{Zr,Zo}) * Eu_{r} + \kappa_{Z11} * \sigma_{Zr,Z11} * Eu_{11} + \kappa_{Z21} * \sigma_{Zr,Z21} * Eu_{21} + \kappa_{Zl} * \sigma_{Zr,Zl} * Eu_{l} + \kappa_{Zf} * \sigma_{Zr,Zf} * Eu_{r} + \kappa_{Zo} * \sigma_{Zr,Zo} * Eu_{o} + EQ$

(A.44) $EZ_{o} = -(\kappa_{Z11} * \sigma_{Zo,Z11} + \kappa_{Z21} * \sigma_{Zo,Z21} + \kappa_{Zl} * \sigma_{Zo,Zl} + \kappa_{Zf} * \sigma_{Zo,Zf} + \kappa_{Zr} * \sigma_{Zo,Zr}) * Eu_{o} + \kappa_{Z11} * \sigma_{Zo,Z11} * Eu_{11} + \kappa_{Z21} * \sigma_{Zo,Z21} * Eu_{21} + \kappa_{Zl} * \sigma_{Zo,Zl} * Eu_{l} + \kappa_{Zf} * \sigma_{Zo,Zf} * Eu_{r} + \kappa_{Zr} * \sigma_{Zo,Zr} * Eu_{r} + EQ$

3.3 Input constrained output supply of ports

(A.45) $EQ_{1} = -\lambda_{Q2} * \tau_{Q1,Q2} * Ep_{1} + \lambda_{Q2} * \tau_{Q1,Q2} * Ep_{2} + EZ^{p}$

(A.46) $EQ_{2} = -\lambda_{Q1} * \tau_{Q1,Q2} * Ep_{2} + \lambda_{Q1} * \tau_{Q1,Q2} * Ep_{1} + EZ^{p}$

3.4 Equilibrium conditions

(A.47) $\kappa_{z11} * EZ_{11} + \kappa_{z21} * EZ_{21} + \kappa_{zl} * EZ_{l} + \kappa_{zf} * EZ_{f} + \kappa_{zr} * EZ_{r} + \kappa_{zo} * EZ_{o} = \lambda_{Q1} * EQ_{1} + \lambda_{Q2} * EQ_{2}$

(A.48) $\kappa_{z11} * Eu_{11} + \kappa_{z21} * Eu_{21} + \kappa_{zl} * Eu_{l} + \kappa_{zf} * Eu_{f} + \kappa_{zr} * Eu_{r} + \kappa_{zo} * Eu_{o} = \lambda_{Q1} * Ep_{1} + \lambda_{Q2} * Ep_{2}$

3.5 Export demand

(A.49) $EQ_{1} = \eta_{Q1,P1} * (Ep_{1} - n_{Q1}) + \eta_{Q1,P2} * (Ep_{2} - n_{q2})$

(A.50) $EQ_{2} = \eta_{Q2,P1} * (Ep_{1} - n_{Q1}) + \eta_{Q2,P2} * (Ep_{2} - n_{q2})$

Appendix 4. Base equilibrium prices, quantities, cost shares and revenue shares

	Quantity (000' tonnes)	**Price ($/tonne)**	**Total Value ($m)**	**Cost Shares**	**Revenue Shares**
	$Q_1 = 7{,}082$	$p_1 = 314$	$TV_{Q1} = 2{,}224$		$\lambda_{Q1} = 0.782$

Port	$Q_2 = 2{,}291$	$p_1 = 271$	$TV_{Q2} = 620$	$\kappa_{Z11} = 0.737$ $\kappa_{Z21} = 0.203$ $\kappa_{Zl} = 0.027$ $\kappa_{Zf} = 0.015$ $\kappa_{Zr} = 0.001$ $\kappa_{Zo} = 0.017$	$\lambda_{Q2} = 0.218$
Storage	$Z_{11} = 7{,}082$ $Z_{21} = 2{,}291$ $Z_{12} = 372$ $Z_{22} = 121$	$u_{11} = 292$ $u_{21} = 249$ $u_{12} = 292$ $u_{22} = 249$	$TV_{Z11} = 2{,}068$ $TV_{Z21} = 569$ $TV_{Z12} = 109$ $TV_{Z22} = 30$	$\kappa_{Y11} = 0.698$ $\kappa_{Y21} = 0.195$ $\kappa_{Yl} = 0.048$ $\kappa_{Yf} = 0.027$ $\kappa_{Yr} = 0.002$ $\kappa_{Yo} = 0.030$	$\lambda_{Z11} = 0.745$ $\lambda_{Z21} = 0.205$ $\lambda_{Z12} = 0.039$ $\lambda_{Z22} = 0.011$
Farm	$Y_{11} = 7{,}455$ $Y_{21} = 2{,}411$ $Y_{12} = 828$ $Y_{22} = 268$	$v_{11} = 258$ $v_{21} = 222$ $v_{12} = 258$ $v_{22} = 222$	$TV_{Y11} = 1820$ $TV_{Y21} = 536$ $TV_{Y12} = 213$ $TV_{Y22} = 60$	$\kappa_{Xl} = 0.027$ $\kappa_{Xf} = 0.139$ $\kappa_{Xr} = 0.039$ $\kappa_{Xo} = 0.796$	$\lambda_{Y11} = 0.704$ $\lambda_{Y21} = 0.196$ $\lambda_{Y12} = 0.078$ $\lambda_{Y22} = 0.022$

Appendix 5. Market elasticity values for the base run

	Demand Elasticities	**Supply Elasticities**	**Input Substitution Elasticities**		**Product Transformation Elasticities**
Port	$\eta_{Q1,P1} = -5.0$ $\eta_{Q1,P2} = 0.1$ $\eta_{Q2,P1} = 0.4$ $\eta_{Q2,P2} = -5.0$	$\varepsilon_{Zl,ul} = 1.5$ $\varepsilon_{Zf,uf} = 0.5$ $\varepsilon_{Zr,ur} = 0.5$ $\varepsilon_{Zo,uo} = 1.5$	$\sigma_{Z11,Z21} = 0.1$ $\sigma_{Z11,Zf} = 0.1$ $\sigma_{Z11,Zo} = 0.1$ $\sigma_{Z21,Zf} = 0.1$ $\sigma_{Z21,Zo} = 0.1$ $\sigma_{Zl,Zr} = 0.1$ $\sigma_{Zf,Zr} = 0.1$ $\sigma_{Zr,Zo} = 0.1$	$\sigma_{Z11,Zl} = 0.1$ $\sigma_{Z11,Zr} = 0.1$ $\sigma_{Z21,Z2l} = 0.1$ $\sigma_{Z21,Zr} = 0.1$ $\sigma_{Zl,Zf} = 0.1$ $\sigma_{Zl,Zo} = 0.1$ $\sigma_{Zf,Zo} = 0.1$	$\tau_{Q1,Q2} = -0.05$
Storage	$\eta_{Z12,u12} = -1.0$ $\eta_{Z12,u22} = 0.1$ $\eta_{Z22,u12} = 0.4$ $\eta_{Z22,u22} = -1.0$	$\varepsilon_{Yl,vl} = 1.5$ $\varepsilon_{Yf,vf} = 0.5$ $\varepsilon_{Yr,vr} = 0.5$ $\varepsilon_{Yo,vo} = 1.5$	$\sigma_{Y11,Y21} = 0.1$ $\sigma_{Y11,Yf} = 0.1$ $\sigma_{Y11,Yo} = 0.1$ $\sigma_{Y21,Yf} = 0.1$ $\sigma_{Y21,Yo} = 0.1$ $\sigma_{Yl,Yr} = 0.1$ $\sigma_{Yf,Yr} = 0.1$ $\sigma_{Yr,Yo} = 0.1$	$\sigma_{Y11,Yl} = 0.1$ $\sigma_{Y11,Yr} = 0.1$ $\sigma_{Y21,Y2l} = 0.1$ $\sigma_{Y21,Yr} = 0.1$ $\sigma_{Yl,Yf} = 0.1$ $\sigma_{Yl,Yo} = 0.1$ $\sigma_{Yf,Yo} = 0.1$	$\tau_{Z12,Z22} = -0.3$ $\tau_{Z12,Z11} = -0.1$ $\tau_{Z12,Z21} = -0.3$ $\tau_{Z22,Z11} = -0.3$ $\tau_{Z22,Z21} = -0.1$ $\tau_{Z11,Z21} = -0.3$
Farm	$\eta_{Y12,v12} = -1.0$ $\eta_{Y12,v22} = 0.1$ $\eta_{Y22,v12} = 0.4$ $\eta_{Y22,v22} = -1.0$	$\varepsilon_{Xl,wl} = 1.5$ $\varepsilon_{Xf,wf} = 0.5$ $\varepsilon_{Xr,wr} = 0.5$ $\varepsilon_{Xo,wo} = 1.5$	$\sigma_{Xl,Xf} = 0.1$ $\sigma_{Xl,Xo} = 1.5$ $\sigma_{Xf,Xo} = 1.5$	$\sigma_{Xl,Xr} = 0.01$ $\sigma_{Xf,Xr} = 0.01$ $\sigma_{Xr,Xo} = 0.01$	$\tau_{Y12,Y22} = -0.3$ $\tau_{Y12,Y11} = -0.1$ $\tau_{Y12,Y21} = -0.3$ $\tau_{Y22,Y11} = -0.3$

				$\tau_{Y22,Y21} = -0.1$ $\tau_{Y11,Y21} = -0.3$

Appendix 6. Percentage changes in prices and quantities (%)

	Scenario 1 ($t_{Xo} = -1\%$)	Scenario 2 ($n_{Q1} = 1\%$)
Quantities:		
EX_l	0.13	0.89
EX_f	0.08	0.52
EX_r	0.62	0.86
EX_o	0.75	0.93
EY_{11}	0.45	0.63
EY_{21}	0.45	0.64
EY_{12}	0.42	0.47
EY_{22}	0.37	0.35
EY_l	0.41	0.65
EY_f	0.36	0.58
EY_r	0.36	0.58
EY_o	0.41	0.65
EZ_{11}	0.45	0.64
EZ_{21}	0.45	0.64
EZ_{12}	0.40	0.47
EZ_{22}	0.35	0.34
EZ_l	0.41	0.66
EZ_f	0.36	0.59
EZ_r	0.36	0.59
EZ_o	0.41	0.66
EQ_1	0.44	0.64
EQ_2	0.44	0.59
Prices:		
Ew_l	0.09	0.59
Ew_f	0.15	1.03
Ew_r	1.24	1.72
Ew_o	-0.50	0.62
Ev_{11}	-0.20	0.63
Ev_{21}	-0.21	0.60
Ev_{12}	-0.47	-0.52
Ev_{22}	-0.54	-0.53
Ev_l	0.27	0.44
Ev_f	0.72	1.16
Ev_r	0.72	1.16
Ev_o	0.27	0.44
Eu_{11}	-0.12	0.68
Eu_{21}	-0.13	0.67
Eu_{12}	-0.45	-0.52
Eu_{22}	-0.51	-0.52
Eu_l	0.27	0.44
Eu_f	0.73	1.18

Eu_r	0.73	1.18
Eu_o	0.27	0.44
Ep_1	-0.09	0.87
Ep_2	-0.09	-0.06

Appendix 7. Economic surplus changes ($ million) and percentage shares of total surplus changes (%) to various industry groups

	Scenario 1 ($t_{Xo} = -1\%$)		Scenario 2 ($n_{Q1} = 1\%$)	
	$m	%	$m	%
ΔPS_{Xl}	0.05	0%	0.31	1%
ΔPS_{Xf}	0.41	3%	2.78	12%
ΔPS_{Xr}	0.93	6%	1.29	6%
ΔPS_{Xo}	7.72	50%	9.58	43%
$\boldsymbol{\Delta PS_{Xl} + \Delta PS_{Xf} + \Delta PS_{Xr} + \Delta PS_{Xo}}$ **Farm subtotal**	9.11	59%	13.97	63%
ΔPS_{Yl}	0.36	2%	0.58	3%
ΔPS_{Yf}	0.54	3%	0.86	4%
ΔPS_{Yr}	0.04	0%	0.07	0%
ΔPS_{Yo}	0.23	1%	0.36	2%
$\boldsymbol{\Delta PS_{Yl} + \Delta PS_{Yf} + \Delta PS_{Yr} + \Delta PS_{Yo}}$ **Storage subtotal**	1.17	8%	1.87	8%
ΔPS_{Zl}	0.21	1%	0.34	2%
ΔPS_{Zf}	0.31	2%	0.50	2%
ΔPS_{Zr}	0.02	0%	0.04	0%
ΔPS_{Zo}	0.13	1%	0.21	1%
$\boldsymbol{\Delta PS_{Zl} + \Delta PS_{Zf} + \Delta PS_{Zr} + \Delta PS_{Zo}}$ **Port subtotal**	0.67	4%	1.08	5%
Domestic consumers:				
$\Delta CS_{Y12} + \Delta CS_{Y22}$	1.33	9%	1.43	6%
$\Delta CS_{Z12} + \Delta CS_{Z22}$	0.65	4%	0.72	3%
Overseas consumers:				
$\Delta CS_{Q1} + \Delta CS_{Q2}$	2.58	17%	3.24	15%
Total Economic Surplus	15.49	100%	22.32	100%