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Measuring the Returns to Investment in RD&E in the WA Grains Industry Using Equilibrium Displacement Modelling[1]

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Abstract

Equilibrium Displacement Models (EDMs) are useful for estimating the net benefits of investments in agricultural research, development and extension (RD&E) and the distribution of these benefits between producers and other participants in the value chain. Information from these models can inform investment decisions by funders of RD&E. In this paper the design and construction of an EDM for the Western Australian grains industry, a major component of the national grains industry, is reported. Using the EDM, two RD&E investment scenarios are examined. The first scenario is for a 1 per cent reduction in the cost of farm production inputs as a result of an investment in RD&E, while the second scenario involved a 1 per cent increase in the willingness of overseas consumers to pay for wheat as a result of an investment in RD&E.

The results show that the farm sector and overseas consumers are the major beneficiaries under each scenario. The WA grains industry is characterised by a short supply chain, where most grain production is exported. The large volume of grain exported means that, if there is an increase in demand or supply, some of the total benefits go to consumers overseas. Still, a high price elasticity of demand for export grains ensures that the farm production sector receives the majority of total benefits, and that these benefits outweigh the share of benefits received by overseas consumers.

Keywords: grains industry, Western Australia, equilibrium displacement models, RD&E

Introduction

The relationship between investments in agricultural RD&E and agricultural productivity has long been studied (Alston *et al.*, 1995). Governments and funding agencies need to demonstrate the potential welfare impacts of research programs to justify their investments and to prioritise future research. Estimating the economic benefits of investment in agricultural RD&E and the distribution of net benefits has conceptual, methodological and practical challenges.

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Equilibrium Displacement Models (EDMs) can be used to estimate the returns to RD&E and the distribution of benefits among participants along the value chain. Such models have previously been developed and applied in other agricultural industries, mostly in the livestock industries such as beef (Zhao *et al.*, 2000), sheep and wool (Mounter *et al.*, 2008), pig meat (Mounter *et al.*, 2004) and dairy (Liu *et al.*, 2012; Ludemann *et al.*, 2016). In addition, EDMs and other associated models have been developed for the wine grapes and wine industries (e.g. Zhao *et al.*, 2002). Applications of EDMs to the grains industry have been few, in part because of difficulties to do with the complexity of multi-product production systems.

First, the grain supply chain has multiple stages and end uses: production, on- and off-farm storage and transport, marketing, processing and exporting. Second, the relationships between different grains in crop rotations and in competing end uses, as well as numerous alternative supply chains across the three different production regions (western, southern and northern), add scale and complexity to the challenges of constructing a grains industry EDM. Third, previous empirical studies show evidence of imperfectly competitive market structures for grains that have implications for evaluating the distribution of benefits (see Griffith, 2000; O'Donnell *et al.*, 2007).

The stated aim in the current Grains Industry National RD&E Strategy (Research and Innovation Committee, 2017) is to use a strategic approach to achieve industry productivity gains. There is a role for an EDM of the Australian grains industry. In this paper, the construction of an EDM of the WA grains industry is detailed and tested. This is an expanded and updated version of the WA grains industry EDM presented in Li *et al.* (2017, 2018).

This paper proceeds as follows. First, an overview of the Australian and WA grains industries is provided. The major commodity types, challenges, and the importance of specific types of RD&E are described. The EDM framework, including its characteristics, benefits and limitations, is reviewed. The market parameters associated with an EDM for grains are discussed. The EDM constructed for the WA grains industry is presented and the simulation results are detailed and examined. Sensitivity analyses are presented and the dynamics and the nature of competition in the grains industry are discussed. Finally, in the summary and conclusion, limitations and scope for further research are discussed.

The Grains Industry

Australia

Worldwide, grains are the most important staple foods, used directly for human consumption and indirectly in livestock production. In Australia, grains are among the most important agricultural commodities. Grain exports worth over $14 billion were recorded during 2016-17 for the three main categories of grains – cereal grains, oilseeds and pulses, representing nearly 30 per cent of total farm export income during that financial year (ABARES, 2017a). In Table 1 is a snapshot of winter crop area and production from 2014-15 to 2016-17. The major winter cereals in Australia are wheat and barley, followed by canola, oats and chickpeas.

Most grain crops have multiple end uses, domestically and overseas. Grain production underpins the Australian food processing sector, including wheat products such as breads, noodles and pastas. Other grains such as barley are used for malting and brewing. Altogether, the milling, malting and brewing sectors in Australia generate annual gross revenues of around $6.6 billion (GRDC, 2016). Coarse grains such as maize and sorghum are used predominantly as animal feed for Australia's grain-fed beef, dairy, pork and poultry industries, valued at over $14.6 billion per annum (GRDC, 2014). Some cereals and pulses are used as supplementary feeds for farm animals such as sheep and cattle.

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

Crop	Area			Production		
	2014–15	2015–16	2016-17	2014–15	2015–16	2016-17
	m ha	m ha	m ha	mmt	mmt	mmt
Wheat	12.16	11.28	12.19	23.08	22.27	31.82
Barley	3.91	4.11	4.83	8.17	8.99	13.51
Canola	2.82	2.09	2.68	3.45	2.78	4.31
Chickpeas	0.43	0.68	1.07	0.55	0.87	2.00
Faba beans	0.16	0.22	0.23	0.28	0.30	0.48
Field peas	0.24	0.24	0.23	0.29	0.20	0.41
Lentils	0.19	0.22	0.28	0.24	0.18	0.68
Lupins	0.44	0.53	0.51	0.55	0.65	1.03
Oats	0.87	0.82	1.03	1.18	1.30	2.27
Triticale	0.13	0.08	0.06	0.22	0.13	0.15

Source: Australian Crop Report, February 2017

Western Australia

The WA grains industry is a major component of the Australian grains industry. The WA grains industry is that state's largest agricultural sector, generating around $4.6 billion annually for the State economy, with most of this coming from cereals ($3.6 billion), followed by oilseeds ($0.8 billion) and pulses ($0.16 billion) (Department of Primary Industries and Regional Development, 2018). The industry accounts for over 50 per cent of the gross farm gate value of WA's agricultural production (GIWA, 2015). As a key cropping region, WA has the highest production of winter crops compared to all other states. A snapshot of the main crops produced in WA is shown in Table 2.

Table 2. Western Australian winter crop production and area, 2014-15 to 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	5,038	4,616	4,678	8,824	8,511	9,645
Barley	1,308	1,384	1,694	3,192	3,248	4,120
Canola	1,397	1,094	1,349	1,641	1,328	2,048
Oats	233	300	403	558	601	1,036
Chickpeas	3	4	4	4	4	7
Field peas	25	22	31	32	29	55
Lupins	287	331	361	382	457	805

Source: Australian Crop Report (December 2016, December 2017, September 2018)

The State has, on average, the highest annual production of wheat, barley and canola in Australia, accounting for around a third of the nation's annual wheat and barley production, and half of Australia's canola production. In WA the farm production of grain is highly skewed. Sixty per cent of farms supplied only 22.5 per cent of the State's grain output from 2015-16 to 2017-18 (Boult & Jackson, 2019) while 20 per cent of farms supplied 56 per cent of the State's grain output over the same period.

The WA grains industry is highly export-oriented. A summary of historical exports is shown in Table 3. Around 90 per cent of grain produced in WA is exported to various international markets worth around $4 billion each year to WA (GIWA, 2015; DPIRD, 2018).

Table 3. Western Australian grain exports, 2011-12 to 2015-16

	2011-12	2012-13	2013-14	2014–15	2015–16
	kt	kt	kt	kt	kt
Wheat	8,421	7,748	8,920	8,951	8,624
Barley	2,250	1,856	3,261	2,882	2,773
Canola	1,126	1,212	1,608	1,562	1,399

Sources: Australian Crop Forecasters, Supply and Demand Report

Major challenges

The grains industry in Australia has grown over the past 30 years with changing markets and an annual average growth in total factor productivity of 1.5 per cent per annum (Boult and Chancellor, 2019). Increases in agricultural productivity lead to 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. A key determinant of growth in total factor productivity is investment in RD&E that generates new information (Khan *et al.*, 2017). The benefits of research-induced knowledge can help advance cropping technology and improve farm management, supply new plant varieties, improve crop rotations, and provide better disease, weed and pest control. However, over the period 1993-94 to 2007- 08 the rate of annual growth in total factor productivity in grain production declined by an average of 0.9 per cent each year (Primary Industries Standing Committee, 2011). This slowing of growth in productivity is attributed to the adverse impacts of a warming climate and more frequent extreme weather events, a decline in expenditure on RD&E, and a slower adoption of new technologies (Hockman *et al*., 2017; Primary Industries Standing Committee, 2011).

These challenges, and others, exist in the WA grains industry. The Grain Industry Association of Western Australia's (GIWA) *WA Grains Industry Strategy 2025+* identifies considerable challenges for the WA industry including:

- Declining broadacre productivity growth, falling from an average gain of 2.2 per cent per annum from 1953-1994 down to an average increase of 0.4 per cent per annum from 1993-2013,
- Increasing input costs, exacerbated by a declining trend in growing season rainfall (BOM, 2019) and problematic soil fertility,
- Fluctuating financial performance since the 1990s with more than 25 per cent of broadacre farms consistently making operating losses, along with increasing farm debt, and
- Declining labour availability.

Funding of grains RD&E

The WA Department of Primary Industry and Regional Development (DPIRD) supports state-focused grain RD&E activities. It coordinates and delivers more than $20 million of grains RD&E each year. Most of this research is co-funded by the GRDC (DPIRD, 2018). However, government funding of farm productivity research is expected to decline (GIWA, 2015) as the capacity of DPIRD to support WA primary industries and regions is constrained by budgetary pressures. DPIRD's staff numbers have been declining and a further reduction of 60 FTEs, down to 1580, is required in 2018-19.

The GRDC also provides significant investments in RD&E for the WA grains industry via national projects, many led by research organisations outside WA (GIWA, 2015). As part of the network of Australia's Rural Research and Development Corporations (RDCs), the GRDC relies on contributions made by producers in the form of statutory RD&E levies along with matching funding from the Australian Government. For this reason, producers have a vested interest in the efficient allocation of funds to maximise returns to the industry and communities.

Strategic approach to RD&E

The Grains Industry National RD&E Strategy recognises the need to improve international competitiveness, aiming to lift the annual growth in total factor productivity to over 2.5 per cent by 2025 (Research and Innovation Committee, 2017). In the WA grains industry, RD&E is provided in accordance with the priority areas identified in the national strategy. One key priority area arising from the *WA Grains Industry Strategy 2025+* (GIWA, 2015) is an emphasis on RD&E to increase farm productivity.

Allocating funding to RD&E has challenges and trade-offs. With governments withdrawing from funding farm productivity research, sound decisions about allocating scarce funding are even more critical. Different investment decisions have different potential distributional effects. As noted in the Grains Industry National RD&E Strategy (2017), '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.'

To evaluate the merits of investments in RD&E, it is necessary to know the likely size of the net benefits from the research, and how the benefits and costs are likely to be distributed among all participants in the value chain. An EDM framework can help answer these questions.

Review of the EDM Framework

Equilibrium Displacement Models have been used in applied economic analysis for decades because of their strong theoretical foundation and low data requirements. These models do not require extensive time series data. They require base data about equilibrium prices and quantities for a representative year or average of recent years, along with estimates of price elasticities of supply and demand, and shares of expenditure. These are obtainable from published work and expert judgements. The EDM framework is a comparative static framework. It does not rely on specific functional forms and gives reliable estimates for small shifts away from the initial equilibrium.

Constructing an EDM involves defining the industry by a set of market supply and demand equations. No functional forms are assumed for these equations. The market is 'shocked' or 'displaced' by a change in the value of one or more exogenous variables in the system. The impacts of the disturbance are approximated by functions that are linear in elasticities. EDMs differ from other comparative static approaches as they are underpinned by the concept of price elasticity – changes in endogenous and exogenous variables are measured in proportionate terms or as ratios of proportionate changes (i.e. elasticities).

In many EDM applications, the industry of interest consists of a multi-stage production system comprising many horizontal and vertical market segments. This is shown by the supply chain representation of agricultural commodities illustrated in Figure 1. Such models can provide estimates of the distribution of welfare effects on all individuals in markets along the supply chain.

As noted by Borrell *et al.* (2014), estimates of the size and distribution of net benefits of a change in productivity resulting from investing in RD&E depend on:

(i) the type and nature of the change caused by successful RD&E;

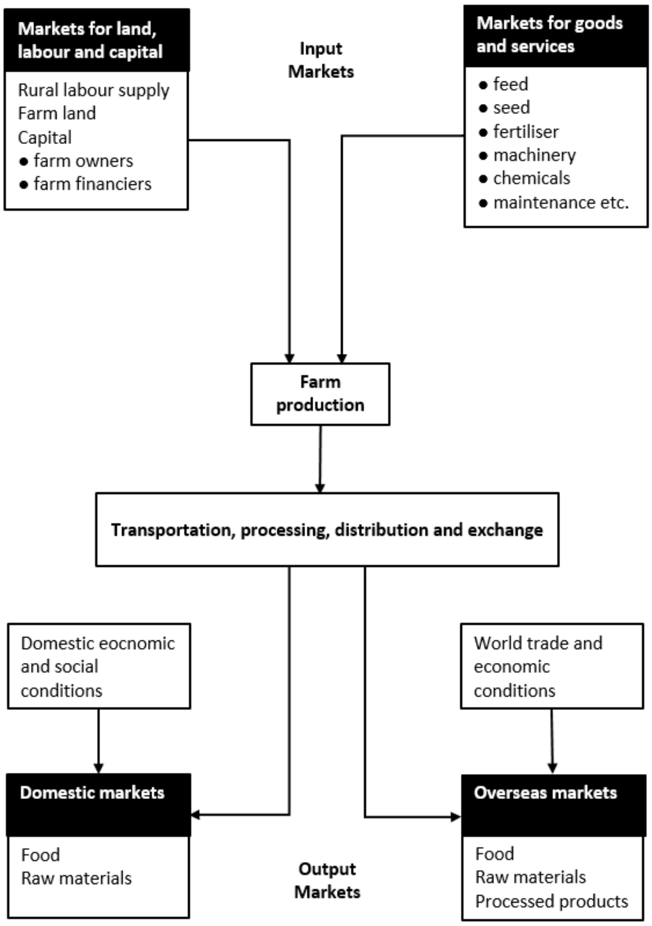
(ii) where the change occurs along the supply chain;

(iii) the price elasticities of supply and demand and substitution between inputs and substitution between final products; and

(iv) the relative sizes of gross value of production at each point along the value chain.

The usefulness of the output of a grains industry EDM analysis depends on accurate estimates of these variables. The distribution of welfare changes along the value chain differs according to the nature of the change caused by the RD&E, as well as to where the change occurs in the value chain.

Figure 1. Agricultural supply chain



Source: Malcolm *et al.* (2009)

EDM of the WA Grains Industry

The EDM constructed in this paper provides a stylised representation of the WA grains industry. It expands and updates a previous EDM constructed and tested by Li *et al.* (2017, 2018) which consisted of only three industry sectors and two commodity types, namely wheat and barley. Here, more of the industry is represented by nine sectors - farm production, wheat storage, barley storage, canola storage, lupin storage, flour milling, stockfeed manufacturing, malt manufacturing, and canola processing - along with four grain types - wheat, barley, canola and lupins.

It is assumed that the cropping sequence of cereals, oilseed and grain legume, viz. wheat/barley/canola/lupins, is representative of typical cropping sequences across the whole industry. It also is assumed that each component of the rotation sequence is present in each year (see Malcolm & Armstrong, 2016, pp. 1-2 for more information about this approach).

Horizontal and vertical market segments

The WA grains industry consists of several market segments along the supply chain. Most grain destined for export is transported from farm to storage receival sites in the regions. This reduces the risk and cost to producers of storing grain on-farm. From the country receival sites, the grain is transported to a port terminal for shipping or to various domestic destinations for secondary processing. In WA, CBH is the main handler of grain, owning a network of 197 receival points, receiving and storing around 90 to 95 per cent of the grain produced in the state, and operating all four main bulk grain port terminals in WA (Stretch *et al.*, 2014). Bunge operates an additional small port terminal at Bunbury.

The structure of the EDM of the WA grains industry is depicted in Figure 2. Each rectangle represents a multi-output production function. Each arrow represents the market for a product, with the arrowed end being the demand for a product, and the non-arrowed end being the supply of the product. Each oval represents the supply and demand schedule of a product where an exogenous shift may occur.

To study the returns from new technologies and methods brought about by RD&E, as well as the distribution of benefits among the various sectors, vertical and horizontal industry disaggregation is required.

Vertically, the industry supply chain is disaggregated into the farm, storage, processing (milling, stockfeed manufacturing, malt manufacturing, oilseed crushing and refining), and consumption.

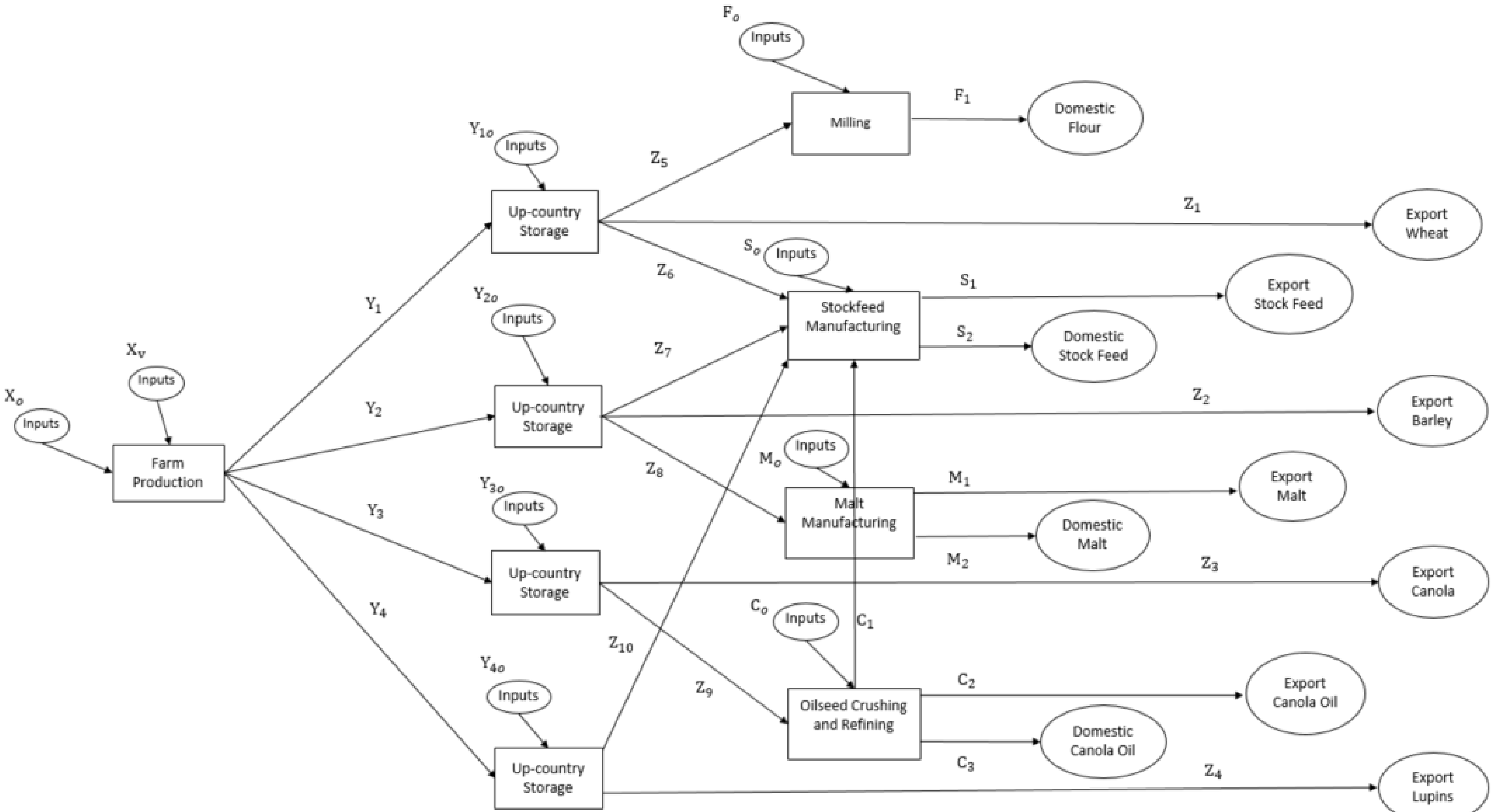
Horizontally, each of the four industry sectors produces different combinations of unprocessed and processed outputs. At the upstream level, farm production is modelled as producing the four grain commodities that represent a standard cropping sequence. The assumption made in the model is that all grain from farm production is delivered and stored in regional (up country) facilities. At the storage and handling stage, grains are either exported or sent for secondary processing, from which multiple end-products are produced for either export or domestic use.

Model structure

The equations for the model follow the specifications of Mounter *et al.* (2004) and Zhao *et al.* (2000). All the production functions are deemed to exhibit constant returns to scale with multi-output production functions separable in inputs and outputs. The objective of profit maximisation is an implicit behavioural assumption of each industry sector within the model.

Perfect competition over the medium term is assumed along each sector of the industry's supply chain. This means that under the assumptions of competition and constant returns to scale, total costs must equal total revenue for each sector (zero pure profits).

Figure 2. Model Structure



From Figure 2, there are nine industry sectors (farm production, up-country storage for wheat, up-country storage for barley, up-country storage for canola, up-country storage for lupins, milling, stockfeed manufacturing, malt manufacturing, and oilseed crushing and refining) whose multi-output production functions and decision-making problems can be specified completely within the model.

The details of the model structure and the model system in structural form are presented in Appendix 1.

The model in displacement form

The analytical system given by equations (19) to (111) in Appendix 1 defines an equilibrium status in all the markets in the model. These equations represent the structural equilibrium model of the WA grains industry in general functional form. To examine the impacts of exogenous shocks in the industry, the system of equations needs to be converted to a 'displacement form'. This can be done by totally differentiating the system of equations at the initial equilibrium points and converting them to percentage change form. This model in displacement form can be found in Appendix 2. A small percentage change in variable (.) is denoted as $E(.) = \Delta(.)/(.)$. Exogenous supply shock variables, denoted by Y(.), represent the impacts brought about by new technology, and exogenous demand shock variables, denoted by N(.), represent the impacts of market research or promotion. This method allows for approximations of the changes in prices and quantities caused by a shock without any knowledge of the specific functional forms of the demand and supply curves, so long as the exogenous shifts are small and parallel.

To satisfy the integrability conditions, homogeneity and symmetry restrictions have been imposed on all the input demand and output supply functions in the EDM, whereas concavity and convexity conditions are satisfied when setting the parameter values (see Zhao *et al.* (2000) for a detailed discussion on integrability conditions).

Price and Quantity Data

The objective of EDM is to estimate changes in all prices and quantities to infer welfare implications of the exogenous shifts. To achieve this requires data on: (i) initial equilibrium price and quantity values for all sectors of the model; (ii) market elasticities; and (iii) values specified for the exogenous shift variables for all simulated scenarios.

Price and quantity data for each sector of the industry were obtained from a combination of sources including ABARES, AEGIC, industry experts, and subjective judgements by the authors. Base equilibrium values for wheat and barley were specified as the average ABARES reported prices and quantities between 2008-09 to 2015-16 to remove the effects of the single-desk wheat marketing arrangements that were in existence prior to 2008[2]. The notation representing the variables and parameters in the model are defined in Table 4. In Table 5 is a summary of the average base equilibrium prices and quantities and associated cost and revenue shares for all sectors of the industry.

Market Parameters

[2] Under the single desk, a national pool operated, with all wheat marketed on behalf of growers by the Australian Wheat Board. The Wheat Board operated as a government statutory body until 1999 when it was privatised and became known as AWB. Deregulation was gradually introduced so that by 2007 only bulk export wheat sales were managed by AWB. Thus the period since 2008-09 represents a relatively competitive market environment with minimal policy intervention.

An EDM uses estimates of price elasticities of supply and demand for each market in the industry. These estimates reflect the nature of the demand, supply, input substitution and product transformation processes in each market. Obtaining empirical estimates of price elasticities of supply and demand of different markets is the key to a reliable EDM. Results are highly sensitive to different values of price elasticities and lead to different conclusions.

Table 4. Definition of variables and parameters in the model

Endogenous Variables	
X_v, X_o	Quantity of variable and fixed inputs used in farm sector, respectively
$w_v,\ w_o$	Price of variable and fixed inputs used in farm sector
X	Aggregate input index of farm production sector
Y_1, Y_2, Y_3, Y_4	Quantity of wheat, barley, canola and lupins from farm to the storage sector
v_1, v_2, v_3, v_4	Price of wheat, barley, canola and lupins from farm to the storage sector
Y	Aggregate output index of farm production sector
Y_{1o}	Quantity of other inputs used in wheat storage
v_{1o}	Price of other inputs used in the wheat storage
Y^w	Aggregate input index of wheat storage
Y_{2o}	Quantity of other inputs used in barley storage
v_{2o}	Price of other inputs used in the barley storage
Y^b	Aggregate input index of barley storage
Y_{3o}	Quantity of other inputs used in canola storage
v_{3o}	Price of other inputs used in the canola storage
Y^c	Aggregate input index of canola storage
Y_{4o}	Quantity of other inputs used in lupin storage
v_{4o}	Price of other inputs used in the lupin storage
Y^l	Aggregate input index of lupin storage
Z_1	Quantity of wheat from wheat storage to export market
Z_2	Quantity of barley from barley storage to export market
Z_3	Quantity of canola from canola storage to export market
Z_4	Quantity of lupins from lupin storage to export market
Z_5, Z_6	Quantity of wheat from wheat storage to flour milling and stock feedback manufacturing, respectively
Z_7, Z_8	Quantity of barley from barley storage to stockfeed manufacturing and malt manufacturing respectively
Z_9	Quantity of canola from canola storage to canola processing
Z_{10}	Quantity of lupins from lupin storage to stockfeed manufacturing
u_1	Price of wheat from wheat storage to the export market
u_2	Price of barley from barley storage to the export market
u_3	Price of canola from canola storage to the export market
u_4	Price of lupins from lupin storage to the export market
u_5, u_6	Price of wheat from wheat storage to flour milling and stock feedback, respectively
u_7, u_8	Price of barley from barley storage to stockfeed manufacturing and malt manufacturing respectively
u_9	Price of canola from canola storage to canola processing
u_{10}	Price of lupins from lupin storage to stockfeed manufacturing
Z^w	Aggregate output index of wheat storage
Z^b	Aggregate output index of barley storage
Z^c	Aggregate output index of canola storage
Z^l	Aggregate output index of lupin storage

F_o	Quantity of other inputs used in flour milling
g_o	Price of other inputs used in flour milling
Z^f	Aggregate input index of flour milling
F_1	Quantity of flour from flour milling to export market
g_1	Price of flour to export market
F_2	Quantity of Millmix from flour milling to Stockfeed Manufacturing
g_2	Price of Millmix from flour milling to Stockfeed Manufacturing
F	Aggregate output index of flour milling
S_o	Quantity of other inputs used in stockfeed manufacturing
t_o	Quantity of other inputs used in stockfeed manufacturing
Z^s	Aggregate input index of stockfeed manufacturing
S_1, S_2	Quantity of stockfeed to Export and Domestic market, respectively
t_1, t_2	Price of stockfeed to Export and Domestic market, respectively
S	Aggregate output index of stockfeed manufacturing
M_o	Quantity of other inputs used in malt manufacturing
n_o	Quantity of other inputs used in malt manufacturing
Z^m	Aggregate input index of malt manufacturing
M_1, M_2	Quantity of malt to export and domestic market, respectively
n_1, n_2	Price of malt to export and domestic market, respectively
M	Aggregate output index of malt manufacturing
C_o	Quantity of other inputs used in Canola processing
d_o	Quantity of other inputs used in Canola processing
Z^c	Aggregate input index of canola processing
C_1	Quantity of canola meal to stockfeed manufacturing
d_1	Quantity of canola meal to stockfeed manufacturing
C_2, C_3	Quantity of canola oil to export and domestic market, respectively
d_2, d_3	Prices of canola oil to export and domestic market, respectively
C	Aggregate output index of canola processing sector
Exogenous Variables	
T_x:	Supply shifter shifting down supply curve of x vertically due to cost reduction in production of x ($x = \mathrm{X}_o, \mathrm{X}_v, \mathrm{Y}_{1o}, \mathrm{Y}_{2o}, \mathrm{Y}_{3o}, \mathrm{Y}_{4o}, \mathrm{F}_o, \mathrm{S}_o, \mathrm{M}_o, \mathrm{C}_o$).
t_x:	Amount of shift T_x as a percentage of price x ($x = \mathrm{X}_o, \mathrm{X}_v, \mathrm{Y}_{1o}, \mathrm{Y}_{2o}, \mathrm{Y}_{3o}, \mathrm{Y}_{4o}, \mathrm{F}_o, \mathrm{S}_o, \mathrm{M}_o, \mathrm{C}_o$).
N_x:	Demand shifter shifting up demand curve of x vertically due to improvements in quality or promotion that increase the demand in x ($x = \mathrm{Z}_1, \mathrm{Z}_2, \mathrm{Z}_3, \mathrm{Z}_4, \mathrm{F}_1, \mathrm{S}_1, \mathrm{S}_2, \mathrm{M}_1, \mathrm{M}_2, \mathrm{C}_2, \mathrm{C}_3$).
n_x:	Amount of shift N_x as a percentage of price of x ($x = \mathrm{Z}_1, \mathrm{Z}_2, \mathrm{Z}_3, \mathrm{Z}_4, \mathrm{F}_1, \mathrm{S}_1, \mathrm{S}_2, \mathrm{M}_1, \mathrm{M}_2, \mathrm{C}_2, \mathrm{C}_3$).
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

Values of price elasticities of supply and demand can be derived from economic theory, or from existing econometric estimations or from expert opinion. Robust estimates of many elasticities are difficult to obtain. Many studies rely on subjective judgements about price elasticities of supply and demand. Estimates of agricultural elasticities vary substantially because of geographic coverage, length of run, sample periods, estimation method, functional form, and explanatory variables used in the estimation process (Griffith *et al.,* 2001).

Table 5. Base equilibrium prices, quantities, cost shares and revenue shares

	Quantity (000' tonnes)	Price ($/tonne)	Total Value ($m)	Cost Shares	Revenue Shares
Farm Production	$Y_1 = 8{,}896$	$v_1 = 253$	$TV_{Y1} = 2{,}253$	$\kappa_{Xv} = 0.66$	$\lambda_{Y1} = 0.62$
	$Y_2 = 2{,}921$	$v_2 = 187$	$TV_{Y2} = 547$	$\kappa_{Xo} = 0.34$	$\lambda_{Y2} = 0.15$
	$Y_3 = 1{,}434$	$v_3 = 504$	$TV_{Y3} = 723$		$\lambda_{Y3} = 0.20$
	$Y_4 = 476$	$v_4 = 279$	$TV_{Y4} = 133$		$\lambda_{Y4} = 0.03$
Up-Country Storage - Wheat	$Z_1 = 8{,}367$	$u_1 = 310$	$TV_{Z1} = 2{,}593$	$\kappa_{Y1o} = 0.17$	$\lambda_{Z1} = 0.95$
	$Z_5 = 205$	$u_5 = 288$	$TV_{Z5} = 59$	$\kappa_{Y1} = 0.83$	$\lambda_{Z5} = 0.02$
	$Z_6 = 323$	$u_6 = 222$	$TV_{Z6} = 72$		$\lambda_{Z6} = 0.03$
Up-Country Storage - Barley	$Z_2 = 2{,}545$	$u_2 = 265$	$TV_{Z2} = 674$	$\kappa_{Y2o} = 0.29$	$\lambda_{Z2} = 0.15$
	$Z_7 = 122$	$u_7 = 243$	$TV_{Z7} = 30$	$\kappa_{Y2} = 0.72$	$\lambda_{Z7} = 0.01$
	$Z_8 = 255$	$u_8 = 240$	$TV_{Z8} = 61$		$\lambda_{Z8} = 0.01$
Up-Country Storage - Canola	$Z_3 = 1{,}375$	$u_3 = 561$	$TV_{Z3} = 771$	$\kappa_{Y3o} = 0.10$	$\lambda_{Z3} = 0.96$
	$Z_9 = 59$	$u_9 = 539$	$TV_{Z9} = 32$	$\kappa_{Y3} = 0.90$	$\lambda_{Z9} = 0.04$
Up-Country Storage - Lupins	$Z_{10} = 131$	$u_{10} = 314$	$TV_{Z10} = 41$	$\kappa_{Y3o} = 0.15$	$\lambda_{Z4} = 0.68$
				$\kappa_{Y3} = 0.85$	$\lambda_{Z10} = 0.32$
Flour Milling	$F_1 = 159$	$g_1 = 620$	$TV_{F1} = 99$	$\kappa_{Fo} = 0.47$	$\lambda_{F1} = 0.89$
	$F_2 = 46$	$g_2 = 270$	$TV_{F2} = 12$	$\kappa_{Z5} = 0.53$	$\lambda_{F2} = 0.11$
Stockfeed Manufacturing	$S_1 = 200$	$t_1 = 402$	$TV_{S1} = 80$	$\kappa_{So} = 0.36$	$\lambda_{S1} = 0.31$
	$S_2 = 467$	$t_2 = 380$	$TV_{S2} = 177$	$\kappa_{Z6} = 0.28$	$\lambda_{S2} = 0.69$
				$\kappa_{Z7} = 0.11$	
				$\kappa_{Z10} = 0.17$	
				$\kappa_{F2} = 0.05$	
				$\kappa_{C1} = 0.03$	
Malt Manufacturing	$M_1 = 183$	$n_1 = 530$	$TV_{M1} = 97$	$\kappa_{Mo} = 0.49$	$\lambda_{M1} = 0.81$
	$M_2 = 46$	$n_2 = 508$	$TV_{M2} = 23$	$\kappa_{Z8} = 0.51$	$\lambda_{M2} = 0.19$
Oilseed Crushing and Refining	$C_1 = 33$	$d_1 = 220$	$TV_{C1} = 7$	$\kappa_{Co} = 0.12$	$\lambda_{C1} = 0.20$
	$C_2 = 12$	$d_2 = 1{,}150$	$TV_{C2} = 14$	$\kappa_{Z9} = 0.88$	$\lambda_{C2} = 0.38$
	$C_3 = 13$	$d_3 = 1{,}128$	$TV_{C3} = 14$		$\lambda_{C3} = 0.41$

In addition, the magnitudes of price elasticities of supply and demand depend largely on where in the value chain the elasticity is being measured. For instance, marketing intermediaries such as processors and retailers have their own production technologies and respond to changes in relative prices. This affects consumer demand in the value chain, to the extent where it is unlikely the derived demand elasticities for the primary product will match consumer demand (Asche *et al.*, 2002; Hartmann *et al.*, 2001). For instance, price elasticities of supply and demand at the farm gate tend to be lower than those measured at retail (Maclaren, 1995). Elasticity estimates are not readily available for all stages in the value chain. Most price elasticities reviewed are measures of consumer demand using price data at the retail level.

Demand elasticities

Domestic

Estimates for own-price and cross-price elasticities of demand are required to represent demand in the domestic markets of the EDM. Own-price elasticities of demand indicate the degree to which buyers respond to purchases of a product as the price of that product rises or falls. The steepness of the demand curve visually represents the elasticity of demand for a grain commodity, and changes in quantity demanded to change in own-prices can be depicted as movements along a demand curve.

Although some estimates are available (Ahammad and Islam, 2004; Xayavong *et al*., 2011), the model structure presented in this paper does not explicitly require information on domestic own-price elasticities of demand at the farm gate level. A few studies have estimated own-price elasticities of demand for grain products. Ulubasoglu *et al.* (2015) estimated the own-price elasticity of demand for bread in Australian households to be -0.733. Since bread is further up the value chain than flour, it is logical to assume that the domestic own-price elasticity of demand for flour would be more inelastic than the farm gate value of own-price elasticity of demand. An earlier study by Seale *et al.* (2003), using a different data sample and method, estimated the own-price elasticity of demand for bread to be lower at -0.115.

A value of -0.5 has been specified for the own-price elasticity of demand for flour in the base model for WA. Similarly, the own-price elasticity of domestic demand for the other processed grain products - stockfeed, malt and canola oil - have also been assigned a value of -0.5. It is also assumed that there is zero substitutability between the final outputs for all the relevant sectors within the model.

Export

Studies examining export demand elasticities for Australian grains are scarce. Australian grain sellers on export markets are largely regarded as being price takers (Alston *et al.*, 2004). The consensus is that export demand is price elastic.

Jomini *et al.* (1994) provided a series of parameter estimates used in the calibration of the Industry Commission's SALTER global trade model. The elasticity values differed depending on the destination region. In Table 6, below, a summary of these estimates of price elasticities is provided. Based on these figures, a value of -5.0 has been specified for the export demand elasticity for wheat, barley, canola and lupins in the base model for WA.

In the case of export stockfeed, malt and canola, there is a higher degree of product differentiation for these processed grain products compared to primary grains. However, as Australia's world market share is very small for each of these products, a value of -4.0 has been assigned for their export demand elasticities.

Table 6. Australian export demand elasticities by commodity and destination region

	Wheat	Other Grains
New Zealand	-1.5	-3.3
Canada	-4.4	-4.4
United States	-4.4	-4.4
Japan	-3.8	-4.2
Korea	-4.2	-4.4
European Union	-4.4	-4.4
Indonesia	-2.1	-4.4
Malaysia	-1.7	-4.3
Philippines	-4.4	-4.1
Singapore	-2.1	-4.3
Thailand	-3.1	-2.9
China	-4.1	-3.1
Hong Kong	-4.4	-4.4
Taiwan	-4.4	-4.1
Rest of world	-4.0	-4.4

Source: Jomini, McDougall, Watts & Dee (1994)

Input supply elasticities

In an EDM, price elasticities of supply for exogenous inputs are needed in each sector of the model. Factor inputs exogenous to the EDM include land, labour, capital and fertiliser. In most instances, only own-price elasticities of supply are required in the EDM.

There are few empirical estimates of these factor inputs in Australian agriculture. Most previous EDM studies have aggregated these production inputs into one group and assumed these inputs to be non-specialised and therefore highly elastic in supply (Mounter *et al.*, 2008).

Based on limited empirical studies and subjective judgement, Zhao *et al.* (2003) disaggregated factor supply elasticities in the Australian wine industry into two groups of inputs – capital and mobile factors. Both short-run and long-run adjustment periods were provided for these input elasticities. Capital factor inputs are specialised inputs such as fixed capital and human capital with relatively inelastic supplies. These inputs were estimated to have price elasticities of supply of 0.4 in the short run and 1.0 in the long run. Mobile factor inputs, on the other hand, are those inputs non-specific to the wine industry and include factors such as labour and chemicals. These inputs are more elastic in supply and were estimated to be 5.0 in both the short and long run. These results are largely consistent with Salhofer's (2000) review of various studies on agricultural factor supply elasticities in European countries. It was concluded in this review that a plausible range of own-price land supply elasticities was between 0.1 and 0.4. On the other hand, purchased inputs which included fertiliser, pesticides, fuel energy, were found to be elastic in supply, with a plausible range from 1.0 to 5.0.

Empirical evidence has yet to provide consensus around elasticities for labour supply in agriculture in wealthy countries. This is difficult to model given the income and substitution effects present in farm labour supply. Salhofer (2000) suggested that a plausible range of on-farm labour supply elasticities for farm families in Europe was between 0.1 and 1.0, depending on the time frame, with a plausible base value being 0.5. Other studies suggest the elasticity of labour supply is negative in some cases, meaning that an income effect can sometimes exceed the substitution effect (Linde-Rahr, 2001). Garnett and Lewis (2002) constructed a model of rural labour supply where supply of hired labour depended on the earnings of agriculture relative to earnings in retail and on the unemployment rate in non-metropolitan Australia relative to metropolitan Australia. They found the supply of hired farm labour was elastic with respect to relative wages, with elasticity of supply of hired labour depending on relative employment conditions.

In this EDM, a value of 2.0 has been assigned for the input supply elasticity for variable inputs, and a value of 1.0 has been assigned for the input supply elasticity of other non-variable inputs for the farm production sector. A higher value of 2.5 has been assigned for the input factor supply elasticities in the storage sector due to the assumption that these factor inputs are non-specialised. It is assumed that the flour milling, stockfeed manufacturing, malting, and oilseed crushing and refining sectors require the use of capital-intensive and highly specialised equipment. For this reason a value of 1.5 has been assigned for the input factor supply elasticity for flour milling, and a value of 1.0 has been assigned to the input factor supply elasticities in the stockfeed manufacturing, malting, and oilseed crushing and refining sectors.

Input substitution elasticities

Input substitution matters when there are multiple inputs in production. In an EDM, the degree of substitution between different inputs in each stage of the marketing chain is measured by the price elasticity of input substitution. Alston and Scobie (1983), commenting on Freebairn *et al.* (1982), argued that the elasticity of substitution of inputs plays a crucial role in the distribution of research benefits along the value chain of an EDM. In the absence of substitutability among inputs, research-induced cost reductions in one part of the system deliver positive benefits to producers and consumers at all stages of the system. The distribution of benefits is independent of where the shock is applied in the system (Freebairn *et al.*, 1982). Once input substitution is introduced, these results no longer hold: producers will receive larger benefits if a shock occurs in their sector when the elasticity of substitution of inputs increases.

Different measures of input substitutability are given in the literature, including Hicksian direct elasticity, Allen-Uzawa elasticity, Morishima elasticity, and shadow elasticity. In most EDMs, the Allen-Uzawa elasticity has been the preferred method. The approach measures how one input adjusts to a change in factor price, assuming constant output. Incorporating elasticities of input substitution in the model has implications for results. A small degree of input substitution can have a large effect on the distribution of research benefits (Alston and Scobie, 1983).

Sheng *et al.* (2014) used the Hicks-neutral approach to estimate the price elasticity of substitution between inputs, employing farm data from ABARE's Agriculture and Grazing Industry Survey from 1978 to 2007. The mean values for the elasticities of substitution were estimated to be 0.13 between capital and labour, 1.79 between labour and intermediate inputs, and 1.41 between capital and intermediate inputs.

Salhofer (2000) reviewed 32 studies of agricultural factor substitution across European countries and concluded that a plausible Allen-Uzawa elasticity of substitution ranged between 0.3 to 1.5 for farm-owned inputs and purchased inputs, from 0.0 to 0.8 for land and other farm-owned inputs, and between 0.0 and 0.1 for different purchased inputs.

Elasticities of input substitution can vary between different agricultural zones because of different production techniques. For example, Dixon *et al.* (1982) point out that high rainfall areas are dominated by relatively small-area farms using relatively labour-intensive techniques in contrast to drier zones where these same commodities are produced on much larger-area farms using capital-intensive techniques. An EDM that characterises the grains industry in Australia should accommodate these differences, though doing so is difficult because of the lack of empirical data on substitution elasticities for specific agricultural zones. Most grain produced in Australia comes from large, highly-mechanised farms in drier regions (Boult and Jackson, 2019). The capital-intensive nature of grain production on large farms means these businesses in the short and medium term have little ability to substitute labour for capital or switch away from reliance on intermediate inputs.

In this EDM, a small value of 0.1 has been assigned for the input substitution elasticities between grain-related inputs and 'other inputs' for all sectors. A value of 0.1 has also been assigned for the input substitution elasticity between variable and other non-variable farm inputs. In the storage sector, there is a limited degree of substitutability between the input grains coming from farm production for a given level of outputs. Therefore, all input substitution elasticities between grain inputs in this sector have been assigned a value of 0.1. In terms of the grain inputs used to produce stockfeed, it is assumed that there is a higher degree of flexibility in changing the input mix to produce a certain level of stockfeed output. Because of this, a value of 0.5 has been assigned for the input substitution elasticities between all grain inputs for the stockfeed manufacturing sector.

Product transformation elasticities

Most of Australia's agricultural commodities come from multi-product farms where multiple outputs are produced from the joint use of inputs or production facilities. In an EDM, this is represented by multi-output production functions in the relevant sectors.

A cropping system, for example, is characterised by crop rotations comprising varying mixes of crops grown on a farm area across years and across farm areas in a year. Many crops, to some degree, are substitutes in consumption – for instance, oats, general purpose wheat and barley are animal feeds. Other crops are complements because they are interdependent in the crop rotation. For instance, canola is a disease- and weed-break crop in a rotation with cereal crops. Pulse crops additionally provide soil nitrogen for subsequent cereal and oilseed crop phases. Farmers decide on a mix of crop outputs according to (i) external factors such as relative crop prices, seasonal events such as the timing of the sowing, as well as balancing risks according to goals to do with income stability and (ii) internal factors such as crop sequencing in response to weed and pest burdens and the suitability of crops to certain soil types or parts of the farm's landscape.

Powell and Gruen (1968) defined the product transformation elasticity as a measure of the responsiveness of the product-mix ratio to changes in the marginal rate of transformation; in other words, the possibility of changing the output mix for a given level of inputs. Few estimates of this elasticity measure for broadacre agricultural industries have been made, especially for grains. Dixon *et al.* (1982) estimated product transformation elasticities for Australian agricultural products, but most of these estimated elasticities relate to animal production. The only relevant measure for grains was the transformation elasticity between wheat and barley and this was calculated to be -1.01. Powell and Gruen (1967) examined production transformation relationships in a model with six agricultural products. The partial transformation elasticity between wheat and coarse grains was estimated to be -0.29.

In this EDM model, a value of -3.0 has been assigned to all product transformation elasticities at the farm production level, implying a flexible degree of transformation possibilities between grain outputs.

At the bulk storage level, grains that are identical in quality can be directed towards the export market or the domestic market for secondary processing. It is assumed that there is considerable flexibility in changing the destination or output mix for these grains. Based on this, a value of -3.0 has been assigned for the product transformation elasticities between wheat bound for export markets and wheat bound for domestic milling($\tau_{Z1,Z5}$), barley bound for export markets and barley bound for domestic stockfeed ($\tau_{Z1,Z7}$), barley bound for export markets and barley bound for domestic malting ($\tau_{Z1,Z8}$), and canola bound for export markets and canola bound for domestic crushing ($\tau_{Z1,Z9}$). Export wheat and wheat used for domestic milling is normally of a higher quality compared to wheat used for domestic stockfeed. Because of this, there is less flexibility for changing the output mix between these two qualities of wheat. Therefore, a value of -0.5 has been assigned for the product transformation elasticities between export wheat and wheat used for domestic stockfeed ($\tau_{Z1,Z6}$), as well as that of domestic wheat used for milling and domestic wheat used for stockfeed ($\tau_{Z5,Z6}$). Similarly, a value of -0.5 has been assigned for the product transformation elasticity between domestic barley used for stockfeed and domestic barley used for malting ($\tau_{Z7,Z8}$). All other transformation elasticities in the bulk storage sector are assigned a value of 0.01.

In the milling sector, it can be assumed that there is a very limited degree of transformation flexibility between mill-mix as stockfeed input and flour for domestic consumption. A value of 0.01 has been assigned for the product transformation elasticity here.

In the stockfeed and malting sectors, it is assumed that the final processed grain products are homogeneous, regardless of whether they are destined for the export or domestic market. A value of -2.0 is assigned for the product transformation elasticity of export and domestic stockfeed ($\tau_{s1,s2}$) and the product transformation elasticity for export and domestic malt ($\tau_{m1,m2}$). The oilseed crushing and refining sector produces both canola oil and canola meal. It is assumed that canola oil is close to homogeneous in both the export and domestic markets. A value of -2.0 has been assigned for the product transformation elasticity for export and domestic canola oil ($\tau_{c2,c3}$). There are limited possibilities for changing the output mix between canola meal and canola oil for given inputs. Hence, a value of -0.01 has been assigned to $\tau_{c1,c2}$ and $\tau_{c1,c3}$.

The selected values for all these elasticities for the base run are presented in Table 7. These elasticity values satisfy the concavity and convexity conditions for integrability for all demand and supply functions in the model. The method and details of their verification follow Zhao *et al.* (2000, p. 27).

Exogenous shifts

There are 21 exogenous variables consisting of 10 supply shift variables and 11 demand shift variables. The supply shift variables represent the impacts of alternative research scenarios in various industry sectors and the demand shift variables represent successful promotion investment scenarios in different markets. In this analysis two hypothetical scenarios are considered.

In scenario 1 the focus is on new technologies or practices adopted from RD&E that reduce the costs of production of grains in WA, represented as a 1 per cent reduction in farm production inputs other than land, labour or capital. This is modelled as a downward shift of the supply curve of these other inputs to the farm sector, corresponding to $\mathrm{t}_{\mathrm{Xv}} = -0.01$. These 'other' inputs consist of raw materials such as seed, fertiliser, fuel, water, and chemicals.

In scenario 2 the focus is on the effects of a 1 per cent increase in the price overseas consumers are willing to pay for WA wheat. This could arise through promotion or an improvement of the quality of wheat through RD&E. These effects are modelled as an upward shift of the demand curve for wheat sold in the export market, corresponding to $\mathrm{n}_{\mathrm{z1}} = 0.01$.

Table 7. Market elasticity values for the base run

	Demand Elasticities	**Supply Elasticities**	**Input Elasticities**	**Substitution**	**Product Transformation Elasticities**
Farm Production		$\varepsilon_{\mathrm{Xv,wv}} = 2.0$ $\varepsilon_{\mathrm{Xo,wo}} = 1.0$	$\sigma_{\mathrm{XV,Xo}} = 0.1$		$\tau_{Y1,Y2} = -3.0$ $\tau_{Y1,Y3} = -3.0$ $\tau_{Y1,Y4} = -3.0$ $\tau_{Y2,Y3} = -3.0$ $\tau_{Y3,Y4} = -3.0$
Up-country Storage - Wheat	$\eta_{Z1,u1} = -5.0$	$\varepsilon_{\mathrm{Y1o,v1o}} = 2.5$	$\sigma_{\mathrm{Y1,Y1o}} = 0.1$		$\tau_{Z1,Z5} = -3.0$ $\tau_{Z1,Z6} = -0.5$ $\tau_{Z5,Z6} = -0.5$
Up-country Storage - Barley	$\eta_{Z2,u2} = -5.0$	$\varepsilon_{\mathrm{Y2o,v2o}} = 2.5$	$\sigma_{\mathrm{Y2,Y2o}} = 0.1$		$\tau_{Z2,Z7} = -2.0$ $\tau_{Z2,Z8} = -2.0$ $\tau_{Z7,Z8} = -0.5$
Up-country Storage - Canola	$\eta_{Z3,u3} = -5.0$	$\varepsilon_{\mathrm{Y3o,v3o}} = 2.5$	$\sigma_{\mathrm{Y3,Y3o}} = 0.1$		$\tau_{Z3,Z9} = -3.0$
Up-country Storage - Lupins	$\eta_{Z4,u4} = -5.0$	$\varepsilon_{\mathrm{Y4o,v4o}} = 2.5$	$\sigma_{\mathrm{Y4,Y4o}} = 0.1$		$\tau_{Z4,Z10} = -3.0$
Flour Milling	$\eta_{F1,g1} = -0.5$	$\varepsilon_{\mathrm{Fo,go}} = 1.5$	$\sigma_{\mathrm{Z5,Fo}} = 0.1$		$\tau_{F1,F2} = -0.01$
Stockfeed Manufacturing	$\eta_{S1,t1} = -4.0$ $\eta_{S2,t2} = -0.5$	$\varepsilon_{\mathrm{So,to}} = 1.0$	$\sigma_{\mathrm{Z6,F2}} = 0.5$ $\sigma_{\mathrm{Z6,Z10}} = 0.5$ $\sigma_{\mathrm{Z6,C1}} = 0.5$ $\sigma_{\mathrm{Z7,F2}} = 0.5$ $\sigma_{\mathrm{Z7,C1}} = 0.5$ $\sigma_{\mathrm{Z10,C1}} = 0.5$ $\sigma_{\mathrm{F2,C1}} = 0.5$ $\sigma_{\mathrm{C1,So}} = 0.1$	$\sigma_{\mathrm{Z6,Z7}} = 0.5$ $\sigma_{\mathrm{Z6,So}} = 0.1$ $\sigma_{\mathrm{Z7,Z10}} = 0.5$ $\sigma_{\mathrm{Z7,So}} = 0.1$ $\sigma_{\mathrm{Z10,F2}} = 0.5$ $\sigma_{\mathrm{Z10,So}} = 0.1$ $\sigma_{\mathrm{F2,So}} = 0.1$	$\tau_{S1,S2} = -2.0$
Malt Manufacturing	$\eta_{S1,t1} = -4.0$ $\eta_{S2,t2} = -0.5$	$\varepsilon_{\mathrm{Mo,no}} = 1.0$	$\sigma_{\mathrm{Z8,Mo}} = 0.1$		$\tau_{M1,M2} = -2.0$

Results

Using the data specified, the equations for the EDM are solved to obtain changes to prices and quantities under each policy scenario. For each scenario where an exogenous demand or supply shock occurs in a market, endogenous changes in response to the shock will occur in other markets of the model. Consequently, prices and quantities in all markets will change. The percentage changes in prices and quantities in all sectors of the model for each scenario are presented in Table 8. In both these scenarios, the shifts considered are small parallel shifts, allowing for approximations of price and quantity changes.

The changes in prices and quantities can then be used to estimate the economic welfare implications including the distribution of economic benefits for the different sectors within the industry. In Table 9 these welfare implications are summarized for each investment scenario.

Table 8. Percentage changes in prices and quantities (%)

	Scenario 1 ($t_{Xv} = -1\%$)	Scenario 2 ($n_{Z1} = 1\%$)
Quantities:		
eX_v	0.79	0.81
eX_o	0.65	0.77
eY_1	0.74	1.44
eY_2	0.62	-0.20
eY_3	0.85	-0.28
eY_4	0.64	-0.18
eY_{1o}	0.69	1.45
eY_{2o}	0.57	-0.18
eY_{3o}	0.79	-0.26
eY_{4o}	0.58	-0.16
eZ_1	0.76	1.50
eZ_2	0.66	-0.22
eZ_3	0.86	-0.29
eZ_4	0.81	-0.27
eZ_5	0.12	-0.04
eZ_6	0.41	0.52
eZ_7	0.24	0.03
eZ_8	0.24	-0.08
eZ_9	0.31	-0.06
eZ_{10}	0.24	0.03
eF_o	0.08	-0.02
eF_1	0.10	-0.03
eF_2	0.10	-0.03
eS_o	0.23	0.17
eS_1	0.54	0.41
eS_2	0.16	0.12
eM_o	0.19	-0.06
eM_1	0.25	-0.08
eM_2	0.07	-0.02
eC_o	0.25	-0.04
eC_1	0.30	-0.05

eC_2	0.47	-0.09
eC_3	0.16	-0.03
Prices:		
ew_v	-0.74	0.27
ew_o	0.65	0.77
ev_1	-0.27	0.65
ev_2	-0.31	0.10
ev_3	-0.23	0.08
ev_4	-0.30	0.11
ev_{1o}	0.28	0.58
ev_{2o}	0.23	-0.07
ev_{3o}	0.32	-0.10
ev_{4o}	0.23	-0.06
eu_1	-0.15	0.70
eu_2	-0.13	0.04
eu_3	-0.17	0.06
eu_4	-0.16	0.05
eu_5	-0.37	0.18
eu_6	-0.83	-1.21
eu_7	-0.34	0.17
eu_8	-0.34	0.11
eu_9	-0.36	0.13
eu_{10}	-0.35	0.15
eg_o	0.05	-0.01
eg_1	-0.20	0.06
eg_2	0.03	0.32
et_o	0.23	0.17
et_1	-0.13	-0.10
et_2	-0.32	-0.24
en_o	0.19	-0.06
en_1	-0.06	0.02
en_2	-0.15	0.05
ed_o	0.25	-0.04
ed_1	-0.53	0.39
ed_2	-0.12	0.02
ed_3	-0.31	0.06

Table 9. Economic surplus changes ($ million) and percentage shares of total surplus changes (%) to various industry groups

	Scenario 1 ($t_{Xv} = -1\%$)		Scenario 2 ($n_{z1} = 1\%$)	
	$m	%	$m	%
ΔPS_{Xo}	8.02	33.1%	9.43	36.2%
ΔPS_{Xv}	6.38	26.3%	6.58	25.2%
$\Delta PS_{Xo} + \Delta PS_{Xv}$ Farm subtotal	14.40	59.4%	16.01	61.4%

ΔPS_{Y1o} Bulk Storage for Wheat	1.31	5.4%	2.74	10.5%
ΔPS_{Y2o} Bulk Storage for Barley	0.50	2.1%	-0.16	-0.6%
ΔPS_{Y3o} Bulk Storage for Canola	0.25	1.0%	-0.08	-0.3%
ΔPS_{Y4o} Bulk Storage for Lupins	0.05	0.2%	-0.01	-0.1%
Bulk Storage subtotal $\Delta PS_{Y1o} + \Delta PS_{Y2o} + \Delta PS_{Y3o} + \Delta PS_{Y4o}$	2.11	8.7%	2.49	9.5%
ΔPS_{Fo} Flour Milling	0.03	0.1%	-0.01	0.0%
ΔPS_{So} Stockfeed manufacturing	0.21	0.9%	0.16	0.6%
ΔPS_{Mo} Malt Manufacturing	0.11	0.5%	-0.04	-0.1%
ΔPS_{Co} Canola Processing	0.01	0.0%	-0.00	0.0%
Producer Surplus subtotal:	16.87	69.6%	18.61	71.4%
ΔCS_{Z1} Wheat Export	3.95	16.3%	7.83	30.0%
ΔCS_{Z2} Barley Export	0.89	3.7%	-0.29	-1.1%
ΔCS_{Z3} Canola Export	1.34	5.5%	-0.44	-1.7%
ΔCS_{Z4} Lupins Export	0.16	0.6%	-0.05	-0.2%

ΔCS_{S1} Stockfeed Export	0.11	0.4%	0.08	0.3%
ΔCS_{M1} Malt Export	0.06	0.2%	-0.02	-0.1%
ΔCS_{C2} Canola Oil Export	0.02	0.1%	-0.00	0.0%
Overseas consumers subtotal	6.52	26.9%	7.10	27.2%
ΔCS_{F1} Domestic Flour	0.20	0.8%	-0.06	-0.2%
ΔCS_{S2} Stockfeed Domestic	0.57	2.4%	0.43	1.7%
ΔCS_{M2} Malt Domestic	0.03	0.1%	-0.01	0.0%
ΔCS_{C3} Canola Oil Domestic	0.05	0.2%	-0.01	0.0%
Domestic consumers subtotal	0.85	3.5%	0.36	1.4%
Consumer Surplus Subtotal	7.36	30.4%	7.46	28.6%
Total Economic Surplus	24.23	100.0%	26.07	100.0%

Scenario 1

In Scenario 1, the exogenous shock examined is a 1 per cent reduction in farm cost, represented as a downward shift of the supply curve for variable farm inputs ($t_{Xv} = -0.01$). This can arise through any research-induced technical change that reduces the cost of producing these inputs or increases the productivity of these inputs. The changes in demand and supply, shown as shifts in supply and demand curves across all markets, are depicted in Figure 3 (not to scale).

This downwards shift in supply for variable farm inputs results in higher quantities and lower prices of these inputs. The reduction in costs of these inputs causes a downward shift of the supply curves of these outputs (Y_1, Y_2, Y_3, Y_4), increasing quantities and reducing prices of these outputs. The reduced cost in grain production causes the supply curves of outputs in all downstream sectors $(Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7, Z_8, Z_9, Z_{10}, F_1, F_2, S_1, S_2, M_1, M_2, C_1, C_2, C_3)$ to shift downwards, causing prices to decrease and quantities to increase for these outputs.

On the demand side, a reduction in prices for raw grains and processed grain products causes increased consumption in the domestic and overseas markets for these products. This causes the demand curves for grain outputs from farm production going into the storage sector (Y_1, Y_2, Y_3, Y_4), as well as grain outputs from the storage sector going into the secondary processing sectors, $(Z_5, Z_6, Z_7, Z_8, Z_9, Z_{10})$ to shift upwards to the right. The demand curves for mill-mix (F_2) and canola meal (C_1) going into stockfeed manufacturing shift for these reasons. In addition, second round shifts in input demand and output supply take effect because of substitution effects. Figure 3 illustrates the end results of all these shifts. On balance, the downward supply shifts dominate for the majority of these grain and grain products because the base results show that the prices for these grains decrease. The only instance where the upwards shift in demand dominates is for millmix (F_2), where both its prices and quantities have increased.

The supply curves of other inputs in all sectors $(X_o, Y_{1o}, Y_{2o}, Y_{3o}, Y_{4o}, F_o, S_o, M_o, C_o)$ remain stationary as they are exogenous inputs to the model. Their demand curves have all shifted upwards because of increases in consumption of grain and grain products.

These displacements cause the total surplus gain for the industry to be an estimated $24.22 million per year. All industry groups experience gains in welfare. The farm sector is the main beneficiary of the technology shock with a total producer surplus of $14.40 million, translating to 59.4 per cent of the total surplus gain. The bulk storage and handling sector obtains $2.11 million or 8.7 per cent of the total benefits. The prices for export grain and grain products are largely unaffected by the technological shock because of their high export demand elasticities, but export quantities increase. The total benefit accruing to all overseas consumers is $6.52 million or 26.9 per cent of the total benefits.

These results are consistent with theory and with findings from previous studies. Alston *et al.* (2004) point out that for export-oriented agricultural industries operating in markets where prices are determined internationally (high export demand elasticity), the larger share of the benefits from research will be retained by the innovating industry and the factors of production it uses. This logic was supported by the Productivity Commission (2011) which inquired into the benefits of investments by rural R&D corporations. It reported that 'while some of the research has contributed to better environmental and social outcomes, most of the reported benefits have taken the form of saving in producers' inputs costs or other sources of productivity improvement, such as higher yields or more efficient farming practices.'(p.108).

Scenario 2

In Scenario 2, the exogenous shock examined is a 1 per cent upward shift of the demand curve for export wheat $(t_{Z1} = 0.01)$. This can be the result of quality enhancing research which increases the willingness to pay by overseas consumers or through investments in advertising and promotion in overseas markets.

The upward shift of the demand of export wheat increases both its quantity (Z_1) and price (u_1). Due to the increase in export demand for wheat, the derived input demand curves for grain input going into the wheat storage sector (Y_1) is shifted upwards along with the input demand curves for farm inputs (X_o, Y_o). The higher farm gate price of wheat triggers a decrease in production supply of the other grains (Y_2, Y_3, Y_4), facilitated by the high elasticity of output transformation between wheat and other grains at farm production. This will also result in upward shifts in their supply curves (decreasing supply) of these grain inputs going into storage resulting in decreases in their quantities and increases in their prices as shown in Table 8. This subsequently causes a reduction in the supply for most output coming from the storage of these grains $(Z_2, Z_3, Z_4, Z_8, Z_9)$.

As the aggregate input index of the storage sector (EY^w) has now increased, this then results in increases (downward shifts) in the supply for export wheat (Z_1), partially offsetting the initial upwards shift in its demand. The output supply of feed wheat (Z_6) increases and subsequently causes the supply of outputs in the stockfeed manufacturing sector$(\mathrm{S}_1, \mathrm{S}_2)$ to also increase. The supply of barley and lupins destined for stockfeed manufacturing$(\mathrm{Z}_7, \mathrm{Z}_{10})$ increase due to their substitutability for stockfeed wheat. The output supply of wheat going into milling (Z_5) decreases because of its high level of output substitution with export wheat $(\tau_{Z1,Z5} = -3.0)$. This decrease in supply for milling wheat decreases the supply of flour (F_1) and millmix (F_2) in the final domestic market and stockfeed manufacturing sector respectively.

The supply of other inputs in all sectors remains stationary as they are exogenous inputs to the model. The demand curves for X_o, X_v Y_{1o} and S_o shift upwards because of the increase in export demand for wheat as well as an increase in supply for stockfeed. Demand for $\mathrm{Y}_{2o}, \mathrm{Y}_{3o}, \mathrm{Y}_{4o}, \mathrm{F}_o, \mathrm{S}_o, \mathrm{M}_o, \mathrm{C}_o$ shifts downwards.

The estimated total surplus gain for the export wheat market for WA from this hypothetical scenario is $26.07 million per year. The economic benefit to the farm sector is $16.01 million or 61.4 per cent of the total benefits. The other major beneficiaries in this scenario include bulk storage ($2.49 million) and overseas wheat consumers ($7.83 million).

Sensitivity Analysis

The results of running the EDM of the WA grains industry indicate the magnitude and distribution of net benefits generated by different hypothetical RD&E investment decisions. The model was calibrated using point estimates for the market parameters, with the results depending critically on these estimates. Accuracy of the results depends on the reliability of the chosen elasticity values: different elasticity estimates yield different results.

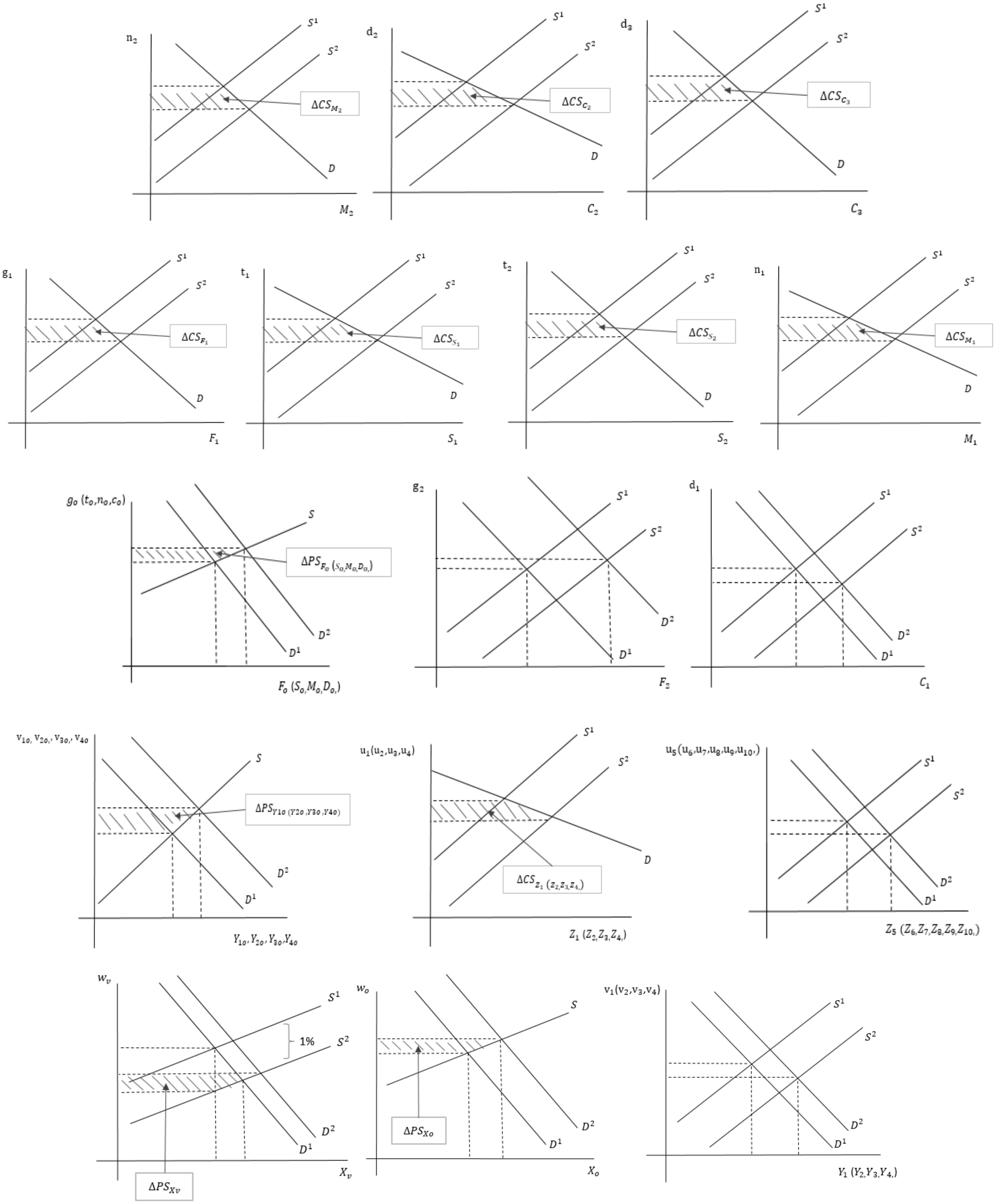
Given the uncertainty of the parameters used to calibrate the EDM, it is useful to do stochastic sensitivity analysis. This involves replacing point estimates for uncertain parameters with probability distributions. Sensitivity analysis would be applied to the results to produce probability distributions for the estimated changes in economic surplus for each sector. Such an approach is not undertaken for the model reported in this paper, but will be explored in the next stage during the development of the comprehensive Australian EDM.

Dynamics

Equilibrium Displacement Modelling is a form of comparative static analysis as it compares 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 include the dynamic path of adjustment towards equilibrium, nor the process of change itself.

There is a time dimension involved in the research investment cycle. Research does not affect agricultural production directly or instantaneously. Usually a considerable time elapses before usable technologies can be generated from research investments and implemented on farm and elsewhere. Further, as with any other form of capital, the knowledge generated through agricultural research depreciates over time, and eventually becomes obsolete. Important time lags exist between commencing research, full adoption and eventual dis-adoption of an innovation or technology. A limitation of EDMs is that they do not account for these dynamic responses within the framework. Exogenous shifts in the model representing 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 (Mounter *et al.*, 2008, p.80).

Figure 3. Market Displacement and Surplus Changes in Scenario 1 ($\mathbf{t_{Xv} = -0.01}$)



An implication of incorporating dynamics in the analysis is that the price elasticities of supply and demand in the EDM can no longer be treated as constants and will change over the adjustment process. Piggott (1992) highlighted that this could be remedied to some extent by repeated applications of EDM using elasticities corresponding to different lengths of run. Just *et al.* (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 lengths of run. In many other cases, a dynamic problem is simply treated as a comparative static problem, with the uncertainty of research benefits associated with dynamics being managed by carrying out stochastic sensitivity analysis on the market parameters.

For the grains industry, the issue of dynamics becomes more challenging with crop rotations. In a crop rotation, different crops are grown in succession on the same area of land over time. This allows crops within a rotation to have complementary effects on crop yield through disease management, soil fertility, and weed control. Consequently, the decision to grow a crop cannot be made in isolation as grain cropping forms part of a system of activities (Malcolm *et al.*, 2005). When deciding on a crop rotation sequence on an area of farmland, farmers will have in mind the stream of benefits that the sequence on that land will bring over the next several years, as well as the implications for the total crop activity mix present on the farm in any one year. Though this adds a layer of complexity in the modelling process, it can be dealt with by assuming that each phase of the rotation sequence is present during each year. This means that, instead of examining the problem across time, the problem can be examined at a point in time. This allows the problem to be analysed using a comparative static framework like an EDM.

The Nature of Competition

Most studies of the impacts of agricultural research have the assumption that markets along the production and marketing chain are perfectly competitive; this is also the case for EDMs. For a perfectly competitive EDM, two market clearing conditions are imposed. First, profit maximisation requires that marginal costs are equal to marginal prices (revenue) in each market. Second, for a perfectly competitive EDM, the long-run competitive equilibrium condition of zero economic profit is imposed, whereby the total cost of inputs for each individual market is equal to the total revenue of its outputs.

Several studies have tested for non-competitive behaviour in the grain industry. Notably, Griffith (2000) examined competition across the Australian food marketing chain. He found statistically significant evidence of non-competitive buying power exerted by grain buyers in the processing and marketing sectors. This finding was supported by O'Donnell *et al.* (2007) who tested for market power in the grains and oilseeds industries, for 13 grain and oilseed products handled by seven groups of agents. Empirical evidence in this study suggested buyers of grain act as oligopsonists, and this was particularly evident in the wheat and barley industries.

Imperfectly competitive markets can have significant implications for the estimated returns from R&D. McCorriston (2002) noted that the degree of market power influences the extent to which price changes are transferred along the marketing chain. This could mean that price changes originating at the farm gate may not be passed fully to end consumers. Alston *et al.* (1997) examined the effects of varying degrees of market power held by agribusiness firms on the size and distribution of benefits from R&D. Alston *et al.* (1997) found that increasing the degree of either oligopsony or oligopoly power reduced total benefits from R&D and distorted the distribution of benefits away from consumers and producers in favour of the agribusiness firms with the power that purchase, process and sell the raw farm products.

The research reported above highlights potential pitfalls in an EDM in which the key assumption is that the markets are perfectly competitive. Interest in understanding competitiveness in the grains industry has heightened since deregulation of the single-desk wheat marketing arrangements in 2008. A full scale EDM for the Australian grains Industry will test for market power to see whether a competitive EDM framework is realistic. Non-competitive market characteristics will be incorporated in the model if the assumed competitive model structure has shortcomings.

Summary

The grains industry is one of Australia's staple industries contributing around a quarter of Australia's total agricultural exports. The industry has grown significantly since the 1970s yet slowing growth in total factor productivity during the 1990s and 2000s signals a challenge for the industry. Advances in agricultural technology and innovations from investing in RD&E will play a key role in meeting this productivity challenge and help to maintain and increase international competitiveness.

As public fiscal conditions tighten so too does the imperative for accountability and measuring the potential and actual economic impacts of agricultural research. Sound investment evaluation before and after investment is essential.

Equilibrium Displacement Models (EDMs) are useful techniques for evaluating likely returns from alternative RD&E investments and indicating the likely distribution of benefits for different participants in the value chain.

In this paper, an EDM for the WA grains industry, based on Li *et al.* (2017, 2018), has been constructed and analysed. The WA grains industry is predominantly export-oriented, with around 85-95 per cent of total annual grains production being exported to various countries, mostly in in Asia. Using the EDM, two investment scenarios were examined. The first scenario was a 1 per cent reduction in the cost of farm production inputs that include raw materials such as seed, fertiliser, fuel, water, and chemicals (or a 1 per cent improvement in efficiency). The improved input efficiency can arise from new technologies or practices adopted that reduce the costs of production. The second scenario involved a 1 per cent increase in willingness of overseas consumers to pay for WA wheat. This could arise through promotion investment or from investments that improve the quality of WA wheat.

The results of the preliminary model show that the economic benefits as well as the distribution of benefits from both scenarios are comparable. The farm sector and overseas consumers are the major beneficiaries under each scenario. This is due to two reasons. First, the WA grains industry is characterised by a short supply chain, where most grain production is exported. The high volume of grain flows to the export market corresponds to a high total market value, which in turn ensures that high share of benefits is enjoyed by overseas consumers in response to any demand or supply side shock in the industry. Second, the assumption of a high export demand elasticity for export grains ensures that the farm production sector shares most of total benefits, and that these benefits outweigh the share of benefits received by overseas consumers.

Although not covered in this paper, another approach would use stochastic sensitivity analysis on uncertain parameters and variables to produce probability distributions for the estimated economic changes. Also, the model has the assumption of perfect competition in the industry, with prices in all sectors assumed to equal marginal costs. Some previous studies tested for non-competitive behaviour in the grains industry and found statistically significant evidence of non-competitive buying power exerted by grain buyers in the processing and marketing sectors. Further work will be taken in the future to test and account for non-competitive markets in the grains industry.

In conclusion, the EDM presented here is a useful approach to measuring the magnitude and distribution of potential returns to RD&E in the Australian grains industry and can help guide RD&E investment decisions.

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Appendix 1. Model Specification and the Structural Model

The product transformation functions for the nine industry sectors can be written as follows:

(1)	$Y(Y_1, Y_2, Y_3, Y_4) = X(X_v, X_o)$	*farm production*
(2)	$Z^W(Z_1, Z_5, Z_6) = Y^W(Y_1, Y_{1o})$	wheat *storage*
(3)	$Z^b(Z_2, Z_7, Z_8) = Y^b(Y_2, Y_{2o})$	barley *storage*
(4)	$Z^c(Z_3, Z_9) = Y^c(Y_3, Y_{3o})$	canola *storage*
(5)	$Z^l(Z_4, Z_{10}) = Y^l(Y_4, Y_{4o})$	lupin *storage*
(6)	$F(F_1, F_2,) = Z^f(Z_5, F_o)$	*milling*
(7)	$S(S_1, S_2) = Z^s(Z_6, Z_7, Z_{10}, C_1, F_2, S_o)$	*stockfeed manufacturing*
(8)	$M(M_1, M_2) = Z^m(Z_8, M_o)$	*malt manufacturing*
(9)	$C(C_1, C_2, C_3) = Z^c(Z_9, C_o)$	*oilseed crushing & refining*

The variables on the left sides of the equations are outputs for the relevant sectors and the variables on the right sides are the inputs.

Cost functions related to these production functions are written as:

(10)	$C_Y = Y * c_Y(w_v, w_o)$	*farm production*
(11)	$C_{Zw} = Z^w * c_{Zw}(v_1, v_{1o})$	wheat *storage*
(12)	$C_{Zb} = Z^b * c_{Zb}(v_2, v_{2o})$	barley *storage*
(13)	$C_{Zc} = Z^c * c_{Zc}(v_3, v_{3o})$	canola *storage*
(14)	$C_{Zl} = Z^l * c_{Zl}(v_4, v_{4o})$	lupin *storage*
(15)	$C_F = F * c_F(u_5, g_o)$	*milling*
(16)	$C_S = S * c_S(u_6, u_7, u_{10}, d_1, g_2, t_o)$	*stockfeed manufacturing*
(17)	$C_M = M * c_M(u_8, n_o)$	*malt manufacturing*
(18)	$C_C = C * c_C(u_9, d_o)$	*oilseed crushing & refining*

where C_x denotes the total cost of producing output index x and c_x stands for the unit cost function (for each $x = Y, Z^w, Z^b, Z^c, Z^l$ F, S, M and C). Quantities are represented by capital letters and prices by lower case letters.

Similarly, the revenue functions subject to given input levels for the nine multi-output sectors can be represented as:

(19)	$R_X = X * r_X(v_1, v_2, v_3, v_4)$	*farm production*
(20)	$R_{Yw} = Y^w * r_{Yw}(u_1, u_5, u_6)$	wheat *storage*
(21)	$R_{Yb} = Y^b * r_{Yb}(u_2, u_7, u_8)$	barley *storage*
(22)	$R_{Yc} = Y^c * r_{Yc}(u_3, u_9)$	canola *storage*
(23)	$R_{Yl} = Y^l * r_{Yl}(u_4, u_{10})$	lupin *storage*
(24)	$R_{Zf} = Z^f * r_{Zf}(g_1, g_2)$	*milling*
(25)	$R_{Zs} = Z^s * r_{Zs}(t_1, t_2)$	*stockfeed manufacturing*
(26)	$R_{Zm} = Z^m * r_{Zm}(n_1, n_2)$	*malt manufacturing*
(27)	$R_{Zc} = Z^c * r_{Zc}(d_1, d_2, d_3)$	*oilseed crushing & refining*

where R_x denotes the total revenue generated from the fixed input index x and r_x stands for the unit revenue function (for each $x = X, Y^w, Y^b, Y^c, Y^l, Z^f, Z^s, Z^m$ and Z^c). Similarly, quantities are represented by capital letters and prices by lower case letters.

Next, the equations representing the EDM of the WA grains industry are specified. There are 84 equations in total, consisting of a pair of supply and demand functions for each product and a pair of equilibrium conditions in each of the three industry sectors. In addition, there are 21 exogenous variables corresponding to the products flowing into or out of the end uses (ovals) depicted in Figure 2.

These exogenous variables are supply and demand shifters and represent the potential impact of new technologies and promotion. These equations expressed in general form as part of the structural model as follows:

Input supply to farm sector

(28) $\mathrm{X}_v = \mathrm{X}_v(\mathrm{w}_v, T_{xv})$

(29) $\mathrm{X}_o = \mathrm{X}_o(\mathrm{w}_v, T_{xo})$

Output-constrained input demand of farm sector

(30) $\mathrm{X}_v = Y * c'_{Y,wv}(\mathrm{w}_v, w_o)$

(31) $\mathrm{X}_o = Y * c'_{Y,wo}(\mathrm{w}_o, w_o)$

Input-constrained output supply of farm enterprises

(32) $Y_1 = X * r'_{X,v1}(v_1, v_2, v_3, v_4)$

(33) $Y_2 = X * r'_{X,v2}(v_1, v_2, v_3, v_4)$

(34) $Y_3 = X * r'_{X,v3}(v_1, v_2, v_3, v_4)$

(35) $Y_4 = X * r'_{X,v4}(v_1, v_2, v_3, v_4)$

Equilibrium conditions of farm enterprises

(36) $\mathrm{X}(\mathrm{X_v}, \mathrm{X_o}) = \mathrm{Y}(\mathrm{Y}_1, \mathrm{Y}_2, \mathrm{Y}_3, \mathrm{Y}_4)$

(37) $c_Y(\mathrm{w}_v, w_o) = r_X(v_1, v_2, v_3, v_4)$

Other input supply to wheat storage

(38) $\mathrm{Y}_{1o} = \mathrm{Y}_{1o}(\mathrm{v}_{1o}, T_{Y1o})$

Output-constrained input demand of wheat storage

(39) $\mathrm{Y}_1 = Z^w * c'_{Zw,v1}(\mathrm{v}_1, \mathrm{v}_{1o})$

(40) $\mathrm{Y}_{1o} = Z^w * c'_{Zw,v1o}(\mathrm{v}_1, \mathrm{v}_{1o})$

Input-constrained output supply of wheat storage

(41) $Z_1 = Y^w * r'_{Yw,u1}(u_1, u_5, u_6)$

(42) $Z_5 = Y^w * r'_{Yw,u5}(u_1, u_5, u_6)$

(43) $Z_6 = Y^w * r'_{Yw,u6}(u_1, u_5, u_6)$

Equilibrium conditions of wheat storage

(44) $Y^w(\mathrm{Y}_1, \mathrm{Y}_{1o}) = Z^w(\mathrm{Z}_1, \mathrm{Z}_5, \mathrm{Z}_6)$

(45) $c_{Zw}(\mathrm{v}_1, \mathrm{v}_{1o}) = r_{Yw}(u_1, u_5, u_6)$

Export Demand for wheat

(46) $\mathrm{Z}_1 = \mathrm{Z}_1(\mathrm{u}_1, N_{Z1})$

Other input supply to barley storage

(47) $\mathrm{Y}_{2o} = \mathrm{Y}_{2o}(\mathrm{v}_{2o}, T_{Y2o})$

Output-constrained input demand of barley storage

(48) $\mathrm{Y}_2 = Z^b * c'_{Zb,v2}(\mathrm{v}_2, \mathrm{v}_{2o})$

(49) $\mathrm{Y}_{2o} = Z^b * c'_{Zb,v2o}(\mathrm{v}_2, \mathrm{v}_{2o})$

Input-constrained output supply of barley storage

(50) $Z_2 = Y^b * r'_{Yb,u2}(u_2, u_7, u_8)$

(51) $Z_7 = Y^b * r'_{Yb,u7}(u_2, u_7, u_8)$
(52) $Z_8 = Y^b * r'_{Yb,u8}(u_2, u_7, u_8)$

Equilibrium conditions of barley storage
(53) $Y^b(\mathrm{Y}_2, \mathrm{Y}_{2o}) = Z^b(\mathrm{Z}_2, \mathrm{Z}_7, \mathrm{Z}_8)$
(54) $c_{Zb}(\mathrm{v}_2, \mathrm{v}_{2o}) = r_{Yb}(u_2, u_7, u_8)$

Export Demand for barley
(55) $\mathrm{Z}_2 = \mathrm{Z}_2(\mathrm{u}_2, \mathrm{N}_{Z2})$

Other input supply to canola storage
(56) $\mathrm{Y}_{3o} = \mathrm{Y}_{3o}(\mathrm{v}_{3o}, T_{Y3o})$

Output-constrained input demand of canola storage
(57) $\mathrm{Y}_3 = Z^c * c'_{Zc,v3}(\mathrm{v}_3, \mathrm{v}_{3o})$
(58) $\mathrm{Y}_{3o} = Z^c * c'_{Zc,v3o}(\mathrm{v}_2, \mathrm{v}_{3o})$

Input-constrained output supply of canola storage
(59) $Z_3 = Y^c * r'_{Yc,u3}(u_3, u_9)$
(60) $Z_9 = Y^c * r'_{Yc,u9}(u_3, u_9)$

Equilibrium conditions of canola storage
(61) $\mathrm{Y}_3 = Z^c * c'_{Zc,v3}(\mathrm{v}_3, \mathrm{v}_{3o})$
(62) $\mathrm{Y}_{3o} = Z^c * c'_{Zc,v3o}(\mathrm{v}_2, \mathrm{v}_{3o})$

Export Demand for canola
(63) $\mathrm{Z}_3 = \mathrm{Z}_3(\mathrm{u}_3, \mathrm{N}_{Z3})$

Other input supply to lupin storage
(64) $\mathrm{Y}_{4o} = \mathrm{Y}_{4o}(\mathrm{v}_{4o}, T_{Y4o})$

Output-constrained input demand of lupin storage
(65) $\mathrm{Y}_4 = Z^l * c'_{Zl,v4}(\mathrm{v}_4, \mathrm{v}_{4o})$
(66) $\mathrm{Y}_{4o} = Z^l * c'_{Zl,v4o}(\mathrm{v}_4, \mathrm{v}_{4o})$

Input-constrained output supply of lupin storage
(67) $Z_4 = Y^l * r'_{Yl,u4}(u_4, u_{10})$
(68) $Z_{10} = Y^l * r'_{Yl,u10}(u_4, u_{10})$

Equilibrium conditions of lupin storage
(69) $Y^l(\mathrm{Y}_4, \mathrm{Y}_{4o}) = Z^l(\mathrm{Z}_4, \mathrm{Z}_{10})$
(70) $c_{Zl}(\mathrm{v}_1, \mathrm{v}_{1o}) = r_{Yl}(u_4, u_{10})$

Export demand of lupins
(71) $\mathrm{Z}_4 = \mathrm{Z}_4(\mathrm{u}_4 \mathrm{N}_{Z4})$

Other input supply to milling sector
(72) $\mathrm{F_o} = \mathrm{F_o}(\mathrm{g_o}, \mathrm{T}_{Fo})$

Output-constrained input demand of milling sector

(73) $\mathrm{Z}_5 = F * c'_{F,u5}(\mathrm{u}_5, \mathrm{g}_o,)$

(74) $\mathrm{F}_o = F * c'_{F,go}(\mathrm{u}_5, \mathrm{g}_o,)$

Input-constrained output supply of milling sector

(75) $F_1 = Z^f * r'_{Zf,g1}(g_1, g_2)$

(76) $F_2 = Z^f * r'_{Zf,g2}(g_1, g_2)$

Equilibrium conditions of milling sector

(77) $F(\mathrm{F}_1, \mathrm{F}_2,) = \mathrm{Z}_f(\mathrm{Z}_5, \mathrm{F}_o)$

(78) $\mathrm{c}_{\mathrm{Zf}}(\mathrm{u}_5, \mathrm{g}_o) = \mathrm{r}_{\mathrm{Fw}}(\mathrm{g}_1,\mathrm{g}_2)$

Domestic demand of milling sector

(79) $F_1 = \mathrm{F}_1(\mathrm{g}_1, \mathrm{N}_{F1})$

Other input supply to stockfeed sector

(80) $\mathrm{S_o} = \mathrm{S_o}(\mathrm{t_o}, \mathrm{T}_{So})$

Output-constrained input demand of stockfeed sector

(81) $\mathrm{Z}_6 = S * c'_{S,Z6}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o)$

(82) $\mathrm{Z}_7 = S * c'_{S,Z7}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o)$

(83) $\mathrm{Z}_{10} = S * c'_{S,Z10}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o)$

(84) $\mathrm{C}_1 = S * c'_{S,d1}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o)$

(85) $\mathrm{F}_2 = S * c'_{S,g2}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o)$

(86) $\mathrm{S}_o = S * c'_{S,to}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o)$

Input-constrained output supply of stockfeed sector

(87) $S_1 = Z^s * r'_{Zs,t1}(t_1, t_2)$

(88) $S_2 = Z^s * r'_{Zs,t2}(t_1, t_2)$

Equilibrium conditions of stockfeed sector

(89) $\mathrm{Z}_s(\mathrm{Z}_6, \mathrm{Z}_7, \mathrm{Z}_{10}, \mathrm{C}_1, \mathrm{F}_2, \mathrm{S}_o) = \mathrm{S}(\mathrm{S}_1, \mathrm{S}_2)$

(90) $\mathrm{c_S}(\mathrm{u}_6, \mathrm{u}_7, \mathrm{u}_{10}, \mathrm{d}_1, \mathrm{g}_2, \mathrm{t}_o) = \mathrm{r_{Zs}}(\mathrm{t}_1,\mathrm{t}_2)$

Export demand of stockfeed sector

(91) $\mathrm{S}_1 = \mathrm{S}_1(\mathrm{t}_1, \mathrm{N}_{S1})$

Domestic demand of stockfeed sector

(92) $\mathrm{S}_2 = \mathrm{S}_2(\mathrm{t}_2, \mathrm{N}_{S2})$

Other input supply to malt manufacturing sector

(93) $\mathrm{M_o} = \mathrm{M_o}(\mathrm{n_o}, \mathrm{T}_{Mo})$

Output-constrained input demand of malt manufacturing sector

(94) $\mathrm{Z}_8 = M * c'_{M,g2}(\mathrm{u}_8, \mathrm{n}_o)$

(95) $\mathrm{M}_o = M * c'_{M,no}(\mathrm{u}_8, \mathrm{n}_o)$

Input-constrained output supply of malt manufacturing sector

(96) $M_1 = Z^m * r'_{Zm,n1}(n_1, n_2)$

(97) $M_2 = Z^m * r'_{Zm,n2}(n_1, n_2)$

Equilibrium conditions of malt manufacturing sector

(98) $\mathrm{Z}_m(\mathrm{Z}_8, \mathrm{M}_o) = \mathrm{M}(\mathrm{M}_1, \mathrm{M}_2)$

(99) $\mathrm{c_M}(\mathrm{u}_8, \mathrm{n}_o) = \mathrm{r_{Zm}}(\mathrm{n}_1,\mathrm{n}_2)$

Export demand of malt manufacturing sector

(100) $\mathrm{M}_1 = \mathrm{M}_1(\mathrm{n}_1, \mathrm{N}_{M1})$

Domestic demand of malt manufacturing sector

(101) $\mathrm{M}_2 = \mathrm{M}_2(\mathrm{n}_2, \mathrm{N}_{M2})$

Other input supply to oilseed crushing and refining sector

(102) $\mathrm{C_o} = \mathrm{C_o}(\mathrm{d_o}, \mathrm{T}_{Co})$

Output-constrained input demand of oilseed crushing and refining sector

(103) $\mathrm{Z}_9 = C * c'_{C,u9}(\mathrm{u}_9, \mathrm{d}_o)$

(104) $\mathrm{C}_o = C * c'_{C,do}(\mathrm{u}_9, \mathrm{d}_o)$

Input-constrained output supply of oilseed crushing and refining sector

(105) $C_1 = Z^c * r'_{Zc,d1}(d_1, d_2, d_3)$

(106) $C_2 = Z^c * r'_{Zc,d2}(d_1, d_2, d_3)$

(107) $C_3 = Z^c * r'_{Zc,d3}(d_1, d_2, d_3)$

Equilibrium conditions of oilseed crushing and refining sector

(108) $\mathrm{Z}_c(\mathrm{Z}_9, \mathrm{C}_o) = \mathrm{C}(\mathrm{C}_1, \mathrm{C}_2, \mathrm{C}_3)$

(109) $\mathrm{c_C}(\mathrm{u}_9, \mathrm{d}_o) = \mathrm{r_{Zc}}(\mathrm{d}_1,\mathrm{d}_2, \mathrm{d}_3)$

Export demand of oilseed crushing and refining sector (Canola Oil)

(110) $\mathrm{C}_2 = \mathrm{C}_2(\mathrm{d}_2, \mathrm{N}_{C2})$

Domestic demand of oilseed crushing and refining sector (Canola Oil)

(111) $\mathrm{C}_3 = \mathrm{C}_3(\mathrm{d}_3, \mathrm{N}_{C3})$

Appendix 2. EDM of the WA Grains Industry in Displacement Form

1. Farm

1.1 Input supply to farm enterprises

(A.1) $\mathrm{EX}_v=\varepsilon_{\mathrm{xv,wv}}*(\mathrm{Ew}_v-\mathrm{t}_{\mathrm{xv}})$

(A.2) $\mathrm{EX_o}=\varepsilon_{\mathrm{xo,wo}}*(\mathrm{Ew_o}-\mathrm{t_{xo}})$

1.2 Output constrained input demands of farm enterprises

(A.3) $\mathrm{EX}_v=-\kappa_{\mathrm{xo}}*\sigma_{\mathrm{xv,xo}}*\mathrm{Ew}_v+\kappa_{\mathrm{xo}}*\sigma_{\mathrm{xv,xo}}*\mathrm{Ew_o}+\mathrm{EY}$

(A.4) $\mathrm{EX}_o=-\kappa_{\mathrm{xv}}*\sigma_{\mathrm{xo,xv}}*\mathrm{Ew}_o+\kappa_{\mathrm{xv}}*\sigma_{\mathrm{xo,xv}}*\mathrm{Ew_v}+\mathrm{EY}$

1.3 Input constrained output supplies of farm enterprises

(A.5) $\mathrm{EY}_1=-(\lambda_{y2}*\tau_{y1,y2}+\lambda_{y3}*\tau_{y1,y3}+\lambda_{y4}*\tau_{y1,y4})*\mathrm{Ev}_1+\lambda_{y2}*\tau_{y1,y2}*\mathrm{Ev}_2+\lambda_{y3}*\tau_{y1,y3}*\mathrm{Ev}_3+\lambda_{y4}*\tau_{y1,y4}*\mathrm{Ev}_4+\mathrm{EX}$

(A.6) $\mathrm{EY}_2=-(\lambda_{y1}*\tau_{y2,y1}+\lambda_{y3}*\tau_{y2,y3}+\lambda_{y4}*\tau_{y2,y4})*\mathrm{Ev}_2+\lambda_{y1}*\tau_{y2,y1}*\mathrm{Ev}_1+\lambda_{y3}*\tau_{y2,y3}*\mathrm{Ev}_3+\lambda_{y4}*\tau_{y2,y4}*\mathrm{Ev}_4+\mathrm{EX}$

(A.7) $\mathrm{EY}_3=-(\lambda_{y1}*\tau_{y3,y1}+\lambda_{y2}*\tau_{y3,y2}+\lambda_{y4}*\tau_{y3,y4})*\mathrm{Ev}_3+\lambda_{y1}*\tau_{y3,y1}*\mathrm{Ev}_1+\lambda_{y2}*\tau_{y3,y2}*\mathrm{Ev}_2+\lambda_{y4}*\tau_{y3,y4}*\mathrm{Ev}_4+\mathrm{EX}$

(A.8) $\mathrm{EY}_4=-(\lambda_{y1}*\tau_{y4,y1}+\lambda_{y2}*\tau_{y4,y2}+\lambda_{y3}*\tau_{y4,y3})*\mathrm{Ev}_4+\lambda_{y1}*\tau_{y4,y1}*\mathrm{Ev}_1+\lambda_{y2}*\tau_{y4,y2}*\mathrm{Ev}_2+\lambda_{y3}*\tau_{y4,y3}*\mathrm{Ev}_3+\mathrm{EX}$

1.4 Equilibrium conditions

(A.9) $\kappa_{\mathrm{xv}}*\mathrm{EX}_v+\kappa_{\mathrm{xo}}*\mathrm{EX}_o=\lambda_{y1}*\mathrm{EY}_1+\lambda_{y2}*\mathrm{EY}_2+\lambda_{y3}*\mathrm{EY}_3+\lambda_{y4}*\mathrm{EY}_4$

(A.10) $\kappa_{\mathrm{xv}}*\mathrm{Ew}_v+\kappa_{\mathrm{xo}}*\mathrm{Ew}_o=\lambda_{y1}*\mathrm{Ev}_1+\lambda_{y2}*\mathrm{Ev}_2+\lambda_{y3}*\mathrm{Ev}_3+\lambda_{y4}*\mathrm{Ev}_4$

2. Wheat Storage

2.1 Input supply to wheat storage

(A.11) $\mathrm{EY_{1o}}=\varepsilon_{\mathrm{y1o,v1o}}*(\mathrm{Ev_{1o}}-\mathrm{t_{y1o}})$

2.2 Output constrained input demands of wheat storage

(A.12) $EY_1=-\kappa_{y1o}*\sigma_{y1,y1o}*Ev_1+\kappa_{y1o}*\sigma_{y1,y1o}*Ev_{1o}+EZ^w$

(A.13) $\mathrm{EY}_{1o}=-\kappa_{\mathrm{y1}}*\sigma_{Y1o,Y1}*\mathrm{Ev}_{1o}+\kappa_{\mathrm{y1}}*\sigma_{\mathrm{y1o,y1}}*\mathrm{Ev}_1+\mathrm{EZ}^w$

2.3 Input constrained output supply of wheat storage

(A.14) $\mathrm{EZ}_1=-(\lambda_{z5}*\tau_{z1,z5}+\lambda_{z6}*\tau_{z1,z6})*\mathrm{Eu}_1+\lambda_{z5}*\tau_{z1,z5}*\mathrm{Eu}_5+\lambda_{z6}*\tau_{z1,z6}*\mathrm{Eu}_6+\mathrm{E}Y^w$

(A.15) $\mathrm{EZ}_5=-(\lambda_{z1}*\tau_{z5,z1}+\lambda_{z6}*\tau_{z5,z6})*\mathrm{Eu}_5+\lambda_{z1}*\tau_{z5,z1}*\mathrm{Eu}_1+\lambda_{z6}*\tau_{z5,z6}*\mathrm{Eu}_6+\mathrm{E}Y^w$

(A.16) $\mathrm{EZ}_6=-(\lambda_{z1}*\tau_{z6,z1}+\lambda_{z5}*\tau_{z6,z5})*\mathrm{Eu}_6+\lambda_{z1}*\tau_{z6,z1}*\mathrm{Eu}_1+\lambda_{z5}*\tau_{z6,z5}*\mathrm{Eu}_5+\mathrm{E}Y^w$

2.4 Equilibrium conditions

(A.17) $\kappa_{Y1} * EY_1 + \kappa_{Y1o} * EY_{1o} = \lambda_{Z1} * EZ_1 + \lambda_{Z5} * EZ_5 + \lambda_{Z6} * EZ_6$
(A.18) $\kappa_{v1} * Ev_1 + \kappa_{v1o} * Ev_{1o} = \lambda_{u1} * Eu_1 + \lambda_{u5} * Eu_5 + \lambda_{u6} * Eu_6$
2.5 Export Demand
(A.19) $EZ_1 = \eta_{z1,u1} * (Eu_1 - n_{z1})$

3. Barley Storage

3.1 Input supply to barley storage
(A.20) $EY_{2o} = \varepsilon_{y2o,v2o} * (Ev_{2o} - t_{y2o})$
3.2 Output constrained input demands of barley storage
(A.21) $EY_2 = -\kappa_{y2o} * \sigma_{y2,y2o} * Ev_2 + \kappa_{y2o} * \sigma_{y2,y2o} * Ev_{2o} + EZ^b$
(A.22) $EY_{2o} = -\kappa_{y2} * \sigma_{Y2o,Y2} * Ev_{2o} + \kappa_{y2} * \sigma_{y2o,y2} * Ev_2 + EZ^b$
3.3 Input constrained output supply of barley storage
(A.23) $EZ_2 = -(\lambda_{z7} * \tau_{z2,z7} + \lambda_{z8} * \tau_{z2,z8}) * Eu_2 + \lambda_{z7} * \tau_{z2,z7} * Eu_7 + \lambda_{z8} * \tau_{z2,z8} * Eu_8 + EY^b$
(A.24) $EZ_7 = -(\lambda_{z2} * \tau_{z7,z2} + \lambda_{z8} * \tau_{z7,z8}) * Eu_7 + \lambda_{z2} * \tau_{z7,z2} * Eu_2 + \lambda_{z8} * \tau_{z7,z8} * Eu_8 + EY^b$
(A.25) $EZ_8 = -(\lambda_{z2} * \tau_{z8,z2} + \lambda_{z7} * \tau_{z8,z7}) * Eu_8 + \lambda_{z2} * \tau_{z8,z2} * Eu_2 + \lambda_{z7} * \tau_{z8,z7} * Eu_7 + EY^b$
3.4 Equilibrium conditions
(A.26) $\kappa_{Y2} * EY_2 + \kappa_{Y2o} * EY_{2o} = \lambda_{Z2} * EZ_2 + \lambda_{Z7} * EZ_7 + \lambda_{Z8} * EZ_8$
(A.27) $\kappa_{v2} * Ev_2 + \kappa_{v2o} * Ev_{2o} = \lambda_{u2} * Eu_2 + \lambda_{u7} * Eu_7 + \lambda_{u8} * Eu_8$
3.5 Export Demand
(A.28) $EZ_2 = \eta_{z2,u2} * (Eu_2 - n_{z2})$

4. Canola Storage

4.1 Input supply to canola storage
(A.29) $EY_{3o} = \varepsilon_{y3o,v3o} * (Ev_{3o} - t_{y3o})$
4.2 Output constrained input demands of canola storage
(A.30) $EY_3 = -\kappa_{y3o} * \sigma_{y3,y3o} * Ev_3 + \kappa_{y3o} * \sigma_{y3,y3o} * Ev_{3o} + EZ^c$
(A.31) $EY_{3o} = -\kappa_{y3} * \sigma_{Y3o,Y3} * Ev_{3o} + \kappa_{y3} * \sigma_{y3o,y3} * Ev_3 + EZ^c$
4.3 Input constrained output supply of canola storage
(A.32) $EZ_3 = -\lambda_{z9} * \tau_{z3,z9} * Eu_3 + \lambda_{z9} * \tau_{z3,z9} * Eu_9 + EY^c$
(A.33) $EZ_9 = -\lambda_{z3} * \tau_{z9,z3} * Eu_9 + \lambda_{z3} * \tau_{z9,z3} * Eu_3 + EY^c$

4.4 Equilibrium conditions

(A.34) $\kappa_{Y4} * EY_4 + \kappa_{Y4o} * EY_{4o} = \lambda_{Z4} * EZ_4 + \lambda_{Z10} * EZ_{10}$

(A.35) $\kappa_{v4} * Ev_4 + \kappa_{v4o} * Ev_{4o} = \lambda_{u4} * Eu_4 + \lambda_{u10} * Eu_{10}$

4.5 Export Demand

(A.36) $EZ_3 = \eta_{z3,u3} * (Eu_3 - n_{z3})$

<u>5.Lupin Storage</u>

5.1 Input supply to lupin storage

(A.37) $EY_{4o}=\varepsilon_{y4o,v4o}*(Ev_{4o} - t_{y4o})$

5.2 Output constraints input demands of lupin storage

(A.38) $EY_4 = -\kappa_{y4o} * \sigma_{y4,y4o} * Ev_4 + \kappa_{y4o} * \sigma_{y4,y4o} * Ev_{4o} + EZ^l$

(A.39) $EY_{4o} = -\kappa_{y4} * \sigma_{Y4o,Y4} * Ev_{4o} + \kappa_{y4} * \sigma_{y4o,y4} * Ev_4 + EZ^l$

5.3 Input constrained output supply of lupin storage

(A.40) $EZ_4 = -\lambda_{z10} * \tau_{z4,z10} * Eu_4 + \lambda_{z10} * \tau_{z4,z10} * Eu_{10} + EY^l$

(A.41) $EZ_{10} = -\lambda_{z4} * \tau_{z10,z4} * Eu_{10} + \lambda_{z4} * \tau_{z10,z4} * Eu_4 + EY^l$

5.4 Equilibrium conditions

(A.42) $\kappa_{Y4} * EY_4 + \kappa_{Y4o} * EY_{4o} = \lambda_{Z4} * EZ_4 + \lambda_{Z10} * EZ_{10}$

(A.43) $\kappa_{v4} * Ev_4 + \kappa_{v4o} * Ev_{4o} = \lambda_{u4} * Eu_4 + \lambda_{u10} * Eu_{10}$

5.5 Export Demand

(A.44) $EZ_4 = \eta_{z4,u4} * (Eu_4 - n_{z4})$

<u>6. Flour Milling</u>

6.1 Input supply to flour milling

(A.45) $EF_o=\varepsilon_{Fo,go}*(Eg_o - t_{Fo})$

6.2 Output constrained input demand of flour milling

(A.46) $EZ_5 = -\kappa_{Fo} * \sigma_{Z5,Fo} * Eu_5 + \kappa_{Fo} * \sigma_{Z5,Fo} * Eg_o + EF$

(A.47) $EF_o = -\kappa_{Z5} * \sigma_{Fo,Z5} * Eg_o + \kappa_{Z5} * \sigma_{Fo,Z5} * Eu_5 + EF$

6.3 Input constrained output supply of flour milling

(A.48) $EF_1 = -\lambda_{F2} * \tau_{F1,F2} * Eg_1 + \lambda_{F2} * \tau_{F1,F2} * Eg_2 + EZ^f$

(A.49) $EF_2 = -\lambda_{F1} * \tau_{F2,F1} * Eg_2 + \lambda_{F1} * \tau_{F2,F1} * Eg_1 + EZ^f$

6.4 Equilibrium conditions

(A.50) $\kappa_{Z5} * EZ_5 + \kappa_{Fo} * EF_o = \lambda_{F1} * EF_1 + \lambda_{F2} * EF_2$

(A.51) $\kappa_{u5} * Eu_5 + \kappa_{go} * Eg_o = \lambda_{g1} * Eg_1 + \lambda_{g2} * Eg_2$

6.5 Domestic demand

(A.52) $EF_1 = \eta_{F1,g1}*(g_1 - n_{F1})$

7. Stockfeed Manufacturing

7.1 Input supply to stockfeed manufacturing

(A.53) $ES_o=\varepsilon_{So,to}*(Et_o - t_{So})$

7.2 Output constrained input demand of stockfeed manufacturing

(A.54) $EZ_6 = -(\kappa_{Z7} * \sigma_{Z6,Z7} + \kappa_{Z10} * \sigma_{Z6,Z10} + \kappa_{C1} * \sigma_{Z6,C1} + \kappa_{F2} * \sigma_{Z6,F2} + \kappa_{So} * \sigma_{Z6,So}) * Eu_6 + \kappa_{Z7} * \sigma_{Z6,Z7} * Eu_7 + \kappa_{Z10} * \sigma_{Z6,Z10} * Eu_{10} + \kappa_{C1} * \sigma_{Z6,C1} * Ed_1 + \kappa_{F2} * \sigma_{Z6,F2} * Eg_2 + \kappa_{So} * \sigma_{Z6,So} * Et_o + ES$

(A.55) $EZ_7 = -(\kappa_{Z6} * \sigma_{Z7,Z6} + \kappa_{Z10} * \sigma_{Z7,Z10} + \kappa_{C1} * \sigma_{Z7,C1} + \kappa_{F2} * \sigma_{Z7,F2} + \kappa_{So} * \sigma_{Z7,So}) * Eu_7 + \kappa_{Z6} * \sigma_{Z7,Z6} * Eu_6 + \kappa_{Z10} * \sigma_{Z7,Z10} * Eu_{10} + \kappa_{C1} * \sigma_{Z7,C1} * Ed_1 + \kappa_{F2} * \sigma_{Z7,F2} * Eg_2 + \kappa_{So} * \sigma_{Z7,So} * Et_o + ES$

(A.56) $EZ_{10} = -(\kappa_{Z6} * \sigma_{Z10,Z6} + \kappa_{Z7} * \sigma_{Z10,Z7} + \kappa_{C1} * \sigma_{Z10,C1} + \kappa_{F2} * \sigma_{Z10,F2} + \kappa_{So} * \sigma_{Z10,So}) * Eu_{10} + \kappa_{Z6} * \sigma_{Z10,Z6} * Eu_6 + \kappa_{Z7} * \sigma_{Z10,Z7} * Eu_7 + \kappa_{C1} * \sigma_{Z10,C1} * Ed_1 + \kappa_{F2} * \sigma_{Z10,F2} * Eg_2 + \kappa_{So} * \sigma_{Z10,So} * Et_o + ES$

(A.57) $EC_1 = -(\kappa_{Z6} * \sigma_{C1,Z6} + \kappa_{Z7} * \sigma_{C1,Z7} + \kappa_{Z10} * \sigma_{C1,Z10} + \kappa_{F2} * \sigma_{C1,F2} + \kappa_{So} * \sigma_{C1,So}) * Ed_1 + \kappa_{Z6} * \sigma_{C1,Z6} * Eu_6 + \kappa_{Z7} * \sigma_{C1,Z7} * Eu_7 + \kappa_{Z10} * \sigma_{C1,Z10} * Eu_{10} + \kappa_{F2} * \sigma_{C1,F2} * Eg_2 + \kappa_{So} * \sigma_{C1,So} * Et_o + ES$

(A.58) $EF_2 = -(\kappa_{Z6} * \sigma_{F2,Z6} + \kappa_{Z7} * \sigma_{F2,Z7} + \kappa_{Z10} * \sigma_{F2,Z10} + \kappa_{C1} * \sigma_{F2,C1} + \kappa_{So} * \sigma_{F2,So}) * Eg_2 + \kappa_{Z6} * \sigma_{F2,Z6} * Eu_6 + \kappa_{Z7} * \sigma_{F2,Z7} * Eu_7 + \kappa_{Z10} * \sigma_{F2,Z10} * Eu_{10} + \kappa_{C1} * \sigma_{F2,C1} * Ed_1 + \kappa_{So} * \sigma_{F2,So} * Et_o + ES$

(A.59) $ES_o = -(\kappa_{Z6} * \sigma_{So,Z6} + \kappa_{Z7} * \sigma_{So,Z7} + \kappa_{Z10} * \sigma_{So,Z10} + \kappa_{C1} * \sigma_{So,C1} + \kappa_{F2} * \sigma_{So,F2}) * Et_o + \kappa_{Z6} * \sigma_{F2,Z6} * Eu_6 + \kappa_{Z7} * \sigma_{F2,Z7} * Eu_7 + \kappa_{Z10} * \sigma_{F2,Z10} * Eu_{10} + \kappa_{C1} * \sigma_{F2,C1} * Ed_1 + \kappa_{So} * \sigma_{F2,So} * Et_o + ES$

7.3 Input constrained output supply of stockfeed manufacturing

(A.60) $ES_1 = -\lambda_{S2} * \tau_{S1,S2} * Et_1 + \lambda_{S2} * \tau_{S1,S2} * Et_2 + EZ^s$

(A.61) $ES_2 = -\lambda_{S1} * \tau_{S2,S1} * Et_2 + \lambda_{S1} * \tau_{S2,S1} * Et_1 + EZ^s$

7.4 Equilibrium conditions

(A.62) $\kappa_{Z6} * EZ_6 + \kappa_{Z7} * EZ_7 + \kappa_{Z10} * EZ_{10} + \kappa_{C1} * EC_1 + \kappa_{F2} * EF_2 + \kappa_{So} * ES_o = \lambda_{S1} * ES_1 + \lambda_{S2} * ES_2$

(A.63) $\kappa_{u6} * Eu_6 + \kappa_{u7} * Eu_7 + \kappa_{u10} * Eu_{10} + \kappa_{d1} * Ed_1 + \kappa_{g2} * Eg_2 + \kappa_{to} * Et_o = \lambda_{t1} * Et_1 + \lambda_{t2} * Et_2$

7.5 Export demand

(A.64) $ES_1 = \eta_{S1,t1}*(t_1 - n_{S1})$

7.6 Domestic demand

(A.65) $\mathrm{ES}_2 = \eta_{S2,t2}$*$(\mathrm{t}_2 - n_{S2})$

8. Malt Manufacturing

8.1 Input supply to stockfeed manufacturing

(A.66) $\mathrm{EM_o}$=$\varepsilon_{\mathrm{Mo,no}}$*$(\mathrm{En_o} - \mathrm{t_{Mo}})$

8.2 Output constrained input demand of malt manufacturing

(A.67) $\mathrm{EZ}_8 = -\kappa_{\mathrm{Mo}} * \sigma_{\mathrm{Z8,Mo}} * \mathrm{Eu}_8 + \kappa_{\mathrm{Mo}} * \sigma_{\mathrm{Z8,Mo}} * \mathrm{En_o} + \mathrm{EM}$

(A.68) $\mathrm{EM_o} = -\kappa_{\mathrm{Z8}} * \sigma_{\mathrm{Mo,Z8}} * \mathrm{En}_o + \kappa_{\mathrm{Z8}} * \sigma_{\mathrm{Mo,Z8}} * \mathrm{Eu}_8 + \mathrm{EM}$

8.3 Input constrained output supply of malt manufacturing

(A.69) $\mathrm{EM}_1 = -\lambda_{M2} * \tau_{M1,M2} * \mathrm{En}_1 + \lambda_{M2} * \tau_{M1,M2} * \mathrm{En}_2 + \mathrm{EZ^m}$

(A.70) $\mathrm{EM}_2 = -\lambda_{M1} * \tau_{M2,M1} * \mathrm{En}_2 + \lambda_{M1} * \tau_{M2,M1} * \mathrm{En}_1 + \mathrm{EZ^m}$

8.4 Equilibrium conditions

(A.71) $\kappa_{\mathrm{Z8}} * \mathrm{EZ}_8 + \kappa_{\mathrm{Mo}} * \mathrm{EM_o} = \lambda_{M1} * \mathrm{EM}_1 + \lambda_{M2} * \mathrm{EM}_2$

(A.72) $\kappa_{\mathrm{u8}} * \mathrm{Eu}_8 + \kappa_{\mathrm{no}} * \mathrm{En_o} = \lambda_{n1} * \mathrm{En}_1 + \lambda_{n2} * \mathrm{En}_2$

8.5 Export demand

(A.73) $\mathrm{EM}_1 = \eta_{M1,t1}$*$(\mathrm{t}_1 - n_{M1})$

8.6 Domestic demand

(A.74) $\mathrm{EM}_2 = \eta_{M2,t2}$*$(\mathrm{t}_2 - n_{M2})$

9. Oilseed Crushing and Refining

9.1 Input supply to oilseed crushing and refining

(A.75) $\mathrm{EC_o}$=$\varepsilon_{\mathrm{Co,do}}$*$(\mathrm{Ed_o} - \mathrm{t_{Co}})$

9.2 Output constrained input demand of oilseed crushing and refining

(A.76) $\mathrm{EZ}_9 = -\kappa_{\mathrm{Co}} * \sigma_{\mathrm{Z9,Co}} * \mathrm{Eu}_9 + \kappa_{\mathrm{Co}} * \sigma_{\mathrm{Z9,Co}} * \mathrm{Ed_o} + \mathrm{EC}$

(A.77) $\mathrm{EC_o} = -\kappa_{\mathrm{Z9}} * \sigma_{\mathrm{Co,Z9}} * \mathrm{Ed}_o + \kappa_{\mathrm{Z9}} * \sigma_{\mathrm{Co,Z9}} * \mathrm{Eu}_9 + \mathrm{EC}$

9.3 Input constrained output supply of oilseed crushing and refining

(A.78) $\mathrm{EC}_1 = -(\lambda_{C2} * \tau_{C1,C2} + \lambda_{C3} * \tau_{C1,C3}) * \mathrm{Ed}_1 + \lambda_{C2} * \tau_{C1,C2} * \mathrm{Ed}_2 + \lambda_{C3} * \tau_{C1,C3} * \mathrm{Ed}_3 + \mathrm{EZ^c}$

(A.79) $\mathrm{EC}_2 = -(\lambda_{C1} * \tau_{C2,C1} + \lambda_{C3} * \tau_{C2,C3}) * \mathrm{Ed}_2 + \lambda_{C1} * \tau_{C2,C1} * \mathrm{Ed}_1 + \lambda_{C3} * \tau_{C2,C3} * \mathrm{Ed}_3 + \mathrm{EZ^c}$

(A.80) $\mathrm{EC}_3 = -(\lambda_{C1} * \tau_{C3,C1} + \lambda_{C2} * \tau_{C3,C2}) * \mathrm{Ed}_3 + \lambda_{C1} * \tau_{C3,C1} * \mathrm{Ed}_1 + \lambda_{C2} * \tau_{C3,C2} * \mathrm{Ed}_2 + \mathrm{EZ^c}$

9.4 Equilibrium conditions

(A.81) $\kappa_{Z9} * \mathrm{EZ}_9 + \kappa_{\mathrm{Co}} * \mathrm{EC}_{\mathrm{o}} = \lambda_{C1} * \mathrm{EC}_1 + \lambda_{C2} * \mathrm{EC}_2$
(A.82) $\kappa_{\mathrm{u}9} * \mathrm{Eu}_9 + \kappa_{\mathrm{do}} * \mathrm{Ed}_{\mathrm{o}} = \lambda_{d1} * \mathrm{Ed}_1 + \lambda_{d2} * \mathrm{Ed}_2$

9.5 Export demand

(A.83) $\mathrm{EC}_2 = \eta_{C2,d2}$*$(\mathrm{d}_2 - n_{C2})$

9.6 Domestic demand

(A.84) $\mathrm{EC}_3 = \eta_{C2,d2}$*$(\mathrm{d}_2 - n_{d2})$