Measuring the Returns to Investment in Research and Development in the Australian Grains Industry

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Contributed paper prepared for presentation at the 61st AARES Annual Conference, Brisbane, Queensland, 8–10 February 2017

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Abstract

Equilibrium Displacement Models (EDMs) are useful for estimating the net benefits of agricultural R&D and the distribution of benefits between producers and other participants in the value chain. Information from these models can assist investment decisions of R&D funders. In Australia, EDMs have been developed for various livestock industries and the wine industry. An EDM is needed for the Australian grains industry. In this paper, the Equilibrium Displacement Modelling method is reviewed in the context of constructing an EDM of the Australian grains industry. Key principles and challenges are identified. As a first step a pilot EDM for the WA grains industry is constructed and presented; a prelude to building an Australia-wide grains industry EDM.

1. Introduction

The relationship between investments in agricultural R&D and agricultural productivity has been long studied. Governments and funding agencies are bound to demonstrate the potential welfare impacts of research programs to justify their investments, as well as to prioritise future research. However, estimating the economic benefits of investment in agricultural R&D and the distribution of net benefits has conceptual, methodical and practical challenges.

Equilibrium Displacement Models (EDMs) can be used to evaluate the returns to R&D and the distribution of benefits for different participants along the value chain. EDMs have previously been developed and applied in other agricultural industries, mostly in the livestock industries. An EDM is now needed for the Australian grains industry, an industry which represents around 26 per cent of Australia's agricultural exports (ABARES, 2015). The reasons are partly because of the complex nature of the grains industry.

The grains industry in Australia produces cereal grains, oilseeds and pulses, often also associated with livestock production. These grains are grown in the northern, southern, and western cropping regions of the country, in crop sequences to meet agronomic and other farm system and farm business criteria. The grain supply chain has multiple stages and end uses: production, on and off-farm storage and transport, marketing, processing and exporting. The relationships of different grains in crop rotations and in competing end uses, as well as numerous alternative supply chains across the three different production regions, add scale and complexity to the challenges of constructing a grains industry EDM. Furthermore, 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, Griffith, Nightingale, & Piggott, 2004).

[1] The authors would like to express their gratitude to the GRDC for sponsoring the research project and the University of Melbourne for their research support. The authors would also like to thank Dr. Vilaphonh Xayavong from the Department of Agriculture and Food, Western Australia for his support on the project.

This paper proceeds as follows: in Section 2 the EDM framework, including its characteristics, benefits and limitations, is reviewed. Section 3 is an overview of the grains industry, describing the major commodity types and their markets, the supply chain, and the processes in grain production. Section 4 details the elasticities associated with an EDM for grains. Section 5 presents a prototype EDM for the WA grains industry and Section 6 explores the static nature of an EDM and its treatment of relevant dynamics that affect adjustment towards equilibrium. Section 7 discusses the importance of verifying the assumption of perfectly competitive markets in the development of an EDM for the grains industry. Summary and conclusions are presented in Section 8.

2. Review of the EDM Framework

Equilibrium Displacement Models have been used in applied economic analysis for decades because of their strong theoretical foundation and non-data intensive requirements. Rather than requiring extensive time series data, EDMs require only base data about equilibrium price and quantity for a representative or average year, along with estimates of price elasticities of supply and demand, and expenditure shares obtainable from published work or expert opinion. The EDM framework is a comparative static framework. An EDM does not rely on functional forms as the equations are expressed in terms of relative changes and elasticities, hence are linear. The method gives reliable estimates for small shifts in equilibrium.

The process of constructing an EDM involves first characterising the market structure of the industry by a set of supply and demand equations. No functional forms are assumed for these equations. Next, the market is 'shocked' 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 elasticity. An EDM differs from other comparative static approaches as it is 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 applications, the industry of interest consists of a multi-stage production system made up of many horizontal and vertical market segments. This can be shown by the supply chain representation of agricultural commodities in Figure 1 below. With an understanding of the industry's market segments, EDMs can capture the distribution of welfare effects on all individuals in markets along the supply chain.

As noted by Borrell, Jiang, Pearce, and Gould (2014), the benefits and distribution of benefits from R&D along the supply chain depend on the market characteristics of the supply chain and the assumptions made about these characteristics. Estimates of the size and distribution of net benefits of a change in productivity resulting from investing in R&D depend particularly on:

(1) the type and nature of the change caused by successful R&D;

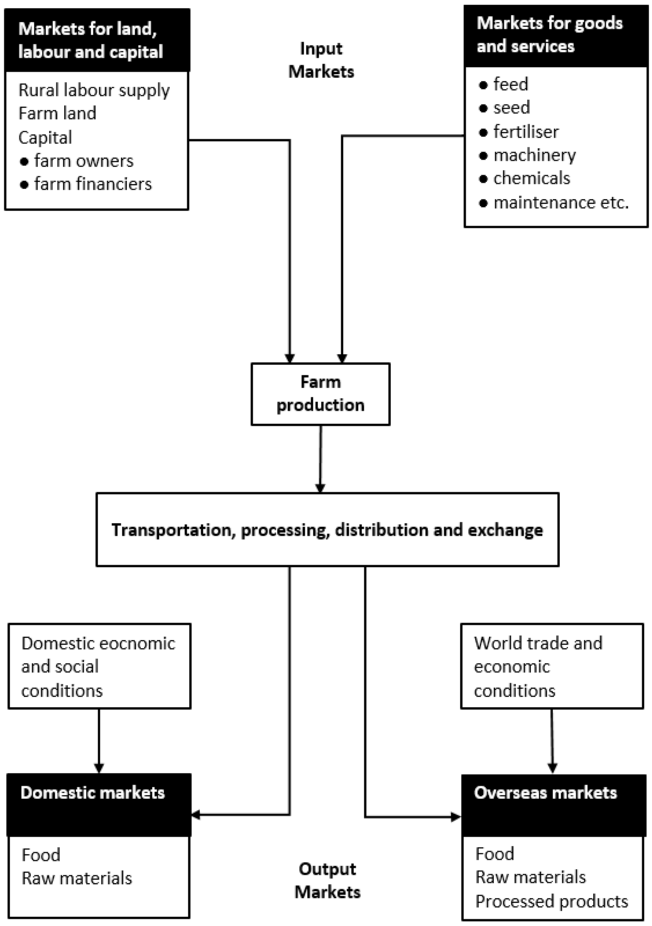
(2) where change occurs along the supply chain;

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

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

The output of a grains industry EDM will be only as valid as the accuracy of the estimates of these variables, with the distribution of welfare changes along the value chain being different according to the nature of the change caused by R&D, as well as where the change occurs.

Figure 1. Marketing channels for agricultural commodities



Source: Malcolm et al. (2009)

EDMs have been used to estimate the possible impacts of new policies in the Australian livestock industry, with EDMs having been developed for a number of industries such as the beef industry (Zhao, Mullen, Griffith, Griffiths, & Piggott, 2000), sheep and wool Industry (Mounter, Griffith, Piggott, Fleming, & Zhao, 2008), pig industry (Mounter, Griffith, & Piggott, 2004), and dairy industry (Liu, Tarrant, Ho, Malcolm, & Griffith, 2012; Ludemann, Griffith, Smith, & Malcolm, n.d.). In addition, EDMs and other associated models have also been developed for the winegrapes and wine industry (e.g. Zhao, Anderson, & Wittwer, 2002).

3. The Australian Grains Industry

Grains are one of the most important staple foods in the world, both directly for human consumption and indirectly as input to livestock production.

In Australia, grains are one of the most important groups of agricultural commodities. In 2014-15, Australian broadacre cropping was valued at $13.9 billion at the farm-gate). Over $11 billion worth of exports was recorded during 2014-15 for the three main categories of grains – cereal grains, oilseeds and pulses (grain legumes), representing around 26 per cent of total agricultural exports during 2014-15 (ABARES, 2015).

The Australian grains industry has grown markedly over the past 30 years, a result of changing markets and an annual growth in total factor productivity of 1.9 per cent on average (GRDC, 2011). Increases in agricultural productivity lead to either more output produced with the same level of measured inputs, or the same amount of output being produced with a smaller quantity of measured inputs. One of the key determinants of growth in total factor productivity is investments in R&D which generate greater knowledge (Khan et al., 2017), with the benefits of research-induced knowledge contributing to:

- improved farming management
- new plant varieties
- improved crop rotations
- better disease, weed and pest control, and
- advances in cropping technology.

The grains industry has challenges. Since the 1990s its rate of annual growth in total factor productivity has declined by an average of 0.9 per cent each year from the period 1993-94 to 2007-08 (GRDC, 2011). This slowing of growth in productivity has been attributed to the adverse impacts of a warming climate and more frequent extreme weather events, a decline in expenditure on research, development and extension, and a slower adoption of new technologies (Hockman, Gobbett, & Horan, 2017; GRDC, 2011). Recognising the need for improvement in order to maintain international competitiveness, the Grains Industry Research, Development and Extension Strategy aims to achieve an annual growth in total factor productivity of more than 2.5 per cent by 2025 (GRDC, 2014). Such an achievement would require greater and better-targeted investments in R&D.

Allocating funding to R&D poses challenges and trade-offs. Decisions must be made about how much scarce funding to allocate to research projects, with different investment decisions having different potential distributional effects. The GRDC (2014) noted that 'the modest size of Australia's RD&E budget in the global context dictates that investment decisions must be strategic to achieve the best effect in industry innovation.' To evaluate the merits of a particular research investment, it is necessary to know the total size of the benefits stemming from research, and also the distribution of benefits and costs among the participants in the whole value chain. An EDM framework helps answer these questions.

3.1 Scope of the Industry

Modelling the grains industry of Australia is made complex by the scope of the industry. The industry comprises of numerous grains types forming three main categories: cereal grains, oilseeds and pulses (grain legumes).

Climate, weather patterns and soils mean Australian grain production can be divided into three grain cropping regions – northern, southern, and western, and two crop growing times– winter and summer (GRDC, n.d.; Australian Grain, 2013).

The northern cropping region encompasses central to southern Queensland through to northern New South Wales. Climate and soil characteristics enable summer and winter crops to be grown. The northern region has the highest diversity of crop production spanning across an entire year, with summer crops including maize, sorghum, and tropical pulses, and winter crops consisting of wheat, barley, winter-pulses and oilseeds (GRDC, n.d.).

The southern cropping region encompasses the Mediterranean and Temperate climates of south-eastern Australia, including central and southern New South Wales, Victoria, Tasmania and south-eastern South Australia. Dry summers are generally characteristic of the southern cropping region. Rainfall in Victoria, Tasmania and South Australia is winter dominated (Australia Grain, 2013), becoming more uniform by month when moving into NSW. Crop yields depend on seasonal rainfall with soils typically having low fertility.

The western cropping region is situated in southern Western Australia that experiences dry summers and mild wet winters. Base soil fertility is generally low in this region. The main crops produced are wheat, barley, canola, and lupins (GRDC, n.d.).

The main grains grown in Australia are shown in Tables 1 and 2. Over 23 million hectares of crops were sown in 2015-16, with the vast majority being winter crops. Wheat is Australia's largest grain crop representing around 55% of total grains produced. This is followed by barley at 19% of total grain grown.

Table 1. Australian winter crop production and area

Crop	Area			Production		
	2013–14	2014–15 s	2015–16 s	2013–14	2014–15 s	2015–16 s
	'000 ha	'000 ha	'000 ha	kt	kt	kt
Wheat	12 613	12 155	12 728	25 303	23 076	24 219
Barley	3 814	3 912	4 100	9 174	8 173	8 490
Canola	2 721	2 824	2 357	3 832	3 447	2 945
Chickpeas	508	425	661	629	555	1 013
Faba beans	152	164	282	328	284	319
Field peas	245	237	238	342	290	205
Lentils	170	189	232	254	242	258
Lupins	387	443	490	626	549	607
Oats	715	869	863	1 255	1 184	1 249
Triticale	80	126	117	126	225	191

s ABARES estimate.
Note: Crop year refers to crops planted during the 12 months to 31 March. Slight discrepancies may appear between tables as a result of including the Australian Capital Territory and the Northern Territory in Australian totals.
Source: Australian crop report, February 2016, ABARES; Australian Bureau of Statistics; Pulse Australia

Table 2. Australian summer crop production and area

Crop	Area			Production		
	2013–14	2014–15 s	2015–16 f	2013–14	2014–15 s	2015–16 f
	'000 ha	'000 ha	'000 ha	kt	kt	kt
Grain sorghum	532	730	712	1 282	2 178	2 240
Cottonseed	392	197	270	1 252	730	772
Cotton lint	392	197	270	885	516	546
Rice	75	71	31	819	724	305
Corn (maize)	52	67	66	390	401	420
Soybeans	25	32	32	32	68	64
Sunflower	17	35	36	18	40	46

f ABARES forecast. **s** ABARES estimate.
Note: Crop year refers to crops planted during the 12 months to 31 March. Slight discrepancies may appear between tables as a result of including the Australian Capital Territory and the Northern Territory in Australian totals.
Sources: Australian crop report, February 2016, ABARES; Australian Bureau of Statistics

Most grain crops have multiple end uses, domestically and overseas (as exports). Grain production underpins the Australian food processing sector, including wheat products such as breads, noodles, pastas. Other grains such as barley are used for malting and brewing. Altogether, the milling, malting and brewing sectors in Australia generate an annual gross revenue of around $6.6 billion (GRDC, 2014). Coarse grains such as maize and sorghum are predominantly used as animal feed for Australia's grain-fed beef, dairy, pork and poultry, 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.

4. Price Elasticities

An EDM uses price elasticity estimates for each market of the industry. These estimates reflect the nature of the demand, supply, input substitution and product transformation processes in each market. These elasticities describe the market responsiveness of quantity variables to price changes. As shown in section 3.1, different types of elasticities are included in the specification of the EDM. Obtaining empirical estimates of elasticities is one of the most crucial aspects of an EDM – setting different elasticity values in the model generates different simulated results and yields different conclusions.

Values of these elasticities can be derived from economic theory, existing econometric estimations or expert opinion. Historically robust estimates of many elasticities have been difficult to obtain, hence many studies rely on expert opinion and subjective judgements about price elasticities of supply and demand. Estimates of agricultural elasticities also vary substantially in terms of factors such as geographic coverage, length of run, sample periods, estimation method, functional form, and explanatory variables used in the estimation process (Griffith & I'Anson, 2001).

In addition, the magnitudes of elasticities depend largely on where in the marketing chain the elasticity is being measured. For instance, marketing intermediaries such as processors and retailers have their own production technologies and will also respond to changes in relative prices. This will alter consumer demand down the marketing chain, to the point where it is unlikely the derived demand elasticities for the primary product will match consumer demand (Asche, Flaaten, Isaksen, & Vassdal, 2002; Hartmann, Jaffry, & Asche, 2001). For instance, prices elasticities at 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. Discussion of estimated elasticities used in the construction of the grains EDM follows.

4.1 Demand Elasticities

The main price elasticities of demand used in an EDM are own-price elasticities of demand and cross-price elasticities of demand.

Own price elasticities of demand indicate the degree to which a buyers respond to purchases of a particular product as the price of that product rises or falls. The steepness of the demand curve is a visual representation of the elasticity of demand for a grain commodity, and changes to demand in response to own-prices can be depicted as movements along a demand curve.

Ulubasoglu, Mallick, Wadud, Hone, and Haszler (2015) highlight that the majority of studies of food demand elasticities focus on aggregate food categories (e.g. food, grains), whereas demand elasticities for disaggregated food categories (e.g. wheat, barley, oats) often are lacking. Most studies also focus on the retail demand side rather than export demand.

Table 3 provides a summary of some relevant own-price elasticities of demand for grains. Most of these estimated elasticities are for grain products measured with retail prices rather than farm gate prices.

As can be seen from the table, the estimated domestic own-price demand elasticities vary depending on the type of grain product, ranging from -0.115 to -2.657. Both Seale, Regmi, and Bernstein (2003) and Ulubasoglu et al. (2015) found bread and cereal products to be price inelastic, whereas rice was found to be highly price elastic, suggesting rice to be less of a staple food in Australian households than bread. Although there is a lack of empirical studies measuring demand elasticities at other stages of the value chain for other value chain participants, it is generally understood that demand at the farm gate tends to be more inelastic than demand at the retail level. This is because it is easier to find close substitutes for products at the retail level.

Studies examining export demand elasticities for Australian grains are scarce. Australian grain sellers on export markets are largely regarded as being price takers (Alston, Freebairn & James, 2004) so the consensus is that export demand is elastic.

Table 3. Own-price elasticities of demand

Commodity	Source	Data	Model and estimation	Estimates
Bread and cereals	Seale et al. (2003)	1996 Cross-country data	Florida–Slutsky, ML, Frish	-0.115
Bread (all Australian households)	Ulubasoglu et al. (2015)	1998-1999 / 2003-2004 national Household Expenditure Surveys	Almost Ideal Demand System	-0.733
Rice (all Australian households)	Ulubasoglu et al. (2015)	1998-1999 / 2003-2004 national Household Expenditure Surveys	Almost Ideal Demand System	-2.657

The cross price elasticity of demand measures the responsiveness of quantity demanded for one good from a change in price of another and is reflected by shifts in the demand curve. Negative cross-price elasticities indicate that goods are substitutes, whereas positive elasticities indicate goods are complements. Ulubasoglu et al. (2015) found that bread and rice were substitutes. The cross price elasticity of demand for rice with respect to a change in the price of bread was 0.15, and the cross price elasticity of demand for bread with respect to a change in price of rice was 1.57. Austin (1977) investigated the demand for feed grain in Australia and found the cross price elasticity of demand for wheat with respect to a change in the price of substitute feed grains was 1.447.

4.2 Factor Supply Elasticities

In an EDM, factor price elasticities of supply for exogenous inputs are needed in each sector of the model. Factor inputs exogenous to the EDM typically include land, labour, capital and fertiliser. In most instances, only own-price elasticities of supply are required in the EDM. The own-price elasticity of supply for factor inputs indicates how much the supply of the factor input changes in response to a change in the price of the input. There are limited empirical estimates for these factor inputs in Australian agriculture. Most previous EDM studies have often aggregated these all 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, Anderson, and Wittwer (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 be 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 been able to provide any consensus around elasticities for labour supply in agriculture. This is especially difficult to model given the income and substitution 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, with a plausible base value being 0.5. Other studies suggest the elasticity of labour supply to be 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.

4.3 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 input substitution elasticity. As emphasised by Alston and Scobie (1983) in their comment on Freebairn, Davis, and Edwards (1982), the elasticity of substitution 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, and the distribution of benefits is independent of where the shock is applied in the system (Freebairn, David, & Edwards, 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 increases.

Different measures of input substitutability are stated 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 input substitution elasticities in the model has implications for results. Even a small degree of input substitution can have a large effect on the distribution of research benefits (Alston and Scobie 1983).

Sheng, Davidson, and Fuglie (2014) used the Hicks-neutral approach to estimate the elasticity of substitution between inputs. The approach used farm data from the 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, concluding 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.

Input substitution elasticities can vary between different agricultural zones. This is because of the variation in production techniques. For example, as pointed out by Dixon, Parmenter, Sutton, and Vincent (1982), 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 has to account for these distinctions, though this can be made difficult by the lack of empirical data on substitution elasticities for specific agricultural zones.

4.4 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 which vary the mix of crops grown across years and across a farm. Many crops, to some degree, are substitutes in consumption – for instance, wheat and barley can both be used in animal feed. Other crops are complements because they are interdependent in the crop rotation – for instance, an oilseed such as canola is a disease and weed break crop in a rotation with cereal crops. 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 planting window, as well as balancing risks according to goals to do with income stability and (ii) internal factors such as technical roles of crops in a rotation, weed and pest burdens and particular suitability of crops to the land areas available for crop in any year.

Powell and Gruen (1968) defined 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, it measures 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.

5. EDM of the WA Grains Industry

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

As a starting point, a simplified EDM for the WA grains industry has been constructed and tested. This EDM aims to serve as a first step in developing a comprehensive model of the entire Australian grains industry. Western Australia is a winter cropping region that produces around 10 million tonnes of grain each year, with the majority of this being wheat (around 70%), followed by barley, canola, oats, lupins and peas (Department of Agriculture and Food, 2016). Conceptually, the WA grains industry is more straightforward as it export-oriented principally, with around 85-95% of total annual grain production exported to various countries in Asia and the Middle-East (Stretch, Carter, & Kingwell, 2014).

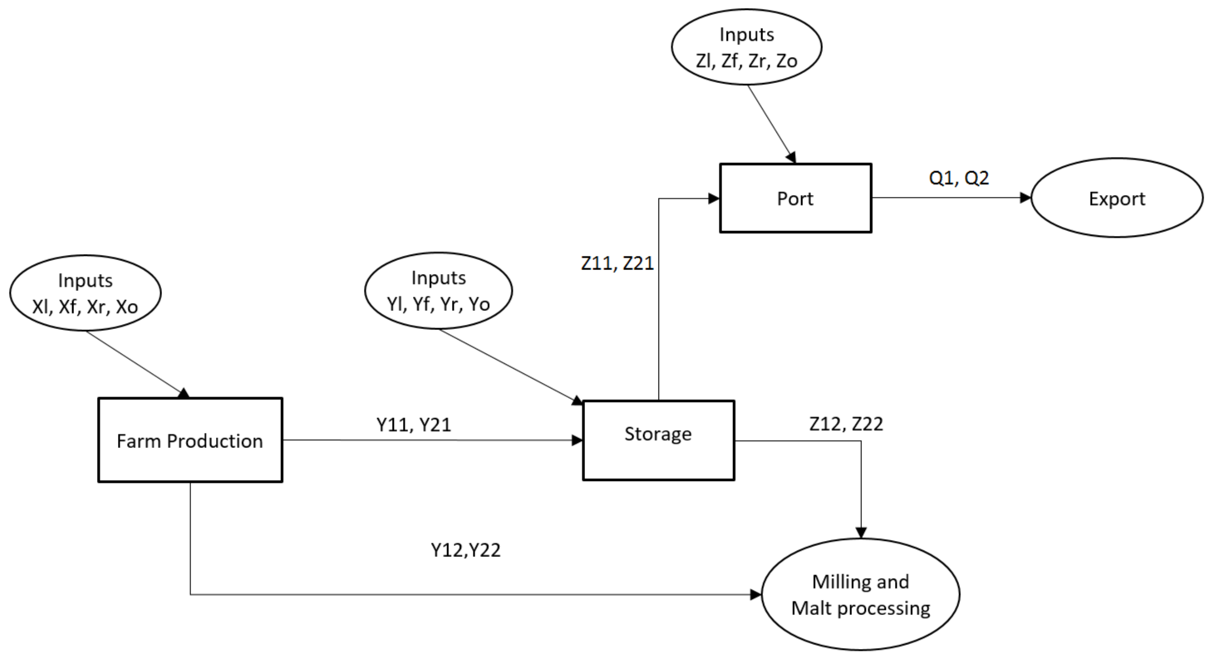
5.1 Horizontal and vertical market segments

The WA grains industry consists of several market segments along the supply chain. The majority of grain destined for export is first transported from farm to storage at upcountry receival sites. 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. In WA, the CBH is the main handler of grain owning a network of 197 receival points. It also operates all four main port terminals in WA (Stretch et al., 2014). Bunge operates a 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 R&D, 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, port and domestic consumption sectors. Horizontally, the industry is disaggregated into the production of grains for both export and domestic use. For simplicity at this stage, the entire industry has been modelled as producing only wheat and barley.

Figure 2. Model Structure



5.2 Model Structure

The equations for the model follow the specifications of Mounter et al. (2004) and Zhao et al. (2000).

From Figure 2, there are three industry sectors (farm production, storage, port) whose multi-output production functions and decision making problems can be specified completely within the model.

The product transformation functions for these three industry sectors can be written as follows:

(1) $\mathrm{Y}(\mathrm{Y}_{11}, \mathrm{Y}_{21}, \mathrm{Y}_{12}, \mathrm{Y}_{22}) = \mathrm{X}(\mathrm{X}_{\mathrm{l}}, \mathrm{X}_{\mathrm{f}}, \mathrm{X}_{\mathrm{r}}, \mathrm{X}_{\mathrm{o}})$ *farm production*
(2) $\mathrm{Z}(\mathrm{Z}_{11}, \mathrm{Z}_{21}, \mathrm{Z}_{12}, \mathrm{Z}_{22}) = \mathrm{Y}(\mathrm{Y}_{11}, \mathrm{Y}_{21}, \mathrm{Y}_{l}, \mathrm{Y}_{f}, \mathrm{Y}_{r}, \mathrm{Y}_{o})$ *storage*
(3) $\mathrm{Q}(\mathrm{Q}_{1}, \mathrm{Q}_{2},) = \mathrm{Z}(\mathrm{Z}_{11}, \mathrm{Z}_{21}\mathrm{Z}_{l}, \mathrm{Z}_{f}, \mathrm{Z}_{r}, \mathrm{Z}_{o})$ *port*

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. All the notation representing the variables and parameters in the model are defined in in Table 4.

Cost functions related to these production functions are written as:

(4) $\mathrm{C}_{\mathrm{Y}} = \mathrm{Y} * \mathrm{c}_{\mathrm{Y}}(\mathrm{w}_{l}, w_{f}, w_{r}, w_{o})$ *farm production*
(5) $\mathrm{C}_{\mathrm{Z}} = \mathrm{Z} * \mathrm{c}_{\mathrm{Z}}(\mathrm{v}_{11}, \mathrm{v}_{21}\ \mathrm{v}_{l}, \mathrm{v}_{f}, \mathrm{v}_{r}, \mathrm{v}_{o})$ *storage*
(6) $\mathrm{C}_{\mathrm{Q}} = \mathrm{Q} * \mathrm{c}_{\mathrm{Q}}(\mathrm{u}_{11}, \mathrm{u}_{21}\ \mathrm{u}_{l}, \mathrm{u}_{f}, \mathrm{u}_{r}, \mathrm{u}_{o})$ *port*

where C_{x} denotes the total cost of producing output index x and c_{x} stands for the unit cost function. Quantities are represented by capital letters and prices by lower case letters.

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

(7) $\mathrm{R}_{\mathrm{X}} = \mathrm{X} * \mathrm{r}_{\mathrm{X}}(\mathrm{v}_{11}, \mathrm{v}_{21}, \mathrm{v}_{12}, \mathrm{v}_{22})$ *farm production*
(8) $\mathrm{R}_{\mathrm{Y}} = \mathrm{Y} * \mathrm{c}_{\mathrm{Y}}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_{12}, \mathrm{u}_{22})$ *storage*
(9) $\mathrm{R}_{\mathrm{Z}} = \mathrm{Z} * \mathrm{c}_{\mathrm{Z}}(\mathrm{p}_{1}, \mathrm{p}_{2})$ *port*

Next, the equations representing the EDM of the WA grains industry are specified. There are 50 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 18 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 impact of new technologies and promotion. These equations expressed in general form as follows:

<u>*Input supply to farm sector*</u>

(10) $\mathrm{X}_{l} = \mathrm{X}_{l}(\mathrm{w}_{l}, T\mathrm{X}_{l})$
(11) $\mathrm{X}_{f} = \mathrm{X}_{f}(\mathrm{w}_{f}, T\mathrm{X}_{f})$
(12) $\mathrm{X}_{r} = \mathrm{X}_{r}(\mathrm{w}_{r}, T\mathrm{X}_{r})$
(13) $\mathrm{X}_{o} = \mathrm{X}_{o}(\mathrm{w}_{o}, T\mathrm{X}_{l})$

<u>*Output-constrained input demand of farm sector*</u>

(14) $\mathrm{X}_{l} = Y^{o} * c'_{YO,Xl}(\mathrm{w}_{l}, w_{f}, w_{r}, w_{o})$
(15) $\mathrm{X}_{f} = Y^{o} * c'_{YO,Xf}(\mathrm{w}_{l}, w_{f}, w_{r}, w_{o})$
(16) $\mathrm{X}_{r} = Y^{o} * c'_{YO,Xr}(\mathrm{w}_{l}, w_{f}, w_{r}, w_{o})$
(17) $\mathrm{X}_{o} = Y^{o} * c'_{YO,Xo}(\mathrm{w}_{l}, w_{f}, w_{r}, w_{o})$

Input-constrained output supply of farm enterprises

(18) $Y_{11} = X * r'_{X,Y11}(v_{11}, v_{21}, v_{12}, v_{22})$
(19) $Y_{21} = X * r'_{X,Y21}(v_{11}, v_{21}, v_{12}, v_{22})$
(20) $Y_{12} = X * r'_{X,Y12}(v_{11}, v_{21}, v_{12}, v_{22})$
(21) $Y_{22} = X * r'_{X,Y22}(v_{11}, v_{21}, v_{12}, v_{22})$

Equilibrium conditions of farm enterprises

(22)$\mathrm{X}(\mathrm{X_l}, \mathrm{X_f}, \mathrm{X_r}, \mathrm{X_o}) = \mathrm{Y}(\mathrm{Y_{11}}, \mathrm{Y_{21}}, \mathrm{Y_{12}}, \mathrm{Y_{22}})$
(23)$c_Y(\mathrm{w}_l, w_f, w_r, w_o) = r_X(v_{11}, v_{21}, v_{12}, v_{22})$

Milling and malt processing demand

(24) $\mathrm{Y_{12}} = \mathrm{Y_{12}}(\mathrm{v_{12}}, \mathrm{v_{22}}, N\mathrm{Y_{12}}, N\mathrm{Y_{22}})$
(25) $\mathrm{Y_{22}} = \mathrm{Y_{22}}(\mathrm{v_{12}}, \mathrm{v_{22}}, N\mathrm{Y_{12}}, N\mathrm{Y_{22}})$

Input supply to storage sector

(26) $\mathrm{Y}_l = \mathrm{Y}_l(\mathrm{v}_l, T\mathrm{Y}_l)$
(27) $\mathrm{Y}_f = \mathrm{Y}_f(\mathrm{v}_f, T\mathrm{Y}_f)$
(28) $\mathrm{Y}_r = \mathrm{Y}_r(\mathrm{v}_r, T\mathrm{Y}_r)$
(29) $\mathrm{Y}_o = \mathrm{Y}_o(\mathrm{v}_o, T\mathrm{Y}_l)$

Output-constrained input demand of storage sector

(30) $\mathrm{Y}_l = Z^O * c'_{ZO,Yl}(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o)$
(31) $\mathrm{Y}_f = Z^O * c'_{ZO,Yf}(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o)$
(32) $\mathrm{Y}_r = Z^O * c'_{ZO,Yr}(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o)$
(33) $\mathrm{Y}_o = Z^O * c'_{ZO,Yo}(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o)$
(34) $\mathrm{Y_{11}} = Z^O * c'_{ZO,Y11}(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o)$
(35) $\mathrm{Y_{21}} = Z^O * c'_{ZO,Y21}(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o)$

Input-constrained output supply of storage sector

(36) $Z_{11} = Y^I * r'_{YI,Z11}(u_{11}, u_{21}, u_{12}, u_{22})$
(37) $Z_{21} = Y^I * r'_{YI,Z21}(u_{11}, u_{21}, u_{12}, u_{22})$
(38) $Z_{12} = Y^I * r'_{YI,Z12}(u_{11}, u_{21}, u_{12}, u_{22})$
(39) $Z_{22} = Y^I * r'_{YI,Z22}(u_{11}, u_{21}, u_{12}, u_{22})$

Equilibrium conditions of farm enterprises

(40) $\mathrm{Y}(\mathrm{Y_{11}}, \mathrm{Y_{21}}, \mathrm{Y}_l, \mathrm{Y}_f, \mathrm{Y}_r, \mathrm{Y}_o) = \mathrm{Z}(\mathrm{Z_{11}}, \mathrm{Z_{21}}, \mathrm{Z_{12}}, \mathrm{Z_{22}})$
(41) $c_Z(\mathrm{v_{11}}, \mathrm{v_{21}}, \mathrm{v}_l, \mathrm{v}_f, \mathrm{v}_r, \mathrm{v}_o) = r_Y(u_{11}, u_{21}, u_{12}, u_{22})$

Milling and malt processing demand

(42) $\mathrm{Z_{12}} = \mathrm{Z_{12}}(\mathrm{u_{12}}, \mathrm{u_{22}}, N\mathrm{Z_{12}}, N\mathrm{Z_{22}})$
(43) $\mathrm{Z_{22}} = \mathrm{Z_{22}}(\mathrm{u_{12}}, \mathrm{u_{22}}, N\mathrm{Z_{12}}, N\mathrm{Z_{22}})$

Input supply of port sector

(44) $\mathrm{Z}_l = \mathrm{Z}_l(\mathrm{u}_l, T\mathrm{Z}_l)$
(45) $\mathrm{Z}_f = \mathrm{Z}_f(\mathrm{u}_f, T\mathrm{Z}_f)$

(46) $\mathrm{Z}_r = \mathrm{Z}_r(\mathrm{u}_r, T\mathrm{Z}_r)$
(47) $\mathrm{Z}_o = \mathrm{Z}_o(\mathrm{u}_o, T\mathrm{Z}_l)$

Output-constrained input demand of port sector

(48) $\mathrm{Z}_l = Q * c'_{Q,Zl}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_l, \mathrm{u}_f, \mathrm{u}_r, \mathrm{u}_o)$
(49) $\mathrm{Z}_f = Q * c'_{Q,Zf}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_l, \mathrm{u}_f, \mathrm{u}_r, \mathrm{u}_o)$
(50) $\mathrm{Z}_r = Q * c'_{Q,Zr}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_l, \mathrm{u}_f, \mathrm{u}_r, \mathrm{u}_o)$
(51) $\mathrm{Z}_o = Q * c'_{Q,Zo}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_l, \mathrm{u}_f, \mathrm{u}_r, \mathrm{u}_o)$
(52) $\mathrm{Z}_{11} = Q * c'_{Q,Z11}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_l, \mathrm{u}_f, \mathrm{u}_r, \mathrm{u}_o)$
(53) $\mathrm{Z}_{21} = Q * c'_{Q,Z21}(\mathrm{u}_{11}, \mathrm{u}_{21}, \mathrm{u}_l, \mathrm{u}_f, \mathrm{u}_r, \mathrm{u}_o)$

Input-constrained output supply of storage sector

(54) $Q_{11} = Z^I * r'_{ZI,Z11}(p_1, p_2)$
(55) $Q_{21} = Z^I * r'_{ZI,Z21}(p_1, p_2)$

Export demand

(56) $\mathrm{Q}_1 = \mathrm{Q}_1(\mathrm{p}_1, \mathrm{p}_2, N\mathrm{Q}_1, N\mathrm{Q}_2)$
(57) $\mathrm{Q}_2 = \mathrm{Q}_2(\mathrm{p}_1, \mathrm{p}_2, N\mathrm{Q}_1, N\mathrm{Q}_2)$

Equilibrium conditions of farm enterprises

(58) $\mathrm{Z}(\mathrm{Z}_{11}, \mathrm{Z}_{21}, \mathrm{Z}_{12}, \mathrm{Z}_{22}) = \mathrm{Q}(\mathrm{Q}_1, \mathrm{Q}_2)$
(59) $c_Q(u_{11}, u_{21}, u_{12}, u_{22}) = Z(p_1, p_2)$

5.3 The Model in Displacement Form

The system given by equations (10) to (59) 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. In order to examine the impacts of exogenous shocks in the industry, the system 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 the Appendix. 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 promotions. This method allows for good 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 considered 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 will be satisfied when setting the parameter values in section 5.4 (see Zhao et al. (2000) for a detailed discussion on integrability conditions).

Table 4. Definition of variables and parameters in the model

Endogenous Variables	
X_l, X_f, X_r, X_o	Quantity of factor inputs (labour, capital, land, other) used in farm sector
w_l, w_f, w_r, w_o	Price of factor inputs (labour, capital, land, other) used in farm sector
X	Aggregate input index of farm sector
Y_l, Y_f, Y_r, Y_o	Quantity of factor inputs used in storage sector
v_l, v_f, v_r, v_o	Prices of factor inputs used in the storage sector
Y_{11}	Quantity of wheat to the storage sector
Y_{21}	Quantity of barley to the storage sector
v_{11}	Price of wheat to the storage sector
v_{21}	Price of barley to the storage sector
Y_{12}	Quantity of wheat from farm to the domestic processing sector
Y_{22}	Quantity of barley from farm to the domestic processing sector
v_{12}	Prices of wheat from farm to the domestic processing sector
v_{22}	Prices of barley from farm to the domestic processing sector
Y	Aggregate output index of farm sector
Z_{12}	Quantity of wheat from storage to the domestic processing sector
Z_{22}	Quantity of barley from storage to the domestic processing sector
u_{12}	Price of wheat from storage to the domestic processing sector
u_{22}	Price of barley from storage to the domestic processing sector
Z_l, Z_f, Z_r, Z_o	Quantity of factor inputs input used in port sector
u_l, u_f, u_r, u_o	Prices of factor inputs used in port sector
Z_{11}	Quantity of wheat to port sector
Z_{21}	Quantity of barley to port sector
u_{11}	Price of wheat to port sector
u_{21}	Price of barley to port sector
Y^s	Aggregate input index of storage sector
Z	Aggregate output index of storage sector
Q_1	Quantity of wheat to the export market
Q_2	Quantity of barley to the export market
p_1	Prices of wheat to the export market
p_2	Prices of barley to the export market
Z^p	Aggregate input index of port sector
Q	Aggregate output index of port sector
Exogenous Variables	
TX_l, TX_f, TX_r, TX_o	Shift in supply for inputs used in farm sector
TY_l, TY_f, TY_r, TY_o	Shift in supply for inputs used in storage sector
TZ_l, TZ_f, TZ_r, TZ_o	Shift in supply for inputs used in port sector
t_{xl}, t_{xf}, t_{xr}, t_{xo}	Amount of shift in supply for farm sector inputs as a percentage of prices
t_{yl}, t_{yf}, t_{yr}, t_{yo}	Amount of shift in supply for storage sector inputs as a percentage of prices
t_{zl}, t_{zf}, t_{zr}, t_{zo}	Amount of shift in supply for port sector inputs as a percentage of prices
NY_{12}	Shift in demand for wheat from farm in the processing sector
NY_{22}	Shift in demand for barley from farm in the processing sector
NZ_{12}	Shift in demand for wheat from storage in the processing sector
NZ_{22}	Shift in demand for barley from storage in the processing sector
NQ_{12}	Shift in demand for wheat from port in the export markets
NQ_{22}	Shift in demand for barley from port in the export markets
n_{y12}	Amount of shift in demand for NY_{12} as a percentage of price of Y_{12}

n_{y22}	Amount of shift in demand for $N\mathrm{Y}_{22}$ as a percentage of price of Y_{22}
n_{z12}	Amount of shift in demand for $N\mathrm{Z}_{12}$ as a percentage of price of Z_{12}
n_{z22}	Amount of shift in demand for $N\mathrm{Z}_{22}$ as a percentage of price of Z_{22}
n_{Q1}	Amount of shift in demand for $N\mathrm{Q}_{1}$ as a percentage of price of Q_{1}
n_{q2}	Amount of shift in demand for $N\mathrm{Q}_{2}$ as a percentage of price of Q_{2}
<u>Parameters</u>	
$\eta_{i,j}$	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

5.4 Data

The objective of the EDM approach is to estimate the resulting changes in all prices and quantities in order to infer the welfare implications of the exogenous shifts. To achieve this, there are three types of data required: (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 was obtained from a combination of different sources including ABARES, AEGIC, industry experts, and subjective judgements. Base equilibrium values for wheat and barley have been specified as the average ABARES reported prices and quantities between 2008-09 to 2015-16 in order to remove the effects of the single-desk wheat marketing arrangements that were in existence prior to 2008. Table 5 provides a summary of the average base equilibrium prices and quantities and associated cost and revenue shares for all sectors of the industry.

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

	Quantity (000' tonnes)	**Price ($/tonne)**	**Total Value ($m)**	**Cost Shares**	**Revenue Shares**
Port	$\mathrm{Q}_1 = 6{,}700$ $\mathrm{Q}_2 = 2{,}291$	$\mathrm{p}_1 = 314$ $\mathrm{p}_1 = 271$	$\mathrm{TV}_{Q1} = 2{,}224$ $\mathrm{TV}_{Q2} = 620$	$\kappa_{Z11} = 0.737$ $\kappa_{Z21} = 0.203$ $\kappa_{Zl} = 0.027$ $\kappa_{Zf} = 0.015$ $\kappa_{Zr} = 0.001$ $\kappa_{Zo} = 0.017$	$\lambda_{Q1} = 0.782$ $\lambda_{Q2} = 0.218$
Storage	$\mathrm{Z}_{11} = 7{,}802$ $\mathrm{Z}_{21} = 2{,}291$ $\mathrm{Z}_{12} = 372$ $\mathrm{Z}_{22} = 121$	$\mathrm{u}_{11} = 292$ $\mathrm{u}_{21} = 249$ $\mathrm{u}_{12} = 292$ $\mathrm{u}_{22} = 249$	$\mathrm{TV}_{Z11} = 2{,}068$ $\mathrm{TV}_{Z21} = 569$ $\mathrm{TV}_{Z12} = 109$ $\mathrm{TV}_{Z22} = 30$	$\kappa_{Y11} = 0.698$ $\kappa_{Y21} = 0.195$ $\kappa_{Yl} = 0.048$ $\kappa_{Yf} = 0.027$ $\kappa_{Yr} = 0.002$ $\kappa_{Yo} = 0.030$	$\lambda_{Z11} = 0.745$ $\lambda_{Z21} = 0.205$ $\lambda_{Z12} = 0.039$ $\lambda_{Z22} = 0.011$
Farm	$\mathrm{Y}_{11} = 7{,}455$ $\mathrm{Y}_{21} = 2{,}411$ $\mathrm{Y}_{12} = 828$	$\mathrm{v}_{11} = 258$ $\mathrm{v}_{21} = 222$ $\mathrm{v}_{12} = 258$	$\mathrm{TV}_{Y11} = 1820$ $\mathrm{TV}_{Y21} = 536$ $\mathrm{TV}_{Y12} = 213$		$\lambda_{Y11} = 0.704$ $\lambda_{Y21} = 0.196$ $\lambda_{Y12} = 0.078$

	$Y_{22} = 268$	$v_{22} = 222$	$TV_{Y22} = 60$	$\kappa_{Xl} = 0.027$ $\kappa_{Xf} = 0.139$ $\kappa_{Xr} = 0.039$ $\kappa_{Xo} = 0.796$	$\lambda_{Y22} = 0.022$

Following the review and discussion of elasticities in section 4, appropriate values for these elasticities have been chosen for the base run and are presented in Table 6 below. 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).

Table 6. Market elasticity values for the base run

	Demand Elasticities	**Supply Elasticities**	**Input Substitution Elasticities**		**Product Transformation Elasticities**
Port	$\eta_{Q1,P1} = -15.0$ $\eta_{Q1,P2} = 0.2$ $\eta_{Q2,P1} = 0.2$ $\eta_{Q2,P2} = -15.0$	$\varepsilon_{Zl,ul} = 1.5$ $\varepsilon_{Zf,uf} = 0.5$ $\varepsilon_{Zr,ur} = 0.5$ $\varepsilon_{Zo,uo} = 1.5$	$\sigma_{Z11,Z21} = 0.1$ $\sigma_{Z11,Zf} = 0.1$ $\sigma_{Z11,Zo} = 0.1$ $\sigma_{Z21,Zf} = 0.1$ $\sigma_{Z21,Zo} = 0.1$ $\sigma_{Zl,Zr} = 0.1$ $\sigma_{Zf,Zr} = 0.1$ $\sigma_{Zr,Zo} = 0.1$	$\sigma_{Z11,Zl} = 0.1$ $\sigma_{Z11,Zr} = 0.1$ $\sigma_{Z21,Z2l} = 0.1$ $\sigma_{Z21,Zr} = 0.1$ $\sigma_{Zl,Zf} = 0.1$ $\sigma_{Zl,Zo} = 0.1$ $\sigma_{Zf,Zo} = 0.1$	$\tau_{Q1,Q2} = -0.05$
Storage	$\eta_{Z12,u12} = -0.5$ $\eta_{Z12,u22} = 0.2$ $\eta_{Z22,u12} = 0.2$ $\eta_{Z22,u22} = -0.5$	$\varepsilon_{Yl,vl} = 1.5$ $\varepsilon_{Yf,vf} = 0.5$ $\varepsilon_{Yr,vr} = 0.5$ $\varepsilon_{Yo,vo} = 1.5$	$\sigma_{Y11,Y21} = 0.1$ $\sigma_{Y11,Yf} = 0.1$ $\sigma_{Y11,Yo} = 0.1$ $\sigma_{Y21,Yf} = 0.1$ $\sigma_{Y21,Yo} = 0.1$ $\sigma_{Yl,Yr} = 0.1$ $\sigma_{Yf,Yr} = 0.1$ $\sigma_{Yr,Yo} = 0.1$	$\sigma_{Y11,Yl} = 0.1$ $\sigma_{Y11,Yr} = 0.1$ $\sigma_{Y21,Y2l} = 0.1$ $\sigma_{Y21,Yr} = 0.1$ $\sigma_{Yl,Yf} = 0.1$ $\sigma_{Yl,Yo} = 0.1$ $\sigma_{Yf,Yo} = 0.1$	$\tau_{Z12,Z22} = -0.3$ $\tau_{Z12,Z11} = 0.1$ $\tau_{Z12,Z21} = -0.3$ $\tau_{Z22,Z11} = -0.3$ $\tau_{Z22,Z21} = 0.1$ $\tau_{Z11,Z21} = -0.3$
Farm	$\eta_{Y12,v12} = -0.5$ $\eta_{Y12,v22} = 0.2$ $\eta_{Y22,v12} = 0.2$ $\eta_{Y22,v22} = -0.5$	$\varepsilon_{Xl,wl} = 1.5$ $\varepsilon_{Xf,wf} = 0.5$ $\varepsilon_{Xr,wr} = 0.5$ $\varepsilon_{Xo,wo} = 1.5$	$\sigma_{Xl,Xf} = 0.1$ $\sigma_{Xl,Xo} = 1.5$ $\sigma_{Xf,Xo} = 1.5$	$\sigma_{Xl,Xr} = 0.01$ $\sigma_{Xf,Xr} = 0.01$ $\sigma_{Xr,Xo} = 0.01$	$\tau_{Y12,Y22} = -0.3$ $\tau_{Y12,Y11} = 0.1$ $\tau_{Y12,Y21} = -0.3$ $\tau_{Y22,Y11} = -0.3$ $\tau_{Y22,Y21} = 0.1$ $\tau_{Y11,Y21} = -0.3$

There are a total of 18 exogenous variables consisting of 12 supply shift variables and 6 demand shift variables. The supply shift represents 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.

Scenario 1 considers new technologies or practices adopted from R&D that reduce the costs of production, represented as a 1% 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 $t_{Xo} = -0.01$. These ‘other’ inputs consist of raw materials such as seed, fertiliser, fuel, water, and chemicals. Scenario 2 models the effects of a 1% increase in overseas consumers’ willingness to pay for wheat. This can arise through promotion investment or an improvement of the quality of wheat through R&D, and is modelled as an upward shift of the demand curve of wheat and barley sold in the export market, corresponding to $n_{Q1} = 0.01$. The modelling results for these investment scenarios are presented and discussed in the next section.

5.5 Results

Using the data specified in section 5.4, the equations for the EDM can be 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 7. In both these scenarios, the shifts considered are small parallel shifts, allowing for good approximations for price and quantity changes.

Table 7. Percentage changes in prices and quantities (%)

	Scenario 1 ($t_{Xo} = -1\%$)	Scenario 2 ($n_{Q1} = 1\%$)
Quantities:		
EX_l	0.06	0.63
EX_f	0.03	0.33
EX_r	0.70	0.62
EX_o	0.73	0.63
EY_{11}	0.63	0.62
EY_{21}	0.63	0.62
EY_{12}	0.46	0.37
EY_{22}	0.37	0.23
EY_l	0.57	0.64
EY_f	0.51	0.57
EY_r	0.51	0.57
EY_o	0.57	0.64
EZ_{11}	0.63	0.63
EZ_{21}	0.63	0.64
EZ_{12}	0.45	0.37
EZ_{22}	0.34	0.22
EZ_{l}	0.59	0.67
EZ_{f}	0.52	0.59
EZ_{r}	0.52	0.59
EZ_{o}	0.59	0.67
EQ_1	0.63	0.65
EQ_2	0.63	0.60
Prices:		
Ew_l	0.04	0.42
Ew_f	0.06	0.67
Ew_r	1.40	1.24
Ew_o	-0.52	0.42
Ev_{11}	-0.22	0.67
Ev_{21}	-0.26	0.62

Ev_{12}	-1.43	-1.09
Ev_{22}	-1.30	-0.90
Ev_{l}	0.38	0.43
Ev_{f}	1.01	1.14
Ev_{r}	1.01	1.14
Ev_{o}	0.38	0.43
Eu_{11}	-0.08	0.75
Eu_{21}	-0.10	0.72
Eu_{12}	-1.39	-1.09
Eu_{22}	-1.24	-0.89
Eu_{l}	0.39	0.44
Eu_{f}	1.04	1.18
Eu_{r}	1.04	1.18
Eu_{o}	0.39	0.44
Ep_{1}	-0.04	0.96
Ep_{2}	-0.04	-0.04

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 8 these welfare implications are summarized for each investment scenario.

Table 8. Economic surplus changes ($ million) and Percentage Shares of total surplus changes (%) to various industry groups

	Scenario 1 ($t_{Xo} = -1\%$)		Scenario 2 ($n_{Q1} = 1\%$)	
	$m	%	$m	%
ΔPS_{Xl}	0.02	0%	0.22	1%
ΔPS_{Xf}	0.16	1%	1.81	10%
ΔPS_{Xr}	1.05	6%	0.94	5%
ΔPS_{Xo}	7.52	41%	6.55	36%
$\boldsymbol{\Delta PS_{Xl} + \Delta PS_{Xf} + \Delta PS_{Xr} + \Delta PS_{Xo}}$ **Farm subtotal**	8.75	48%	9.51	53%
ΔPS_{Yl}	0.51	3%	0.57	3%
ΔPS_{Yf}	0.75	4%	0.85	5%
ΔPS_{Yr}	0.06	0%	0.07	0%
ΔPS_{Yo}	0.32	2%	0.36	2%
$\boldsymbol{\Delta PS_{Yl} + \Delta PS_{Yf} + \Delta PS_{Yr} + \Delta PS_{Yo}}$ **Storage subtotal**	1.64	9%	1.85	10%
ΔPS_{Zl}	0.30	2%	0.34	2%
ΔPS_{Zf}	0.44	2%	0.50	3%
ΔPS_{Zr}	0.04	0%	0.04	0%
ΔPS_{Zo}	0.19	1%	0.21	1%
$\boldsymbol{\Delta PS_{Zl} + \Delta PS_{Zf} + \Delta PS_{Zr} + \Delta PS_{Zo}}$ **Port subtotal**	0.96	5%	1.09	6%

Domestic consumers:				
$\Delta CS_{Y12} + \Delta CS_{Y22}$	3.85	21%	2.88	16%
$\Delta CS_{Z12} + \Delta CS_{Z22}$	1.88	10%	1.46	8%
Overseas consumers:				
$\Delta CS_{Q1} + \Delta CS_{Q2}$	1.21	7%	1.22	7%
Total Economic Surplus	18.29	100%	18.00	100%

5.5.1 Scenario 1

In Scenario 1, the exogenous shock examined is a 1% downward shift of the supply curve for other purchased farm inputs ($t_{Xo} = -0.01$). This can arise through any research-induced technical change that reduces the cost of producing these inputs.

This downward shift in supply for other purchased inputs results in higher quantities and lower prices of these inputs. The reduction in costs of these inputs causes an increase in the supply of farm outputs ($Y_{11}, Y_{21}, Y_{12}, Y_{22}$), resulting in a downward shift of the of the supply curves of these inputs, increasing quantities and reducing prices of these outputs. As these farm outputs flow directly into the storage and processing sectors as inputs, this increases the supply of stored grains ($Z_{11}, Z_{21}, Z_{12}, Z_{22}$), leading to a downward shift in the supply curves of these outputs. The same process then carries through to the port sector, resulting in a downward shift of the supply curves of export grains (Q_1, Q_2). In addition, the demand curves of farm grains directed to storage (Y_{11}, Y_{21}) and stored grains directed into processing (Z_{11}, Z_{21}) are also shifted upwards because of greater use of grains in both domestic feed markets and export markets.

By construct, the supply curves for labour (X_l), capital (X_f), and land (X_r) are determined completely exogenously and do not shift as a result of the initial shock. Their demand curves, however, do shift as evidenced by the movements in their quantities and prices. For labour, the reduction in other purchased farm inputs causes its demand curve to shift downwards and its quantities (X_l) and prices (w_l) to decrease. This is caused by a dominant substitution effect between labour and other farm inputs driven by the elasticity of substitution between these two inputs ($\sigma_{Xl,Xo}$), which has been set at a high value of 1.5. Similarly, the same effect is observed for capital due to the substitution of elasticity between capital and other inputs ($\sigma_{Xr,Xo}$) set equal to 1.5, causing a downward shift in the demand curve for capital. On the other hand, land is a fixed input that cannot readily be changed in the immediate production period, and hence the elasticity of substitution between land and other inputs ($\sigma_{Xr,Xo}$) has been set to 0.1. In this instance, the reduction in other farm inputs leads to an increase in the demand for land, as the substitution effect is dominated by the scale effect due to increased consumption of grain. In terms of the other sectors of the model, the demand for factor inputs in storage (Y_l, Y_f, Y_r, Y_o) are also increased and their demand curves shifted upwards due to the increased consumption, and also similarly for factor inputs used in ports (Z_l, Z_f, Z_r, Z_o).

As a result of all these displacements, the total surplus gain for the industry is estimated to be $18.29 million per year. All industry groups experience gains in welfare. In terms of the distribution of benefits, the farm sector is the main beneficiary of the technology shock with a total producer surplus of $8.75 million, equalling 48% of the total surplus gain. Domestic consumers receive $5.73 million or 31% of the total benefits, and the grain handlers and port operator share 9% and 5% of the total benefits respectively. The prices for export grains are largely unaffected by the technological shock due to the very high export demand elasticity for grains. In this instance, the total benefits accruing to overseas consumers is $1.21 million or 7% of the total benefits.

5.5.2 Scenario 2

In Scenario 2, the exogenous shock examined is a 1% upward shift of the demand curve for export wheat ($\mathrm{t}_{\mathrm{Q}1} = 0.01$). 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 (Q_1) and prices (P_1). Given that wheat and barley are assumed to be substitutes in demand, the exogenous shock causes an immediate decrease in barley exports (Q_1), shifting the demand curve for export barley downwards (this relationship is given in equations A.49 and A.50). This initial downwards shift, however, is then offset by a subsequent upwards shift in the demand for barley exports because of the increase in export wheat prices (substitution effect). The increase in wheat prices makes wheat more profitable, causing the supply curve for export wheat to shift upwards and the supply for export barley to shift downwards. However, given that the product transformation elasticity is assumed to be low in the port sector ($\tau_{Q1,Q2} = -0.05$), this effect is small. Both the supply for export wheat and barley also increase because of the increased levels of input supply upstream ($\mathrm{EZ}^{\mathrm{p}} > 0$ in equations A.45 and A.46). The result is an increase in the quantity of export barley (Q_2) and a decrease in its prices (P_2).

The increase in both Q_1 and Q_2 causes an increase in input demand in the port sector (Z_l, Z_f, Z_r, $\mathrm{Z}_o, \mathrm{Z}_{11}, \mathrm{Z}_{21}$). This in turn, causes an increase in input demand in input demand in storage (Y_l, Y_f, Y_r, $\mathrm{Y}_o, \mathrm{Y}_{11}, \mathrm{Y}_{21}$) and farm production ($\mathrm{X}_l$, X_f, X_r, X_o), increasing the quantities and prices in all these input markets. The increase in input supply in upstream input supply cause increases in demand for wheat and barley in the from both the farm ($\mathrm{Y}_{12}, \mathrm{Y}_{22}$) and storage ($\mathrm{Z}_{12}, \mathrm{Z}_{22}$) sectors, resulting in increases in quantities and decreases in prices in these markets.

The total returns here are comparable to those in Scenario 1, with the total surplus gain estimated to be $18.00 million per year. The economic benefits to the farm sector is significant at $9.51 million or 53% of the total benefits. The grain handlers and port operator gain 10% and 6% of the total benefits respectively. The domestic consumers gain 22% of the total benefits and overseas consumers receive 7%.

6. Sensitivity

The results of running the model in section 5 give an indication of the magnitude and distribution of net benefits generated by different hypothetical R&D investment decisions. The model, like most previous EDMs, was calibrated using point estimates for the market parameters with the results obtained depend critically on these choices of estimates. Accuracy of the results depends heavily on the reliability of the chosen elasticity values, as a different set of elasticity estimates would yield different results.

There is much uncertainty around the true values of these market parameters. Robust estimates for price elasticities of supply and demand have always been difficult to obtain for a host of reasons, with considerable subjective judgement being used. Of the estimates of elasticities published in literature, the majority are measured at the retail level rather than farm gate and are not geographically differentiated. Further, many of the previous estimates reviewed in section 4 are dated and are not likely to be representative of the current state in Australia's agricultural industries.

Given the uncertainty of the parameters used to calibrate the EDM, it would be useful to apply stochastic sensitivity analysis to the estimation process. This would involve replacing point estimates for uncertain parameters with probability distributions. Besides market parameters, this approach can also be applied to other variables in the model that are not known with certainty, namely the prices and quantities used to define the base equilibrium values of these markets, and also the size of the exogenous shock brought about by R&D. Sensitivity analysis would be applied to the results to produce probability distributions for the estimated changes in economic surplus for each sector.

There have been several past EDMs that have incorporated this method into the estimation approach, including Jackson, Griffith, and Malcolm (2012) and Liu et al. (2012). Such an approach will not be carried out for the WA grains EDM developed in this paper, but will be explored in the next stage during the development of the comprehensive Australian EDM.

7. 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.

In reality, 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 becomes depreciates over time, eventually becoming obsolete. Important time lags exist between the commencement of research, full adoption and eventual disadoption of a new 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 or the returns assuming full adoption and complete market adjustment (Mounter et al., 2008, p.80).

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, Hueth, and Schmitz (1982, as cited in Zhao et al., 2000) presented an approach to measuring the welfare impacts for the years after the initial exogenous shock and before reaching the new equilibrium, using different supply curves of different 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, a number of 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. As such, the decision to grow a crop cannot be made in isolation as grain cropping forms part of a system of activities (Malcolm, Makeham, & Wright, 2005; Malcolm & Armstrong, 2016). Thus, when deciding on a 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 (see Malcolm & Armstrong, 2016, pp. 1-2). This means that instead of examining the problem across time, we can instead examine the problem at a particular point in time. This then allows the problem to be analysed using a comparative static framework like an EDM.

8. Competition

The majority of studies evaluating the impacts of agricultural research assume that markets along the production and marketing chain are perfectly competitive, with this also being the case for EDMs. For a perfectly competitive EDM, two market clearing conditions are imposed. Firstly, profit maximisation requires that marginal costs are equal to marginal prices (revenue) in each market. Secondly, 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 past studies have tested for non-competitive behaviour in the grain industry. Notably, Griffith (2000) examined competition across the Australian food marketing chain and found statistically significant evidence of non-competitive buying power exerted by grain buyers in the processing and marketing sectors. This was supported by O'Donnell, Griffith, Nightingale, and Piggot (2007), which 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 oligopsonistically, and was particularly evident in the wheat and barley industries.

Imperfectly competitive markets can have significant implications on the estimated returns from R&D. McCorriston (2002) noted that the degree of market power can influence the extent to which price changes are transferred along the marketing chain, highlighting that this could mean that price changes originating at the farm gate may not be fully passed to end consumers. Alston, Sexton, and Zhang (1997) examined the effects of varying degrees of market power held by agribusiness firms on the size and distribution of benefits from R&D. In this study, it was 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 the potential pitfalls in an EDM that assumes perfectly competitive markets. Interest in understanding competitiveness in the grains industry has heightened since deregulation of the single-desk wheat marketing arrangements in 2008. In developing a full scale EDM for the Australian Grains Industry, it will help to test for market power to see whether a competitive EDM framework is practical, and second, to incorporate non-competitive market characteristics in the model if the assumed competitive model structure has shortcomings.

9. Summary

The grains industry is one of Australia's staple industries representing around a quarter of Australia's total agricultural exports. The industry has enjoyed significant growth since the 1970s, yet slowing growth in total factor productivity during the 1990s and 2000s signal a major challenge for the industry. Advances in agricultural technology and innovations from investing in R&D will play a key role in meeting this challenge and maintaining and increasing 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 is essential.

Equilibrium Displacement Models (EDMs) are one useful means of evaluating anticipated returns from alternative R&D investments and for indications about the distribution of benefits for different participants along the value chain. EDMs have been used in many different Australian industries but as yet no comprehensive EDM exists for the Australian grains industry.

In this paper, the modelling approach of EDMs has been reviewed with reference to the Australian grains industry, with all its complexities and challenges. As a starting point, a pilot EDM for the Western Australian grains industry has been constructed and analysed. The Western Australian grains industry is predominantly export-oriented, with around 85-95% of total annual grains production being exported to various counties in Asia and the Middle-East. Using the EDM, two investment scenarios were examined. In the first scenario was a 1% reduction in farm production inputs that include raw materials such as seed, fertiliser, fuel, water, and chemicals. This can arise from new technologies or practices adopted that reduce the costs of production. The second scenario involved a 1% increase in willingness of overseas consumers to pay for wheat. This could arise through promotion investment or from investments that improve the quality of wheat.

The results of the preliminary model were that the total benefits generated in both scenarios were similar. The farm sector and domestic consumers are the major beneficiaries in both scenarios. Overseas consumers gain a much smaller share of total benefits because of Australia's limited influence on the world market price of grains.

Caution, however, needs to be taken when examining the study's findings. First, the model is a simplified representation of the WA grains industry and does not capture fully activities in the domestic market. Second, the EDM was calibrated using point estimates for the price elasticities of supply and demand, prices, and quantities, with the findings depending critically on the values of these parameters. A more useful approach would use stochastic sensitivity analysis on these uncertain parameters and variables to produce probability distributions for the estimated economic changes. Third, the EDM considered in this paper assumes perfect competition in the industry, with prices in all sectors assumed to equal marginal costs. Some previous studies testing for non-competitive behaviour in the grains industry found statistically significant evidence of non-competitive buying power exerted by grain buyers in the processing and marketing sectors. Nonetheless, the pilot model presented in the paper paves the way constructing a useful, expanded EDM of the grains industry in Australia.

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Appendix. EDM of the WA Grains Industry

The model in equilibrium displacement form

1. <u>Farm</u>

1.1 Input Supply to farm enterprises

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

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

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

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

1.2 Output constrained input demands of farm enterprises

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

(A.6) $EX_f = -(\kappa_{xl} * \sigma_{xf,xl} + \kappa_{xr} * \sigma_{xf,xr} + \kappa_{xo} * \sigma_{xf,xo}) * Ew_f + \kappa_{xf} * \sigma_{xf,xl} * Ew_l + \kappa_{xr} * \sigma_{xf,xr} * Ew_r + \kappa_{xo} * \sigma_{xf,xo} * Ew_o + EY$

(A.7) $EX_r = -(\kappa_{xl} * \sigma_{xr,xl} + \kappa_{xf} * \sigma_{xr,xf} + \kappa_{xo} * \sigma_{xr,xo}) * Ew_r + \kappa_{xl} * \sigma_{xr,xf} * Ew_f + \kappa_{xo} * \sigma_{xf,xo} * Ew_o + \kappa_{xo} * \sigma_{xr,xo} * Ew_o + EY$

(A.8) $EX_o = -(\kappa_{xl} * \sigma_{xo,xl} + \kappa_{xf} * \sigma_{xo,xf} + \kappa_{xr} * \sigma_{xo,xr}) * Ew_o + \kappa_{xl} * \sigma_{xo,xl} * Ew_l + \kappa_{xf} * \sigma_{xo,xf} * Ew_f + \kappa_{xr} * \sigma_{xo,xr} * Ew_r + EY$

1.3 Input constraints output supplies of farm enterprises

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

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

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

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

1.4 Equilibrium conditions

(A.13) $\kappa_{xl} * EX_l + \kappa_{xf} * EX_f + \kappa_{xr} * EX_r + \kappa_{xo} * EX_o = \lambda_{y12} * EY_{12} + \lambda_{y22} * EY_{22} + \lambda_{y11} * EY_{11} + \lambda_{y21} * EY_{21}$

(A.14) $\kappa_{xl} * Ew_l + \kappa_{xf} * Ew_f + \kappa_{xr} * Ew_r + \kappa_{xo} * Ew_o = \lambda_{y12} * Ev_{12} + \lambda_{y22} * Ev_{22} + \lambda_{y11} * Ev_{11} + \lambda_{y21} * Ev_{21}$

1.5 Demands from domestic processing sector

(A.15) $EY_{12} = \eta_{y12,v12}*(Ev_{12} - n_{y12}) + \eta_{y12,v22} * (Ev_{22} - n_{y22})$

(A.16) $EY_{22} = \eta_{y22,v12}*(Ev_{12} - n_{y12}) + \eta_{y22,v22} * (Ev_{22} - n_{y22})$

2. <u>Storage</u>

2.2 Input supplies to storage sector

(A.17) $EY_l=\varepsilon_{yl,vl}*(Ev_l - t_{yl})$

(A.18) $EY_f=\varepsilon_{yf,vf}*(Ev_f - t_{yf})$

(A.19) $EY_r=\varepsilon_{yr,vr}*(Ev_r - t_{yr})$

(A.20) $EY_o=\varepsilon_{yo,vo}*(Ev_o - t_{yo})$

2.1 Output constraints input demands of storage sector

(A.21) $EY_{11} = -(\kappa_{y21} * \sigma_{y11,y21} + \kappa_{yl} * \sigma_{y11,yl} + \kappa_{yf} * \sigma_{y11,yf} + \kappa_{yr} * \sigma_{y11,yr} + \kappa_{yo} * \sigma_{y11,yo}) * Ev_{11} + \kappa_{y21} * \sigma_{y11,y21} * Ev_{21} + \kappa_{yl} * \sigma_{y11,yl} * Ev_l + \kappa_{yf} * \sigma_{y11,yf} * Ev_f + \kappa_{yr} * \sigma_{y11,yr} * Ev_r + \kappa_{yo} * \sigma_{y11,yo} * Ev_o + EZ$

(A.22) $EY_{21} = -(\kappa_{y11} * \sigma_{y21,y11} + \kappa_{yl} * \sigma_{y21,yl} + \kappa_{yf} * \sigma_{y21,yf} + \kappa_{yr} * \sigma_{y21,yr} + \kappa_{yo} * \sigma_{y21,yo}) * Ev_{21} + \kappa_{y11} * \sigma_{y21,y11} * Ev_{11} + \kappa_{yl} * \sigma_{y21,yl} * Ev_l + \kappa_{yf} * \sigma_{y21,yf} * Ev_f + \kappa_{yr} * \sigma_{y21,yr} * Ev_r + \kappa_{yo} * \sigma_{y21,yo} * Ev_o + EZ$

(A.23) $EY_l = -(\kappa_{y11} * \sigma_{Yl,Y11} + \kappa_{Y21} * \sigma_{Yl,Y21} + \kappa_{Yf} * \sigma_{Yl,yf} + \kappa_{yr} * \sigma_{yl,yr} + \kappa_{yo} * \sigma_{yl,yo}) * Ev_l + \kappa_{y11} * \sigma_{y1,y11} * Ev_{11} + \kappa_{y21} * \sigma_{yl,y21} * Ev_{21} + \kappa_{yf} * \sigma_{yl,yf} * Ev_f + \kappa_{yr} * \sigma_{yl,yr} * Ev_r + \kappa_{yo} * \sigma_{yl,yo} * Ev_o + EZ$

(A.24) $EY_f = -(\kappa_{y11} * \sigma_{Yf,Y11} + \kappa_{Y21} * \sigma_{Yf,Y21} + \kappa_{Yl} * \sigma_{Yf,yl} + \kappa_{yr} * \sigma_{yf,yr} + \kappa_{yo} * \sigma_{yf,yo}) * Ev_f + \kappa_{y11} * \sigma_{yf,y11} * Ev_{11} + \kappa_{y21} * \sigma_{yf,y21} * Ev_{21} + \kappa_{yl} * \sigma_{yf,yl} * Ev_l + \kappa_{yr} * \sigma_{yf,yr} * Ev_r + \kappa_{yo} * \sigma_{yf,yo} * Ev_o + EZ$

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

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

2.2 Input constrained output supply of storage sector

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

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

(A.29) $\mathrm{EZ}_{11} = -\left(\lambda_{z12} * \tau_{z11,z12} + \lambda_{z22} * \tau_{z11,z22} + \lambda_{z21} * \tau_{z11,z21}\right) * \mathrm{Eu}_{11} + \lambda_{z12} * \tau_{z11,z12} * \mathrm{Eu}_{12} + \lambda_{z22} * \tau_{z11,z22} * \mathrm{Eu}_{22} + \lambda_{z21} * \tau_{z11,z21} * \mathrm{Eu}_{21} + \mathrm{E}Y^s$

(A.30) $\mathrm{EZ}_{21} = -\left(\lambda_{z12} * \tau_{z21,z12} + \lambda_{z22} * \tau_{z21,z22} + \lambda_{z11} * \tau_{z21,z11}\right) * \mathrm{Eu}_{21} + \lambda_{z12} * \tau_{z21,z12} * \mathrm{Eu}_{12} + \lambda_{z22} * \tau_{z21,z22} * \mathrm{Eu}_{22} + \lambda_{z11} * \tau_{z21,z11} * \mathrm{Eu}_{11} + \mathrm{E}Y^s$

2.3 Equilibrium conditions

(A.31) $\kappa_{y11} * \mathrm{EY}_{11} + \kappa_{y21} * \mathrm{EY}_{21} + \kappa_{yl} * \mathrm{EY}_l + \kappa_{yf} * \mathrm{EY}_f + \kappa_{yr} * \mathrm{EY}_r + \kappa_{yo} * \mathrm{EY}_o = \lambda_{z12} * \mathrm{EZ}_{12} + \lambda_{z22} * \mathrm{EZ}_{22} + \lambda_{z11} * \mathrm{EZ}_{11} + \lambda_{z21} * \mathrm{EZ}_{21}$

(A.32) $\kappa_{y11} * \mathrm{Ev}_{11} + \kappa_{y21} * \mathrm{Ev}_{21} + \kappa_{yl} * \mathrm{Ev}_l + \kappa_{yf} * \mathrm{Ev}_f + \kappa_{yr} * \mathrm{Ev}_r + \kappa_{yo} * \mathrm{Ev}_o = \lambda_{z12} * \mathrm{Eu}_{12} + \lambda_{z22} * \mathrm{Eu}_{22} + \lambda_{z11} * \mathrm{Eu}_{11} + \lambda_{z21} * \mathrm{Eu}_{21}$

2.4 Demands from domestic processing sector

(A.33) $\mathrm{EZ}_{12} = \eta_{z12,u12} * (\mathrm{Eu}_{12} - n_{z12}) + \eta_{z12,u22} * (\mathrm{Eu}_{22} - n_{z22})$

(A.34) $\mathrm{EZ}_{22} = \eta_{z22,u12} * (\mathrm{Eu}_{12} - n_{z12}) + \eta_{z22,u22} * (\mathrm{Eu}_{22} - n_{z22})$

3. <u>Port</u>

3.1 Input supplies to port

(A.35) $\mathrm{EZ}_l = \varepsilon_{zl,ul} * (\mathrm{Eu}_l - \mathrm{t}_{zl})$

(A.36) $\mathrm{EZ}_f = \varepsilon_{zf,uf} * (\mathrm{Eu}_f - \mathrm{t}_{zf})$

(A.37) $\mathrm{EZ}_r = \varepsilon_{zr,ur} * (\mathrm{Eu}_r - \mathrm{t}_{zr})$

(A.38) $\mathrm{EZ}_o = \varepsilon_{zo,uo} * (\mathrm{Eu}_o - \mathrm{t}_{zo})$

3.2 Output constrained input demand of ports

(A.39) $\mathrm{EZ}_{11} = -\left(\kappa_{Z21} * \sigma_{Z11,Z21} + \kappa_{Zl} * \sigma_{Z11,Zl} + \kappa_{Zf} * \sigma_{Z11,Zf} + \kappa_{Zr} * \sigma_{Z11,Zr} + \kappa_{Zo} * \sigma_{Z11,Zo}\right) * \mathrm{Eu}_{11} + \kappa_{Z21} * \sigma_{Z11,Z21} * \mathrm{Eu}_{21} + \kappa_{Zl} * \sigma_{Z11,Zl} * \mathrm{Eu}_l + \kappa_{Zf} * \sigma_{Z11,yf} * \mathrm{Eu}_f + \kappa_{Zr} * \sigma_{Z11,Zr} * \mathrm{Eu}_r + \kappa_{Zo} * \sigma_{Z11,Zo} * \mathrm{Eu}_o + \mathrm{EQ}$

(A.40) $\mathrm{EZ}_{21} = -\left(\kappa_{Z11} * \sigma_{Z21,Z11} + \kappa_{Zl} * \sigma_{Z21,Zl} + \kappa_{Zf} * \sigma_{Z21,Zf} + \kappa_{Zr} * \sigma_{Z21,Zr} + \kappa_{Zo} * \sigma_{Z21,Zo}\right) * \mathrm{Eu}_{21} + \kappa_{Z11} * \sigma_{Z21,Z11} * \mathrm{Eu}_{11} + \kappa_{Zl} * \sigma_{Z21,Zl} * \mathrm{Eu}_l + \kappa_{Zf} * \sigma_{Z21,Zf} * \mathrm{Eu}_f + \kappa_{Zr} * \sigma_{Z21,Zr} * \mathrm{Eu}_r + \kappa_{Zo} * \sigma_{Z21,Zo} * \mathrm{Ev}_o + \mathrm{EQ}$

(A.41) $\mathrm{EZ}_l = -\left(\kappa_{Z11} * \sigma_{Zl,Z11} + \kappa_{Z21} * \sigma_{Zl,Z21} + \kappa_{Zf} * \sigma_{Zl,Zf} + \kappa_{Zr} * \sigma_{Zl,Zr} + \kappa_{Zo} * \sigma_{Zl,Zo}\right) * \mathrm{Eu}_l + \kappa_{Z11} * \sigma_{Z1,Z11} * \mathrm{Eu}_{11} + \kappa_{Z21} * \sigma_{Zl,Z21} * \mathrm{Eu}_{21} + \kappa_{Zf} * \sigma_{Zl,Zf} * \mathrm{Eu}_f + \kappa_{Zr} * \sigma_{Zl,Zr} * \mathrm{Eu}_r + \kappa_{Zo} * \sigma_{Zl,Zo} * \mathrm{Eu}_o + \mathrm{EQ}$

(A.42) $\mathrm{EZ}_f = -\left(\kappa_{Z11} * \sigma_{Zf,Z11} + \kappa_{Z21} * \sigma_{Zf,Z21} + \kappa_{Zl} * \sigma_{Zf,Zl} + \kappa_{Zr} * \sigma_{Zf,Zr} + \kappa_{Zo} * \sigma_{Zf,Zo}\right) * \mathrm{Eu}_f + \kappa_{Z11} * \sigma_{Zf,Z11} * \mathrm{Eu}_{11} + \kappa_{Z21} * \sigma_{Zf,Z21} * \mathrm{Eu}_{21} + \kappa_{Zl} * \sigma_{Zf,Zl} * \mathrm{Eu}_l + \kappa_{Zr} * \sigma_{Zf,Zr} * \mathrm{Eu}_r + \kappa_{Zo} * \sigma_{Zf,Zo} * \mathrm{Eu}_o + \mathrm{EQ}$

(A.43) $\mathrm{EZ}_r = -\left(\kappa_{Z11} * \sigma_{Zr,Z11} + \kappa_{Z21} * \sigma_{Zr,Z21} + \kappa_{Zl} * \sigma_{Zr,Zl} + \kappa_{Zf} * \sigma_{Zr,Zf} + \kappa_{Zo} * \sigma_{Zr,Zo}\right) * \mathrm{Eu}_r + \kappa_{Z11} * \sigma_{Zr,Z11} * \mathrm{Eu}_{11} + \kappa_{Z21} * \sigma_{Zr,Z21} * \mathrm{Eu}_{21} + \kappa_{Zl} * \sigma_{Zr,Zl} * \mathrm{Eu}_l + \kappa_{Zf} * \sigma_{Zr,Zf} * \mathrm{Eu}_r + \kappa_{Zo} * \sigma_{Zr,Zo} * \mathrm{Eu}_o + \mathrm{EQ}$

(A.44) $\mathrm{EZ}_o = -\left(\kappa_{Z11} * \sigma_{Zo,Z11} + \kappa_{Z21} * \sigma_{Zo,Z21} + \kappa_{Zl} * \sigma_{Zo,Zl} + \kappa_{Zf} * \sigma_{Zo,Zf} + \kappa_{Zr} * \sigma_{Zo,Zr}\right) * \mathrm{Eu}_o + \kappa_{Z11} * \sigma_{Zo,Z11} * \mathrm{Eu}_{11} + \kappa_{Z21} * \sigma_{Zo,Z21} * \mathrm{Eu}_{21} + \kappa_{Zl} * \sigma_{Zo,Zl} * \mathrm{Eu}_l + \kappa_{Zf} * \sigma_{Zo,Zf} * \mathrm{Eu}_r + \kappa_{Zr} * \sigma_{Zo,Zr} * \mathrm{Eu}_r + \mathrm{EQ}$

3.3 Input constrained output supply of ports

(A.45) $\mathrm{EQ}_1 = -\lambda_{Q2} * \tau_{Q1,Q2} * \mathrm{Ep}_1 + \lambda_{Q2} * \tau_{Q1,Q2} * \mathrm{Ep}_2 + \mathrm{EZ}^{\mathrm{p}}$

(A.46) $\mathrm{EQ}_2 = -\lambda_{Q1} * \tau_{Q1,Q2} * \mathrm{Ep}_2 + \lambda_{Q1} * \tau_{Q1,Q2} * \mathrm{Ep}_1 + \mathrm{EZ}^{\mathrm{p}}$

3.4 Equilibrium conditions

(A.47) $\kappa_{z11} * \mathrm{EZ}_{11} + \kappa_{z21} * \mathrm{EZ}_{21} + \kappa_{zl} * \mathrm{EZ}_l + \kappa_{zf} * \mathrm{EZ}_f + \kappa_{zr} * \mathrm{EZ}_r + \kappa_{zo} * \mathrm{EZ}_o = \lambda_{Q1} * \mathrm{EQ}_1 + \lambda_{Q2} * \mathrm{EQ}_2$

(A.48) $\kappa_{z11} * \mathrm{Eu}_{11} + \kappa_{z21} * \mathrm{Eu}_{21} + \kappa_{zl} * \mathrm{Eu}_l + \kappa_{zf} * \mathrm{Eu}_f + \kappa_{zr} * \mathrm{Eu}_r + \kappa_{zo} * \mathrm{Eu}_o = \lambda_{Q1} * \mathrm{Ep}_1 + \lambda_{Q2} * \mathrm{Ep}_2$

3.5 Export demand

(A.49) $\mathrm{EQ}_1 = \eta_{Q1,P1} * (\mathrm{Ep}_1 - n_{Q1}) + \eta_{Q1,P2} * (\mathrm{Ep}_2 - n_{q2})$

(A.50) $\mathrm{EQ}_2 = \eta_{Q2,P1} * (\mathrm{Ep}_1 - n_{Q1}) + \eta_{Q2,P2} * (\mathrm{Ep}_2 - n_{q2})$