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The Distribution of Gains from Investments in the Australian Apple Industry: Projections Using an Equilibrium Displacement Model¹

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Abstract

The Australian apple industry is one of the nation's largest fruit industries with apples consumed in almost every household. To assist in industry development, levies are paid by producers on processing and fresh apples with funds directed towards research, development and marketing. While specific chain actors contribute to these developments, it is important to identify the beneficiaries to ensure the costs associated with the levies are allocated to those who will benefit. Within a framework depicting the Australian apple value chain, an equilibrium displacement model illustrates the distribution of surplus changes resulting from specified research, development and marketing actions. The distribution of surplus change shares indicates where the costs would be appropriately directed and the total impact to the value chain. It is evident that relatively small changes within the chain have the potential to induce significant increases to the values received by chain participants.

Key words: apple industry; equilibrium displacement model; investment; surplus changes

Introduction

Fresh apples make up a significant amount of the Australian fresh fruit market with domestic production worth \$513 million in 2018/2019 (Hort Innovation, 2021a). Excluding table grapes and grouped fruits, apples are the second most valuable fruit in Australia and are purchased by 91 per cent of Australian households (Hort Innovation, *ibid*). Australian apple growers pay compulsory levies on apple production that are calculated on a per kilogram basis except when apples are used for juicing or processing in which case a per tonne rate is applied. Current levies are \$18.95 per tonne for domestic and export fresh apples, \$2.75 per tonne for juicing and \$5.50 per tonne for processing (Department of Agriculture, Water and the Environment, 2019). The levies are collected by the Australian Government, Department of Agriculture and Water Resources (DAWR), and administered by Hort Innovation with current investment of these funds undertaken in research and development

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(R&D), marketing, residue testing, and plant health and pest management programs (Hort Innovation, 2021b). The Australian Government also contributes public money to R&D investments and, to a lesser extent, investment from marketing levies (APAL, 2020). There are several key objectives that are developed through consultation with levy payers (Hort Innovation, 2021b) with the common themes being around decreasing the cost of production, increasing profitability for all members, increasing competitiveness and working towards sustainability (ibid). The funding collected from levies is invested in programs targeted towards achieving these objectives with significant returns expected (ibid). All industry participants are potential beneficiaries from R&D and promotion investments, hence knowledge of the distributional gains from such investments can assist with policy decisions about resource allocation among competing investment options.

Equilibrium Displacement Models (EDMs) have commonly been used to estimate the impacts from new technologies resulting from R&D, promotion and policy changes across a broad range of areas. Several EDMs have been developed in relation to Australian agricultural sectors for those purposes including Mullen et al. (1989), Zhao et al. (2001, 2002), Mounter et al. (2005a, 2005b, 2008), Hill et al. (2001) and Li et al. (2019). Within this framework an industry can be horizontally disaggregated, for example, into different regions, or vertically disaggregated into the main stages of the value chain (for example processors, retailers, consumers).

In this paper an EDM of the Australian apple industry is specified and the results from a number of scenarios are presented. The objective is to identify the distribution of surplus and value changes and to compare the outcomes with the objectives identified by Hort Innovation (2021b) which are increased profitability, increased competitiveness and reduced production costs. The outline of the paper is as follows. The structure of the Australian apple industry is described first, followed by a description of the EDM framework, the data requirements for the model and the chosen hypothetical R&D and promotion scenarios. Interpretations and comparisons of the results are then given followed by a discussion of the sensitivity of the results to changes in parameter values. Some general comments and concluding remarks complete the paper.

Structure of the Australian Apple Industry

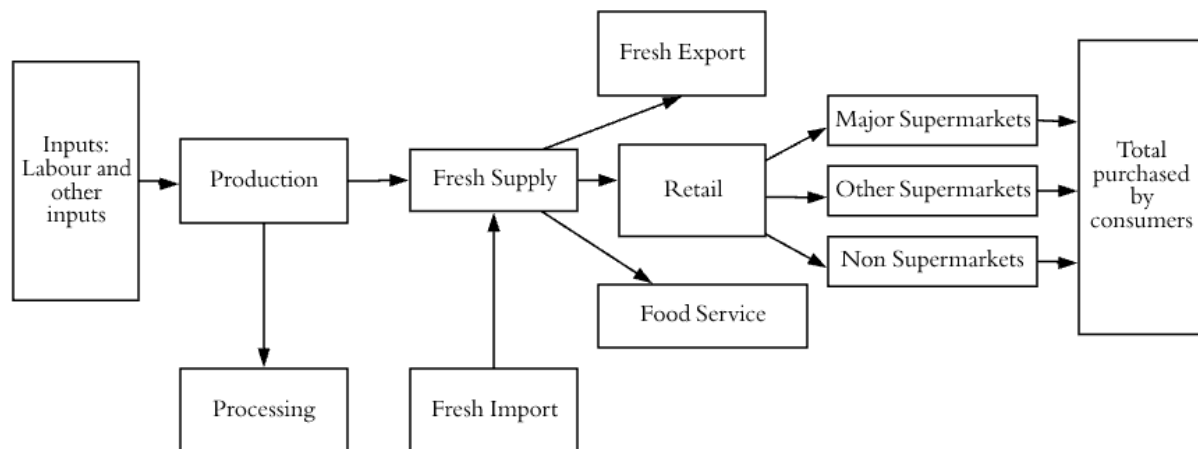
The Australian fresh apple market is primarily supplied by domestically produced apples which are available year-round from controlled atmosphere storage (Hort Innovation, 2019). Fresh apples receive a higher farm gate price than apples destined for processing. Prices received for processing apples can be close to the cost of production, so farmers typically aim for processing apples to comprise 10 per cent or less of total yield². From the farm gates, apples are distributed to the fresh domestic market or processing market. At the industry level, apples for fresh domestic supply and for processing account for around 70 and 29 per cent, respectively, of farm-gate production (Hort Innovation, 2021a). Volumes of apples for fresh export are small at approximately 1 per cent of farm-gate quantity (Hort Innovation, 2019).

Fresh supply includes imports of fresh apples which are accounted for at the wholesale level in the chain; however, volumes are insignificant. The domestic retail and food service avenues account for approximately 83 and 17 per cent of 2018/19 fresh apple supply, respectively (Hort Innovation, 2021a). Sales to consumers are primarily through 'major' Australian supermarkets (around 77 per cent of fresh apple sales), approximately 15 per cent are sold through non-supermarkets (such as green grocers) and around 8 per cent of sales are attributed to other, smaller or independent supermarkets (Harvest to Home, 2019). The structure of the Australian apple value chain is illustrated in Figure 1. Post farm gate the industry is horizontally disaggregated into fresh supply and processing. Vertical

² Anonymous, personal communication with a General Manager for an Australia apple producing organisation, October 17, 2019.

disaggregation of the industry includes production, fresh supply (wholesale), export, retail and consumption.

Figure 1. The Australian apple value chain



An EDM of the Australian Apple Industry

An EDM is a partial equilibrium framework which utilises linear approximation of changes in market prices and quantities that are induced by exogenous changes to the market system. These changes are modelled as shifts in market demand and supply. Calculated changes in producer and consumer surplus represent the changes in producer and consumer welfare that occur as the result of market equilibrium displacement. The initial market equilibriums are specified using a single set of base quantity and price data. Hence one key advantage of using the EDM framework is that it does not require extensive time-series data which can be difficult and costly to obtain. A further advantage of the EDM framework is that it allows for the use of previously determined market elasticity values without having to re-estimate the values for each application of the model. Uncertainties about true parameter values can be considered through sensitivity analysis.

Model Structure

The conceptual structure of the EDM, based on the Australian apple value chain shown in Figure 1, is presented in Figure 2. The variables and parameters included in the model are defined in Table 1. In Figure 2 each rectangle represents a production function and each arrowed line represents the supply and demand for a product, with the non-arrowed end indicating the supply of the product and the arrowed end indicating the demand for the product. The supply and demand schedules, where an exogenous shift may occur, are represented by the ovals.

Post-farm distribution of apples is split into fresh supply and processing channels, with product flows and balances among the stages of the value chain dependent on availability, demand and market prices. The fresh supply stage illustrated in Figure 1 corresponds to the wholesale stage in the EDM in Figure 2³ and consists of a range of organisational structures, including cooperatives, wholesale traders and vertically integrated private organisations. Other inputs in the wholesale stage include packing, storage, labour and marketing to retailers and food service providers.

Processing apples are used in a variety of products such as canned goods, infant food and juices. Data for processed products were not available. Hence, in the EDM processed apple demand is the demand

³ Imports are excluded from the model as they comprise less than 1 per cent of domestic production.

for apples by the processing stage and not the demand for processed apple products (X_{12} in Figure 2). If data for processed apple products were available, X_{12} would represent retail/consumer demand for these products. That being the case there would be differences between quantities X_{11} and X_{12} and between prices $P_{X_{11}}$ and $P_{X_{12}}$, with those differences captured in the value of other processing inputs (X_{10}). In the EDM X_{10} is set to zero, therefore $P_{X_{11}} = P_{X_{12}}$ and $X_{11} = X_{12}$.

Apples are mainly exported to Papua New Guinea and Hong Kong, with exports to other countries varying from year-to-year (Harvest to Home, 2019; Hort Innovation, 2021a and previous issues). In the EDM it is assumed that there is no quality difference between apples channelled into the domestic fresh supply and export avenues. Inputs into the export stage include marketing, packaging, storage and distribution.

The Australian retail market is comprised of ‘major supermarkets’ Coles and Woolworths, smaller supermarkets and non-supermarkets such as specialty stores (Harvest to Home, 2019). Key retail inputs at this stage include labour, marketing, display and location costs. The food service stage includes restaurants, canteens and other outlets such as correctional services (ARCADIS, 2019). Apples supplied to food service are used in a variety of end products but price and quantity data for specific food service end products were not available. In the EDM, therefore, food service demand refers to the demand for apples by food service rather than the demand for apple products produced and sold by food service, so the same explanation applies to food service as to processing demand.

Figure 2. Australian apple EDM framework

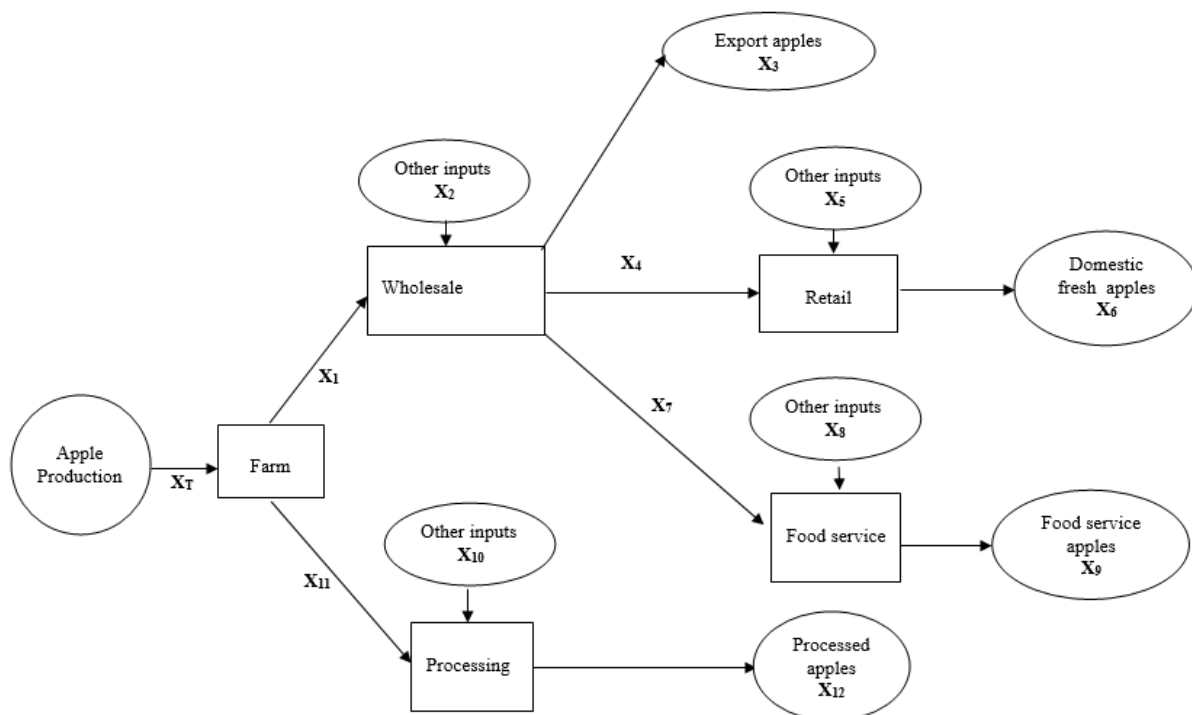


Table 1. Definitions of variables and parameters in the EDM

Endogenous Variables	
X_1	Quantity of apples for wholesale
X_{11}	Quantity of apples for processing
X_T	Quantity of total apples $= (X_1 + X_{11})$
X_2	Quantity of other inputs for wholesale

X_3	Quantity of export apples
X_4	Quantity of apples for the retail
X_5	Quantity of other inputs for the retail
X_6	Quantity of domestic fresh apples (consumer retail purchases)
X_7	Quantity of apples for food service
X_8	Quantity of other inputs for the food service
X_9	Quantity of food service apples
X_{10}	Quantity of other inputs for the processing
X_{12}	Quantity of processing apples
P_{XT}	Price of apples at farm $= (X_1 * P_{X1} + X_{11} * P_{X11}) / X_T$
P_{X1}	Price of apples for wholesale
P_{X11}	Price of apples for processing
P_{X2}	Price of other inputs for wholesale
P_{X3}	Price of export apples
P_{X4}	Price of apples for retail
P_{X5}	Price of other inputs for retail
P_{X6}	Price of domestic fresh apples
P_{X7}	Price of apples for food service
P_{X8}	Price of other inputs for food service
P_{X9}	Price of food service apples
P_{X10}	Price of other inputs for processing
P_{X12}	Price of processing apples
X_F	Aggregated output index for the farm stage
X_W	Aggregated input index for the wholesale stage
Y_W	Aggregated output index for the wholesale stage
Exogenous Variables	
N_X	Demand shifter
T_X	Supply shifter
Parameters	
$\mathcal{E}_{(XT, P_{XT})}$	Own-price elasticity of supply of apples
$\mathcal{E}_{(X2, P_{X2})}$	Own-price elasticity of supply of other wholesale inputs
$\mathcal{E}_{(X5, P_{X5})}$	Own-price elasticity of supply of other retail inputs
$\mathcal{E}_{(X8, P_{X8})}$	Own-price elasticity of supply of other food service inputs
$\mathcal{E}_{(X10, P_{X10})}$	Own-price elasticity of supply of other processing inputs
β_{X1}	Quantity share of fresh apple production
β_{X11}	Quantity share of processed apple production
$\eta_{(X3, P_{X3})}$	Own-price elasticity of demand for exported apples
$\eta_{(X6, P_{X6})}$	Own-price elasticity of demand for domestic fresh apples
$\eta_{(X9, P_{X9})}$	Own-price elasticity of demand for food service apples
$\eta_{(X12, P_{X12})}$	Own-price elasticity of demand for processed apples
k_X	Cost share of input x ($x = x_1, x_2, x_4, x_5, x_7, x_8, x_{10}, x_{11}$)
λ_X	Revenue share of output x ($x = x_3, x_4, x_7$)
$\sigma_{(X,Y)}$	Allen's elasticity of input substitution between input x and input y
$\tau_{(X,Y)}$	Allen's elasticity of product transformation between output x and output y

Structural Model

As illustrated in Figure 2 there are five industry sectors (designated by the rectangles). It is assumed that all sectors are profit maximisers, all multi-output production functions are separable in inputs

and outputs⁴, and all production functions are characterised by constant returns to scale (Zhao et al., 2001). The product transformation functions for each of the industry sectors can be written as follows where outputs equal inputs. The farm and wholesale market stages are characterised by multi-output production.

- | | | |
|-----|--------------------------------------|---------------------|
| (1) | $X_F(X_1, X_{11}) = X_T$ | <i>farm</i> |
| (2) | $Y_W(X_3, X_4, X_7) = X_W(X_1, X_2)$ | <i>wholesale</i> |
| (3) | $X_6 = (X_4, X_5)$ | <i>retail</i> |
| (4) | $X_9 = (X_7, X_8)$ | <i>food service</i> |
| (5) | $X_{12} = (X_{10}, X_{11})$ | <i>processing</i> |

The total cost functions related to the five industry sector production functions are

- | | | |
|------|--|---------------------|
| (6) | $C_{XF} = X_F * c_{XF}(p_{XT})$ | <i>farm</i> |
| (7) | $C_{YW} = Y_W * c_{YW}(p_{X1}, p_{X2})$ | <i>wholesale</i> |
| (8) | $C_{X6} = X_6 * c_{X6}(p_{X4}, p_{X5})$ | <i>retail</i> |
| (9) | $C_{X9} = X_9 * c_{X9}(p_{X7}, p_{X8})$ | <i>food service</i> |
| (10) | $C_{X12} = X_{12} * c_{X12}(p_{X10}, p_{X11})$ | <i>processing</i> |

where C_g signifies the total cost of producing output level g and $c_g(p)$ represents the unit cost function ($g = X_F, Y_W, X_6, X_9, X_{12}$).

The multi-output revenue functions for the farm and wholesale industry sectors can be represented as

- | | | |
|------|---|------------------|
| (11) | $R_{XT} = X_T * r_{XT}(p_{X1}, p_{X11})$ | <i>farm</i> |
| (12) | $R_{XW} = X_W * r_{XW}(p_{X3}, p_{X4}, p_{X7})$ | <i>wholesale</i> |

where R_i represents the total revenue produced from the input level i and $r_i(p)$ represents the unit revenue function ($i = X_T, X_W$).

The structural model of the Australian apple industry is specified in the general functional form equations 13-41. Comparative statics are applied to the model to derive the relationships among the changes in all variables (Zhao et al., 2001). The displacement forms of the equations are provided in Appendix 1.

Apple input supply to fresh and processed stages

$$(13) \quad X_T = X_T(p_{XT}, T_{XT})$$

Equation (13) is total apple supply. T_{XT} is a supply shifter and represents exogenous changes such as new technologies in apple production.

Input-constrained output supply of farm stage

$$(14) \quad X_1 = X_T * r'_{XT,X1}(p_{X1}, p_{X11}) \quad \text{supply of apples to wholesale}$$

$$(15) \quad X_{11} = X_T * r'_{XT,X11}(p_{X1}, p_{X11}) \quad \text{supply of apples to processing}$$

Equations (14) and (15) are derived from the underlying revenue function of the farm stage (equation 12) using the Samuelson-McFadden Lemma where $r'_{XF,i}(p_{X1}, p_{X11})$ ($i = X_1, X_{11}$) are partial derivatives of the revenue function.

⁴ The output and input separability assumptions ensure the existence of scalar output and input indexes (see Zhao et al. 2001; Chambers 1988). In this EDM there are two aggregated output indices (X_F and Y_W) and one aggregated input index (X_W) – see Table 1.

Farm stage equilibrium

$$(16) \quad X_T = X_F(X_1, X_{11})$$

quantity equilibrium

$$(17) \quad c(p_{XT}) = r_{XF}(p_{X1}, p_{X11})$$

value equilibrium

Equation (16) is the multi-output product transformation function of the farm stage and specifies that input quantity equals aggregated output quantities. Equation (17) ensures that the unit costs incurred per unit of aggregated outputs is equal to the unit revenue earned per unit of inputs.

Other input supply to wholesale stage

$$(18) \quad X_2 = X_2(p_{X2}, T_{X2})$$

supply of other wholesale inputs

Equation (18) is the supply of other wholesale inputs. T_{X2} is a supply shifter and represents exogenous changes such as new technologies in the wholesale sector.

Output-constrained input demand of wholesale stage

$$(19) \quad X_1 = Y_W * c'_{YW,X1}(p_{X1}, p_{X2})$$

wholesale apple demand

$$(20) \quad X_2 = Y_W * c'_{YW,X2}(p_{X1}, p_{X2})$$

other wholesale input demand

Equations (19) and (20) are derived from the underlying cost function of the wholesale sector (equation 7) using Shephard's Lemma where $c'_{YW,j}(p_{X1}, p_{X2})$ ($j = X_1$ and X_2) are partial derivatives of the unit cost function.

Input-constrained output supply of wholesale stage

$$(21) \quad X_3 = X_W * r'_{XW,X3}(p_{X3}, p_{X4}, p_{X7})$$

export apple supply

$$(22) \quad X_4 = X_W * r'_{XW,X4}(p_{X3}, p_{X4}, p_{X7})$$

retail apple supply

$$(23) \quad X_7 = X_W * r'_{XW,X7}(p_{X3}, p_{X4}, p_{X7})$$

food service apple supply

Equations (21), (22) and (23) are derived from the underlying wholesale revenue function (equation 12) using the Samuelson-McFadden Lemma where $r'_{XW,i}(p_{X3}, p_{X4}, p_{X7})$ ($i = X_3, X_4$ and X_7) are partial derivatives of the revenue function.

Wholesale stage equilibrium

$$(24) \quad X_W(X_1, X_2) = Y_W(X_3, X_4, X_7)$$

quantity equilibrium

$$(25) \quad c_{YW}(p_{X1}, p_{X2}) = r_{XW}(p_{X3}, p_{X4}, p_{X7})$$

value equilibrium

Equation (24) is the multi-output product transformation function of the wholesale stage and specifies that aggregate input quantities equals aggregated output quantities. Equation (25) ensures that the unit costs incurred per unit of aggregated outputs are equal to the unit revenue earned per unit of aggregated inputs.

Other input supply to retail stage

$$(26) \quad X_5 = X_5(p_{X5}, T_{X5})$$

other retail input supply

Equation (26) is the supply function of retail inputs. T_{X5} is a supply shifter and represents exogenous changes such as new technologies in the retail sector.

Output-constrained input demand of retail stage

$$(27) \quad X_4 = X_6 * c'_{X6,X4}(p_{X4}, p_{X5})$$

retail apple demand

$$(28) \quad X_5 = X_6 * c'_{X6,X5}(p_{X4}, p_{X5})$$

other retail input demand

Equations (27) and (28) are derived from the underlying cost function of the retail stage (equation 8) using Shephard's Lemma where $c'_{X6,j}(p_{X4}, p_{X5})$ ($j = X_4$ and X_5) are partial derivatives of the unit cost function.

Retail stage equilibrium

$$(29) \quad P_{X6} = C(p_{X4}, p_{X5})$$

value equilibrium

Equation (29) ensures that the unit costs incurred per unit of output are equal to the unit revenue earned per unit of inputs.

Export apple demand

$$(30) \quad X_3 = X_3(p_{X3}, N_{X3}) \quad \text{export apple demand}$$

Equation (30) is the export demand function for Australian apples. Income is assumed constant and the N_{X3} term is an exogenous demand shifter representing changes in demand for Australian apples in overseas markets due to promotion or changes in consumer preferences

Domestic fresh apple demand

$$(31) \quad X_6 = X_6(p_{X6}, N_{X6}) \quad \text{domestic fresh apple demand}$$

Equation (31) is domestic fresh apple demand. Income is assumed constant and the N_{X6} term is an exogenous demand shifter representing changes in demand for Australian apples in the domestic market due to promotion or changes in consumer preferences.

Other input supply to food service stage

$$(32) \quad X_8 = X_8(p_{X8}, T_{X8}) \quad \text{supply of other food service inputs}$$

Equation (32) is the supply function of food service inputs. T_{X8} is an exogenous supply shifter and represents exogenous changes such as new technologies in the food service sector.

Output-constrained input demand of food service stage

$$(33) \quad X_7 = X_9 * c'_{X9,X7}(p_{X7}, p_{X8}) \quad \text{food service apple demand}$$

$$(34) \quad X_8 = X_9 * c'_{X9,X8}(p_{X7}, p_{X8}) \quad \text{other food service input demand}$$

Equations (33) and (34) are derived from the underlying cost function of the food service stage (equation 9) using Shephard's Lemma where $c'_{X,j}(p_{X7}, p_{X8})$ ($j = X_7$ and X_8) are partial derivatives of the unit cost function.

Food service stage equilibrium

$$(35) \quad P_{X9} = C(p_{X7}, p_{X8}) \quad \text{value equilibrium}$$

Equation (35) ensures that the unit costs incurred per unit of output are equal to the unit revenue earned per unit of inputs.

Food service stage demand

$$(36) \quad X_9 = X_9(p_{X9}, N_{X9}) \quad \text{food service demand}$$

Equation (36) is food service demand. Income is assumed constant and the N_{X9} term is an exogenous demand shifter representing changes in demand due to promotion or changes in consumer preferences.

Other input supply to processing stage

$$(37) \quad X_{10} = X_{10}(p_{X10}, T_{X10}) \quad \text{supply of other processing inputs}$$

Equation (37) is the supply function of other processing inputs. T_{X10} is an exogenous supply shifter and represents exogenous changes such as new technologies in the processing sector.

Output-constrained input demand for processing stage

$$(38) \quad X_{10} = X_{12} * c'_{X12,X10}(p_{X10}, p_{X11}) \quad \text{other processing input demand}$$

$$(39) \quad X_{11} = X_{12} * c'_{X12,X11}(p_{X10}, p_{X11}) \quad \text{processing apple demand}$$

Equations (38) and (39) are derived from the underlying cost function of the processing stage (equation 10) using Shephard's Lemma where $c'_{X12,j}(p_{X10}, p_{X11})$ ($j = X_{10}$ and X_{11}) are partial derivatives of the unit cost function.

Processing stage equilibrium

$$(40) \quad P_{X12} = C(p_{X10}, p_{X11}) \quad \text{value equilibrium}$$

Equation (40) ensures that the unit costs incurred per unit of output are equal to the unit revenue earned per unit of inputs.

Processing stage demand

$$(41) \quad X_{12} = X_{12}(p_{X12}, N_{X12}) \quad \text{processing demand}$$

Equation (41) is processing demand. Income is assumed constant and the N_{X12} term is an exogenous demand shifter representing changes in demand due to promotion or changes in consumer preferences.

Data

Prices and quantities

The base prices and quantities specified in the EDM and the cost and revenue shares for each industry stage are shown in Table 2.

Table 2. Base equilibrium prices, quantities, cost shares and revenue shares, average 2016-2018

	Quantity (‘000 tonnes)	Price (\$/kg)	Total Value (\$m)	Cost Shares	Revenue Shares
Farm	$X_1 = 225.61$	$P_{X1} = 1.90$	$TV_{X1} = 428.66$		
Production	$X_{11} = 91.60$ $X_T = 317.21$	$P_{X11} = 0.45$	$TV_{X11} = 41.22$ $TV_{XT} = 469.88$		$\lambda_{X1} = 0.89$ $\lambda_{X11} = 0.09$
Wholesale	$X_3 = 4.89$ $X_4 = 183.20$ $X_7 = 37.52$	$P_{X3} = 2.48$ $P_{X4} = 2.51$ $P_{X7} = 2.51$	$TV_{X3} = 12.13$ $TV_{X4} = 459.83$ $TV_{X7} = 94.17$ $TV_{X347} = 554.00$	$k_{X1} = 0.76$ $k_{X2} = 0.24$	$\lambda_{X3} = 0.02$ $\lambda_{X4} = 0.81$ $\lambda_{X7} = 0.17$
Retail	$X_6 = 125.95$	$P_{X6} = 3.85$	$TV_{X6} = 484.91$	$k_{X4} = 0.95$ $k_{X5} = 0.05$	
Food Service	$X_9 = 37.52$	$P_{X9} = 2.51$	$TV_{X9} = 94.18$	$k_{X7} = 1.00$ $k_{X8} = 0.00$	
Processing	$X_{12} = 91.60$	$P_{X12} = 0.45$	$TV_{X12} = 41.22$	$k_{X10} = 0.00$ $k_{X11} = 1.00$	

Implementing the EDM requires point price and quantity data specifying initial equilibria in all market stages in the model that are representative of a typical period of time. Average annual prices and quantities were obtained for the period 2016-2018 from a variety of sources including Hort Innovation, Harvest to Home and industry consultation.

Farm gate prices differ depending on whether apples are sold for fresh consumption or for processing into end-products such as canned goods or juices. The farm-gate price of apples sold for processing was based on industry consultation (Anonymous, personal communication, October 17, 2019). The farm gate price for both apples sold for domestic consumption and for export was calculated by deducting the farm-gate value of processing apples from the total farm-gate value of apples and dividing by the combined export and fresh domestic quantities sourced from Hort Innovation (2019). This assumes that both domestic fresh and export supplies of apples meet the same standard of quality. The distribution of fresh apples between the domestic retail and food service markets was specified as 83 per cent and 17 per cent respectively (Spencer and Kneebone, 2012). This split was confirmed in 2019 communications with Hort Innovation.

Retail data on prices are not readily available. In the absence of retail prices, two approaches were used to estimate the per kg retail price of fresh apples. Household purchase data for 2017 and 2018 were obtained from Harvest to Home (2019). The value of purchases was divided by quantity purchased to obtain a per kg price. O’Kane et al. (2018), in a study of fruit and vegetables at farmers’ markets and other retail streams, included retail prices from major Australian supermarkets for the period of 15-28 September 2014. The O’Kane et al. prices were adjusted using annual inflation rates to calculate proxy 2016, 2017, and 2018 prices. Recent retail prices were deflated to also obtain proxy 2016, 2017, and 2018 prices. Although lacking rigorous validation, the two approaches yielded similar retail price approximations to provide an estimate of the average annual retail price for 2016-2018.

Market parameters

Estimates of medium-run (three-to-five years) price elasticities of demand and supply, input substitution elasticities and product transformation elasticities which characterise the responsiveness of market participants to changes in prices are required as inputs into the EDM. Few empirical estimates of elasticity values relevant to the Australian apple industry exist in the literature. As there were few data specific to the Australian apple industry, values from the United States were also considered. In addition to the range of geographical origins, some of the values referenced are from several decades ago and this was considered in determining appropriate values. The elasticity values in Table 3, sourced from previous studies, are empirical estimates mostly relating to the United States apple industry.

Table 3. Elasticity values from past studies

	Elasticity	Source	Elasticity
Own-price elasticity of demand for fresh apples	Long run	Okrent and Alston (2012)	-0.58
	Short run	Durham et al. (2010)	-1.13
Long-run own-price elasticity of demand for processing apples	Long run	Roosen, J. (1999)	-0.7
	Long run	Baumes and Conway (1985)	-1.171
Own-price elasticity of demand for fresh apples, retail level	Long run	Baumes and Conway (1985)	-2.288
Own-price elasticity of export demand for Australian fresh apples	Short run	Scobie and Johnson (1979)	-14.3
Own-price elasticity of supply of fresh apples, farm level	Long run	Baumes and Conway (1985)	0.007

Apples are a perennial crop and production of fruit generally does not occur until four-to-five years after planting (ABS, 2018). Hence, supply response to price changes, particularly in the short run, is low and therefore supply is price inelastic. Baumes and Conway (1985), in a study of the United States apple industry, estimated an own-price elasticity for the farm supply of apples of 0.007, much smaller than the 0.23 estimated value by Tomek (as cited by Baumes and Conway, 1985). While it is expected that supply is price inelastic due to the time taken to produce fruit from orchard development (Weisong et al., 2010), it is likely that supply is more price elastic than previous estimates suggest due to improvements in growing practices and the availability of market information. The supply response is also asymmetrical: for example, reducing production through the removal of trees can occur quite quickly. In the EDM a medium-to-longer time frame of adjustment is assumed in moving from the initial equilibrium when a displacement occurs. A value of 0.5 is assigned to the own-price elasticity of supply of farm apples to reflect medium-run adjustment possibilities. The robustness of the results to

a much lower value of 0.1 are assessed using discrete sensitivity analysis which is discussed later in the paper. High and low values are chosen due to the uncertainty about this parameter.

Fresh and processed apples are produced jointly in supply and, after harvest, are graded into fresh supply and processing supply according to quality standards. The supply of processing apples can be likened to a residual supply (of fresh apples) and quantity changes in fresh apples are expected to result in proportional changes in the quantity of apples sent for processing. For example, an increase in demand for fresh apples would increase the price and quantity of fresh apples supplied and also increase the supply of apples for processing.

Values of 2.0 were assigned to elasticities of input supply to other stages in the model (wholesale, retail, food service and processing). This corresponds with values used in previous Australian agricultural market studies (e.g., Zhao et al., 2002; Mounter et al., 2008; Li et al., 2019). Li et al. (2019) developed an EDM of the Western Australia grains industry to model the distribution of benefits throughout the chain from different types of research, development and extension (RD&E) investment. While there are obvious differences between the grains and pome fruit industries, in the Australian context there are commonalities in the mix of production inputs used, such as labour, land, water and equipment.

Own-price elasticities of demand are required to represent the responsiveness of demand to changes in prices in the market in which it is observed. Durham et al. (2010) estimated a value of -1.13 which was derived using weekly store prices at the retail level in the United States. Okrent and Alston (2012) conducted a review of existing values which were then adjusted to a value of -0.58 which was deemed to be representative of more recent market conditions and preferences. While these estimates relate to United States-based demand there are similarities with the Australian industry and instances where the food markets have been grouped together such as in Gustavsson et al. (2011). Given the lack of Australia-specific data, these values are used as a proxy for Australian consumer demand responsiveness. Values of -0.9 were specified for all demand elasticities in the EDM based on the empirical estimates referenced in Table 3. Higher and lower values representative of the Durham and Okrent and Alston estimates were used in discrete sensitivity analyses on this parameter.

Fresh apple exports comprise a very small proportion of Australian apple production, with less than 5,000 tonnes exported in 2017 (Hort Innovation, 2019). Scobie and Johnson (1979) estimated an export demand elasticity of -15 which is consistent with the 'small country assumption' where a country's exports satisfy a small proportion of world demand. Although this value is dated, Australia's export contribution to the global apple market is still consistent with this assumption. In the EDM, export demand is assumed to be price elastic and is allocated an elasticity value of -5; however, it is acknowledged that the true value may be higher. For the purposes of estimation, the true parameter value has little bearing on the results given the minimal contribution of exports in the model.

Input substitution elasticities are used to represent the substitution possibilities among inputs resulting from a change in relative prices. The magnitudes of the input substitution elasticities play a crucial role in the distribution of benefits along the value chain of an EDM (Alston and Scobie, 1983). As in other industry EDMs (e.g., Zhao et al., 2002, 2003; Mounter et al., 2008; Li et al., 2019), in the absence of empirical estimates to indicate otherwise, input substitution between the commodity-related input and other inputs in stages of the value chain are assumed to be very small. A value of 0.1 is specified for input substitution elasticities between apples and other inputs for all stages in the model.

Product transformation elasticities measure the responsiveness of the product-mix ratio to relative changes in output prices and are needed where there are multiple output options or sectors. In their

review, Vincent, Dixon and Powell (1980) (cited by Mounter et al., 2008) include a range of product transformation values relevant to Australian agricultural markets, ranging from -0.04 to -2.13. In this EDM, product transformation elasticities are required at the farm and wholesale levels of the apple chain. At the wholesale level it is assumed that there is considerable flexibility in directing apples to the retail or food service markets as product quality is assumed to be identical. A value of -3.0 was given to this elasticity and corresponds with values assigned by Li et al. (2019) in the Australian grains industry. Apples destined for export markets are also assumed to be of identical quality to apples sold domestically; however, given the small size of the export volume in comparison to the domestic market, the product transformation possibilities are lower. Values of -1.0 were assigned to the elasticities of product transformation between export and retail and between export and food service. This still implies a degree of flexibility in changing the output mix among distribution channels. At the farm level, fresh and processing apples differ according to quality criteria and, therefore, product transformation possibilities are low. Apples failing to meet stringent quality standards for fresh consumption are redirected to the processing channel (Paam et al., 2019). A value of -0.1 is used to represent these limited transformation possibilities.

Given the paucity of available empirical estimates, subjective judgements were made in assigning values to the EDM parameters. The specified elasticities and values are listed in Table 4.

Table 4. Elasticities used in the model

Elasticities of Supply		
$\mathcal{E}_{(X_T, P_{XT})}$	Own-price elasticity of supply of apples	0.5
$\mathcal{E}_{(X_2, P_{X2})}$	Own-price elasticity of supply of wholesale inputs	2.0
$\mathcal{E}_{(X_5, P_{X5})}$	Own-price elasticity of supply of retail inputs	2.0
$\mathcal{E}_{(X_8, P_{X8})}$	Own-price elasticity of supply of food service inputs	2.0
$\mathcal{E}_{(X_{10}, P_{X10})}$	Own-price elasticity of supply of processing inputs	2.0
Elasticities of Demand		
$\eta_{(X_3, P_{X3})}$	-5.0 Own-price elasticity of demand of export apples	-5.0
$\eta_{(X_6, P_{X6})}$	-0.9 Own-price elasticity of demand of domestic fresh apples	-0.9
$\eta_{(X_9, P_{X9})}$	-0.9 Own-price elasticity of demand of food service apples	-0.9
$\eta_{(X_{12}, P_{X12})}$	-0.9 Own-price elasticity of demand of processing apples	-0.9
Elasticities of Input Substitution		
$\sigma_{(x_1, x_2)}$	Elasticity of substitution between fresh apples and other wholesale inputs	0.1
$\sigma_{(x_4, x_5)}$	Elasticity of substitution between apples for retail and retail inputs	0.1
$\sigma_{(x_7, x_8)}$	Elasticity of substitution between apples for food service and food service inputs	0.1
$\sigma_{(x_{10}, x_{11})}$	Elasticity of substitution between apples for processing and processing inputs	0.1
Elasticity of Product Transformation		
$\tau_{(x_1, x_{11})}$	Elasticity of product transformation between fresh and processing apples	-0.1
$\tau_{(x_3, x_4)}$	Elasticity of product transformation between export apples and apples for retail	-1.0
$\tau_{(x_4, x_7)}$	Elasticity of product transformation between apples for retail and apples for food service	-3.0
$\tau_{(x_3, x_7)}$	Elasticity of product transformation between export apples and apples for food service	-1.0

Exogenous shifts

There are six supply shift and four demand shift variables in the EDM that can be used to model various scenarios including effective research, development, and extension (RD&E) and successful promotion investments at different points in the chain. These are modelled as parallel shifts in the relevant demand or supply curves. Details of five hypothetical scenarios are given below.

Scenarios 1, 2 and 3 represent the adoption of a new technology or extension practice that leads to a 1 per cent reduction in the costs of farm-level production of fresh apples, and wholesale and retail production, respectively. These are simulated as 1 per cent downward shifts of the supply curves of both fresh apples for the wholesale and processing ($t_{XT} = -0.01$), and other inputs to the wholesale ($t_{X2} = -0.01$) and retail ($t_{X5} = -0.01$), respectively. Scenarios 4 and 5 simulate an increase in the willingness to pay by domestic consumers in the fresh apple market ($N_{X6} = 0.01$) and an increase in willingness to pay for apples by food service ($N_{X9} = 0.01$). These are modelled as 1 per cent upward shifts in the demand curves in those markets.

Results

For each scenario, percentage changes in price and quantities across the different market segments of the apple value chain were predicted in response to the specified exogenous shocks. The resulting changes in prices and quantities were used to calculate changes in consumer and producer surplus which are measures of the changes in economic welfare. These price and quantity changes are included in Appendix 2. The distribution of economic surplus changes for each scenario are shown in Table 5.

Scenario 1: Apple production R&D ($t_{XT} = -0.01$)

Scenario 1 depicts a decrease in the cost of on-farm production as the result of R&D. This may be from the development or implementation of a new technology, process or method which reduces the costs of production by 1 per cent from their original value.

A 1 per cent decrease in the cost of production at the farm level is simulated as a downward shift in the supply of apples ($T_{XT} = -0.01$). The directions of the demand and supply shifts in all markets are illustrated in Figure 3. The downward supply curve shifts decrease the prices and increase the quantities in those markets. Quantities of fresh apples and associated inputs increase, as do the prices of those other inputs due to increased input demands (X_2 , X_5 , X_8 and X_{10}). The prices of fresh apples decrease in each downstream stage of the chain due to the initial shifts at the farm level. Hence downward shifts of supply functions are observed in all downstream stages (X_1 , X_3 , X_4 , X_6 , X_7 , X_9 , X_{11} , and X_{12}) resulting in higher quantities and lower prices.

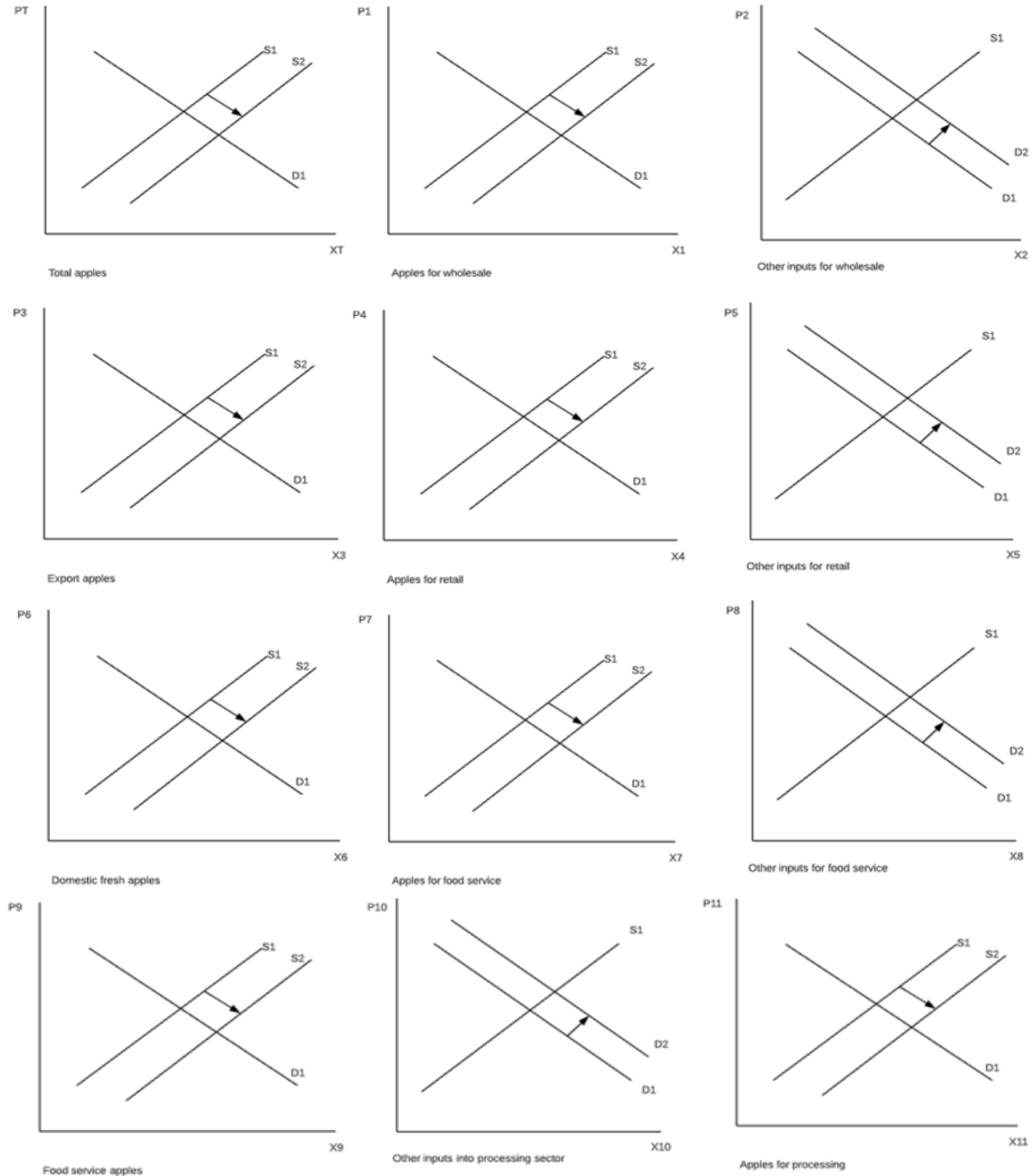
The total annual industry surplus gain is \$4.71 million with apple producers receiving around 57 per cent of the total and domestic consumers gaining just over 30 per cent. The remaining 13 per cent is distributed among the other industry stages. The directional shifts in demand or supply at each stage of the value chain are illustrated in Figure 3. In each instance D1 and S1 represent the original demand curve and the original supply curve, respectively.

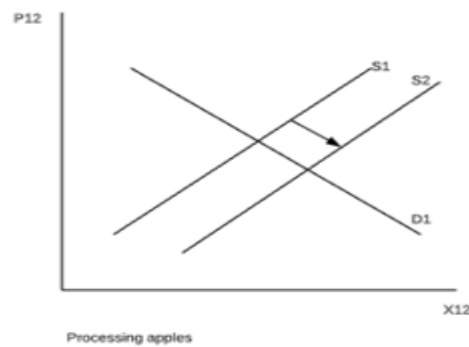
Scenario 2: Wholesale research ($t_{X2} = -0.01$)

Scenario 2 represents a decrease in the cost of inputs at the wholesale stage which may occur from adopting a new cost-saving practice or technology. A 1 per cent cost reduction at the wholesale stage increases the demand for fresh apples from the farm. Both the quantity supplied (X_1) and the price

of apples increase. The increased throughput leads to lower prices in downstream markets X_3 , X_4 , X_6 , X_7 , X_9 , X_{11} and X_{12}) and higher prices in input supply from increased demand for those factors of production.

Figure 3. Scenario 1 - apple production R&D: market demand and supply shifts





In this scenario the economic benefit to the wholesale stage is \$0.12 million, just under 9 per cent of the total industry gains of \$1.38 million. Apple producers and domestic consumers of fresh apples receive 46 per cent and 34 per cent of the total industry gains respectively.

Scenario 3: Retail research ($t_{x5} = -0.01$)

A cost reduction at the retail level could likely be a result of a new cost-saving practice or a reduction in input costs such as energy, rent or labour. Increased demand for apples by retail flows through to increased demand at the farm level, increasing prices and quantities of apples supplied (X_1). The input cost reduction in retail and increased apple supply (X_4) reduces the retail price of fresh apples paid by domestic consumers. Product transformation possibilities in output from the wholesale stages leads to some switching of apples from food service (X_7) to the retail channel. There is also a small diversion of apples that were previously destined for export (X_3) back onto the domestic market. Prices increase in upstream input stages (X_2 , X_8 , and X_{10}) as demand increases for those inputs. The price of processing apples falls as overall apple production increases.

Overall surplus gains for the industry in this scenario are small (\$0.25 million) as other inputs into retail apples are a small proportion of cost. Domestic producers receive around 44 per cent of the benefits, domestic consumers 48 per cent and the retail stage 6 per cent. The food service and export stages exhibit small losses.

Scenario 4: Domestic apple promotion ($n_{x6} = 0.01$)

Scenario 4 simulates a 1 per cent increase in domestic consumers' willingness to pay for fresh apples (X_6). This increased demand flows back to wholesale and farm-level production resulting in an increase in the quantity of apples supplied (X_1 , X_4 , and X_{11}). Increased demands for other inputs in the wholesale and retail stages (X_2 and X_5) increases the prices in those markets. There is a redirection of apples from food service (X_7) and export (X_3) to the domestic retail channel. Supply increases are also observed for processing quality apples as overall apple production increases.

Total economic surplus gains for the Australian apple industry are estimated to be \$4.9 million with producers and domestic consumers receiving most of the benefits.

Scenario 5: Food service increase in willingness to pay ($n_{x9} = 0.01$)

In comparison to retail, food service accounts for a relatively small proportion of apple sales. A 1 per cent increase in the willingness to pay by food service results in increased demand for apples at wholesale and at the farm level. The quantity of apples supplied (X_1 and X_7) increases in response to the increased demand. Small apple product flows are directed from retail (X_4) to food service (X_7), increasing the retail price of fresh apples. Increased demand for inputs at the wholesale and food service levels (X_1 and X_8) results in higher prices for these factors of production. At the retail level

there is a small decrease in demand for other inputs (X_5) associated with the substitution effects between food service and retail. Domestic consumers pay higher prices with fewer apples available.

A 1 per cent increase in food service willingness to pay for apples results in a total of \$0.94 million additional economic surplus for the industry. Food service receives \$0.67 million, apple farmers gain an additional \$0.52 million and there is a small gain to processors of \$0.03 million. Domestic consumers suffer a surplus loss of around \$0.31 million as apples are diverted from retail to the food service sector.

Comparison of economic surplus changes

The economic surplus changes for each of the five scenarios are listed in Table 5. Amounts are in \$ AUD millions. Note that the surplus changes ΔPS_{x8} and ΔPS_{x10} (food service and processing) are zero in all scenarios as the 'other input' cost shares in these stages are set to zero. Apples supplied to the food service and processing stages are used to produce a range of end products. Data for these outputs were not available to allow for their inclusion in the model. Hence, the surplus changes attributable to these stages only reflect those associated with the demand for apples by each stage and are captured as changes in consumer surplus (ΔCS_{x9} and ΔCS_{x12}).

In terms of absolute value, apple production research (Scenario 1) and domestic market promotion (Scenario 4) provide the largest total returns of the five hypothetical scenarios. The lowest total benefits result from retail stage research (Scenario 3) and increased willingness to pay by the food service stage (Scenario 5). Apple producers are the main beneficiaries in Scenarios 1, 2 and 4, receiving between 45 per cent and 56 per cent of the total benefits. Depending on the scenario of interest, domestic consumers receive between 30 per cent and 48 per cent of the total surplus gains. The wholesale, retail and processing stages all receive small shares of total benefits (less than 10 per cent) in Scenarios 1, 2, 3 and 4. Small positive shares accrue to the food service stage in Scenarios 1 and 2 with small losses experienced in Scenarios 3 and 4 due to redirection of apples from food service to the domestic retail channel. In Scenario 5 a 1 per cent increase in food service willingness to pay for apples delivers large positive surplus changes to the food service sector and apple producers while domestic consumers suffer a significant surplus loss.

Two key results emerge from examination of the shares of total benefits presented in Table 5. The first is that on-farm research in apple production provides apple producers with a larger share of the total returns compared with off-farm research in downstream industry sectors. This result is consistent with other studies where input substitution is assumed to be non-zero (e.g. Mullen et al. 1989; Zhao et al 2001). The second key outcome which answers a question of relevance to industry groups, and in particular to levy-paying producers, is whether investment funds should be spent on R&D or promotion. The percentage shares of total benefits indicate that on-farm research is more beneficial for apple producers than is promotion of apples in the domestic market. That is, producers gain more, for example, from a reduction in production costs than from an equivalent increase in demand resulting from successful promotion investment.

Sensitivity Analysis

Given the paucity of available empirical estimates for the parameter values in the EDM, it is desirable to undertake sensitivity analysis on the parameters to determine the robustness of the results. Discrete sensitivity analysis was undertaken by varying the values of key parameters in the model. To test the robustness of the results for Scenario 1 (apple production R&D), the own price elasticity of supply of apples (X_7) was reduced from 0.5 to 0.1 with all other parameter values remaining the same. This is identified as Scenario 1 (B) in Table 6.

Table 5. Surplus changes

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	\$ Million AUD	%	\$ Million AUD	%	\$ Million AUD	%	\$ Million AUD	%	\$ Million AUD	%
ΔPS_{XT} (Total apples)	2.674	56.83%	0.631	45.90%	0.112	44.48%	2.551	52.52%	0.525	55.56%
ΔPS_{X2} (Other inputs for wholesale)	0.158	3.36%	0.118	8.60%	0.009	3.72%	0.213	4.39%	0.044	4.64%
ΔPS_{X5} (Other inputs for retail)	0.028	0.59%	0.009	0.68%	0.014	5.72%	0.055	1.13%	-0.006	-0.65%
Total Change Producer Surplus	2.860	60.79%	0.759	55.18%	0.135	53.92%	2.820	58.04%	0.562	59.55%
ΔCS_{X3} (Overseas Consumers)	0.012	0.25%	0.004	0.29%	0.000	-0.09%	-0.005	-0.10%	-0.001	-0.11%
ΔCS_{X6} (Domestic Consumers)	1.417	30.12%	0.474	34.43%	0.122	48.68%	2.187	45.01%	-0.312	-33.00%
ΔCS_{X9} (Food service)	0.292	6.20%	0.097	7.09%	-0.014	-5.44%	-0.311	-6.41%	0.660	69.90%
ΔCS_{X12} (Processing)	0.124	2.64%	0.042	3.02%	0.007	2.93%	0.168	3.46%	0.035	3.66%
Total Change in Consumer Surplus	1.845	39.21%	0.616	44.82%	0.116	46.08%	2.038	41.96%	0.382	40.45%
Total Change in Economic Surplus	4.705	100.00%	1.375	100.00%	0.251	100.00%	4.858	100.00%	0.944	100.00%

Table 6. Surplus changes for discrete sensitivity analysis

	Original Scenario 1		Scenario 1 (B)		Original Scenario 4		Scenario 4 (B)		Scenario 4 (C)	
	\$ Million AUD	%	\$ Million AUD	%	\$ Million AUD	%	\$ Million AUD	%	\$ Million AUD	%
ΔPS_{XT} (Total apples)	2.674	56.83%	4.081	86.81%	2.551	52.52%	2.082	42.86%	2.875	59.19%
ΔPS_{X2} (Other inputs for wholesale)	0.158	3.36%	0.048	1.03%	0.213	4.39%	0.174	3.58%	0.240	4.95%
ΔPS_{X5} (Other inputs for retail)	0.028	0.59%	0.009	0.18%	0.055	1.13%	0.045	0.92%	0.062	1.28%
Total Change Producer Surplus	2.860	60.79%	4.138	88.02%	2.820	58.04%	2.301	47.37%	3.178	65.41%
ΔCS_{X3} (Overseas Consumers)	0.012	0.25%	0.004	0.08%	-0.005	-0.10%	-0.004	-0.08%	-0.006	-0.11%
ΔCS_{X6} (Domestic Consumers)	1.417	30.12%	0.433	9.20%	2.187	45.01%	2.677	55.09%	1.848	38.05%
ΔCS_{X9} (Food service)	0.292	6.20%	0.089	1.89%	-0.311	-6.41%	-0.254	-5.23%	-0.351	-7.22%
ΔCS_{X12} (Processing)	0.124	2.64%	0.038	0.81%	0.168	3.46%	0.138	2.83%	0.189	3.90%
Total Change in Consumer Surplus	1.845	39.21%	0.563	11.98%	2.038	41.96%	2.556	52.61%	1.682	34.61%
Total Change in Economic Surplus	4.705	100.00%	4.701	100.00%	4.858	100.00%	4.858	100.00%	4.858	100.00%

A lower supply elasticity represents a lower supply response to market price changes, which likely reflects the nature of apple supply over a shorter period of time. Given the lead time from planting to production is four to five years (ABS, 2018), and assuming the land requires preparation ahead of planting, significant changes to production will likely be slow. In Scenario 1 (B), the distribution of gains favours apple producers (almost 87 per cent of the total surplus, compared to almost 57 per cent in the original scenario). The results from Scenario 1 (B) are consistent with expectations that producer surplus gains will be larger as the own-price elasticity of supply becomes more price-inelastic (Alston et al., 1995, p.64).

In Scenario 4 (B) the own-price elasticity of demand for fresh apples was reduced from -0.9 to -0.6, and in Scenario 4 (C) this value was increased to -1.2, with all other parameters kept the same as in the base version. Scenario 4 (B) indicated a decrease in the share of apple producers' surplus and an increased share of surplus received by domestic consumers who received an additional 10 per cent compared to the original Scenario 4. Conversely, the increase in value of the own-price elasticity of demand in Scenario 4 (C) resulted in an increase in the producer share of the surplus while domestic consumers lost around 7 per cent compared to the amount of surplus in the original Scenario 4. For both Scenarios 4 (B) and (C), the changes in surplus shares are as expected. A lower own-price elasticity of demand redistributes surplus to consumers, while an increase in the own-price elasticity of demand increases the shares of other stages in the chain, particularly to the early-stage actors.

The results of the discrete sensitivity analysis highlight the need for reliable estimates of key parameter values. A redistribution of surplus between producers and consumers results from changes in own-price demand and supply elasticity values. Producers received the largest distributional increase from a lower own-price elasticity of supply associated with on-farm R&D (over \$AUD 1.2 million). In the sensitivity analysis, consumers lost the greatest shares of their surplus in scenarios 1 (B), with the decrease in elasticity of supply resulting in over a 20 per cent decrease in consumer surplus. The own price elasticity of the supply of apples appears to be the most imperative from those tested to producers and resulted in the largest shifts of surplus distribution. Testing of the own-price elasticity of demand resulted in smaller shifts throughout the value chain.

Conclusion

One qualification to note is that the results are conditional on the price, quantity and parameter values used in the model and this should be kept in mind when interpreting the results. Having reliable estimates of prices, quantities, and parameter values that are representative of the Australian apple industry structure is critical to being able to provide credible input into decision-making processes. Sensitivity analyses assist in this regard, but further work is required in this area. It is also important to qualify that the monetary returns of the different scenarios presented in this paper are only directly comparable if the investment costs of bringing about the 1 per cent demand or supply shifts in each stage are the same. However, the distributions of the returns among various investment scenarios are comparable, irrespective of the magnitude of the initial shift. For example, apple producers' percentage share of the total benefits from lower production costs is the same irrespective of whether costs fall by 1 per cent or 10 per cent. If detailed costs are known, the EDM framework is suited for providing cost-benefit analyses with the advantage of disaggregation of costs and benefits among the value chain actors.

Although the simulated scenarios relate to relatively small changes implemented at specific value chain stages, it is evident that there is opportunity for collaborative actions among value chain members to capitalise on 'low hanging fruit'. The model can also readily be applied to assess the economic impacts on the industry from changes in government policies and current challenges confronting the Australian apple industry. One final caveat is that the current EDM framework only

accounts for private benefits and costs within the chain. The framework could be extended to account for external benefits and costs beyond the apple industry.

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Appendix 1. Displacement Form Equations

The displacement form of the general functional form EDM equations (13) to (41) are presented below in (1) to (29).

- (1) $EX_T = \varepsilon_{(X_T, PX_T)}(EP_{X_T} - T_{X_T})$
- (2) $EX_1 = \lambda_{X11}\tau_{(X1, X11)}EP_{X1} - \lambda_{X11}\tau_{(X1, X1)}EP_{X11} + EX_F$
- (3) $EX_{11} = -\lambda_{X1}\tau_{(X1, X11)}EP_{X1} + \lambda_{X1}\tau_{(X1, X1)}EP_{X11} + EX_F$
- (4) $EX_T = \lambda_{X1}EX_1 + \lambda_{X11}EX_{11}$
- (5) $EP_{X_T} = \lambda_{X1}EP_{X1} + \lambda_{X11}EP_{X11}$
- (6) $EX_2 = \varepsilon_{(X2, PX2)}(EP_{X2} - T_{X2})$
- (7) $EX_1 = -\kappa_{X2}\sigma_{(X1, X2)}EP_{X1} + \kappa_{X2}\sigma_{(X1, X2)}EP_{X2} + EY_W$
- (8) $EX_2 = \kappa_{X1}\sigma_{(X1, X2)}EP_{X1} - \kappa_{X1}\sigma_{(X1, X2)}EP_{X2} + EY_W$
- (9) $EX_3 = -(\lambda_{X4}\tau_{(X3, X4)} + \lambda_{X7}\tau_{(X3, X7)})EP_{X3} + \lambda_{X4}\tau_{(X3, X4)}EP_{X4} + \lambda_{X7}\tau_{(X3, X7)}EP_{X7} + EX_W$
- (10) $EX_4 = -(\lambda_{X3}\tau_{(X3, X4)} + \lambda_{X7}\tau_{(X4, X7)})EP_{X4} + \lambda_{X3}\tau_{(X3, X4)}EP_{X3} + \lambda_{X7}\tau_{(X4, X7)}EP_{X7} + EX_W$
- (11) $EX_7 = -(\lambda_{X3}\tau_{(X3, X7)} + \lambda_{X4}\tau_{(X4, X7)})EP_{X7} + \lambda_{X3}\tau_{(X3, X7)}EP_{X3} + \lambda_{X4}\tau_{(X4, X7)}EP_{X4} + EX_W$
- (12) $\kappa_{X1}EX_1 + \kappa_{X2}EX_2 = \lambda_{X3}EX_3 + \lambda_{X4}EX_4 + \lambda_{X7}EX_7$
- (13) $\kappa_{X1}EP_{X1} + \kappa_{X2}EP_{X2} = \lambda_{X3}EP_{X3} + \lambda_{X4}EP_{X4} + \lambda_{X7}EP_{X7}$
- (14) $EX_5 = \varepsilon_{(X5, PX5)}(EP_{X5} - T_{X5})$
- (15) $EX_4 = \kappa_{X5}\sigma_{(X4, X5)}EP_{X4} - \kappa_{X5}\sigma_{(X4, X5)}EP_{X5} + EX_6$
- (16) $EX_5 = \kappa_{X4}\sigma_{(X4, X5)}EP_{X4} - \kappa_{X4}\sigma_{(X4, X5)}EP_{X5} + EX_6$
- (17) $EP_{X6} = \kappa_{X4}EP_{X4} + \kappa_{X5}EP_{X5}$
- (18) $EX_3 = \eta_{(X3, PX3)}(EP_{X3} - n_{X3})$
- (19) $EX_6 = \eta_{(X6, PX6)}(EP_{X6} - n_{X6})$
- (20) $EX_8 = \varepsilon_{(X8, PX8)}(EP_{X8} - t_{X8})$
- (21) $EX_7 = -\kappa_{X8}\sigma_{(X7, X8)}EP_{X7} + \kappa_{X8}\sigma_{(X7, X8)}EP_{X8} + EX_9$
- (22) $EX_8 = -\kappa_{X7}\sigma_{(X7, X8)}EP_{X7} - \kappa_{X7}\sigma_{(X7, X8)}EP_{X8} + EX_9$
- (23) $EP_{X9} = \kappa_{X7}EP_{X7} + \kappa_{X8}EP_{X8}$
- (24) $EX_9 = \eta_{(X9, PX9)}(EP_{X9} - n_{X9})$
- (25) $EX_{10} = \varepsilon_{(X10, PX10)}(EP_{X10} - t_{X10})$
- (26) $EX_{10} = -\kappa_{X11}\sigma_{(X10, X11)}EP_{X10} + \kappa_{X11}\sigma_{(X10, X11)}EP_{X11} + EX_{12}$
- (27) $EX_{11} = \kappa_{X10}\sigma_{(X10, X11)}EP_{X10} - \kappa_{X10}\sigma_{(X10, X11)}EP_{X11} + EX_{12}$
- (28) $EP_{X12} = \kappa_{X10}EP_{X10} + \kappa_{X11}EP_{X11}$
- (29) $EX_{12} = \eta_{(X12, PX12)}(EP_{X12} - n_{X12})$

Appendix 2. Price and Quantity Changes, Scenarios 1 to 5

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
X_T	0.002842	0.000672	0.000119	0.002711	0.000558
X_1	0.002854	0.000649	0.000115	0.002620	0.000539
X_2	0.002295	0.001720	0.000136	0.003099	0.000638
X_3	0.004836	0.001617	-0.000089	-0.002031	-0.000418
X_4	0.002649	0.000886	0.000177	0.004032	-0.000583
X_5	0.002224	0.000744	0.001144	0.004381	-0.000490
X_6	0.002627	0.000878	0.000227	0.004050	-0.000578
X_7	0.002784	0.000931	-0.000130	-0.002978	0.006287
X_8	0.002357	0.000788	-0.000110	-0.002521	0.006275
X_9	0.002784	0.000931	-0.000130	-0.002978	0.006287
X_{10}	0.002952	0.000767	0.000136	0.003099	0.000638
X_{11}	0.002711	0.000907	0.000160	0.003660	0.000753
X_{12}	0.002711	0.000907	0.000160	0.003660	0.000753
P_{XT}	-0.004317	0.001343	0.000237	0.005422	0.001116
P_{X1}	-0.004442	0.001569	0.000277	0.000633	0.001304
P_{X2}	0.001148	-0.009140	0.000068	0.001549	0.000319
P_{X3}	-0.000967	-0.000323	0.000018	0.000406	0.000084
P_{X4}	-0.003139	-0.001050	0.000249	0.005680	0.000691
P_{X5}	0.001112	0.000372	-0.009428	0.002191	-0.000245
P_{X6}	-0.002919	-0.000976	-0.000252	0.005500	0.000643
P_{X7}	-0.003093	-0.001034	0.000145	0.003309	0.003014
P_{X8}	0.001178	0.000394	-0.000055	-0.001261	0.003137
P_{X9}	-0.003093	-0.001034	0.000145	0.003309	0.003014
P_{X10}	0.001148	0.000384	0.000068	0.001549	0.003188
P_{X11}	-0.003012	-0.001007	-0.000178	-0.004067	-0.000837
P_{X12}	-0.003012	-0.001007	-0.000178	-0.004067	-0.000837