The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian
Agricultural and Resource
Economics Society

The Australian Journal of Agricultural and Resource Economics, 54, pp. 491–507

Dairy disaggregation and joint production in an economy-wide model*‡

Angus Charteris and Niven Winchester†

We examine the impact of dairy disaggregation and joint production on trade liberalisation outcomes in an economy-wide model. Depending on parameterisation, our model includes either (i) a single dairy commodity, (ii) several dairy commodities without joint production or (iii) several dairy commodities with joint production. In a numerical application, we consider the removal of US tariffs on dairy exports from New Zealand (the world's largest dairy exporter). We show that failing to account for joint production when dairy commodities are disaggregated leads to misleading results. Our preferred dairy production function differs from those used in other applied trade models. Our analysis can be used to determine when accounting for joint production in other sectors is important.

Key words: disaggregation, joint production, trade liberalisation.

1. Introduction

Economy-wide (or computable general equilibrium, CGE) models are commonly used to evaluate alternative trade negotiation outcomes. Substantial data requirements necessitate the identification of relatively highly aggregated sectors in these models. This can cause serious aggregation issues, especially if exports from a region of interest are dominated by a sector that has not received the same degree of disaggregation as major export sectors in other regions.

Recent research has addressed aggregation issues. Horridge (2005) documents a utility, SplitCom, that facilitates analysis at a finer level of sectoral aggregation than in conventional CGE investigations. SplitCom is a set of programs that enables the disaggregation of one sector in the Global Trade Analysis Project (GTAP) database into two or more new sectors, which can be calibrated to user-provided data. As SplitCom is only a disaggregation tool, models built on SplitCom disaggregations include separate production

* The authors wish to thank James McVitty and Ken Geard from Fonterra and participants at the Eleventh Annual Conference on Global Economic Analysis for helpful comments and suggestions. Remaining errors are the authors' responsibility.

‡ The views in this paper are strictly those of the authors. They do not necessarily reflect the views of the Ministry of Foreign Affairs and Trade. The Ministry takes no responsibility for any errors or omissions in the paper. The paper is presented not as policy, but with a view to inform and stimulate wider debate.

† Angus Charteris is at New Zealand Ministry of Foreign Affairs and Trade. Niven Winchester (email: niven.winchester@otago.ac.nz), MIT Joint Program on the Science and Policy of Global Change & University of Otago.

doi: 10.1111/j.1467-8489.2010.00508.x

functions for each new sector. Aggregation issues are likely to be severe in the dairy sector as dairy is one of the most heavily protected sectors and trade distortions can vary widely across commodities. To this end, Mraz and Matthews (2007) facilitate the use of SplitCom for dairy disaggregation by estimating production cost shares for four dairy commodities in 14 regions. We complement this literature by focusing on joint production in the dairy sector.

An important feature of dairy production is that milk protein is produced by extracting fat from fluid milk, that is, protein-based and fat-based dairy products are produced jointly. Consequently, numerical analyses of dairy liberalisation that do not consider joint production may predict impractical product-mix changes. Although joint dairy production has been considered in partial equilibrium studies (see, for example, Cox *et al.* 1999; Zhu *et al.* 1999; Bouamra-Mechemache *et al.* 2002), to our knowledge, dairy disaggregation and joint production have not been considered in economy-wide studies. It is important to consider joint dairy production in a general equilibrium framework when the dairy sector is large relative to GDP. This is because accounting for sectoral interactions and considering factor markets in an economy-wide setting will improve accuracy relative to partial equilibrium analyses. Typically, economy-wide analyses include only a single processed dairy sector, even when dairy is a significant export earner for one or more countries of interest.[1] Grant *et al.* (2007, 2008), on the other hand, include 24 processed dairy commodities but assume that it is relatively easy for dairy producers to change their product mix. Therefore, the authors' specification resembles a model with a separate sector for each commodity and is prone to overestimating output response changes.

We analyse the impact of joint production and dairy disaggregation using a production specification that nests (i) a single processed dairy commodity, (ii) several processed dairy commodities without joint production and (iii) several processed dairy commodities with joint production as special cases. We do this using a set of constant elasticity of transformation (CET) functions to allocate a sector's output to alternative commodities and by creating a constant elasticity of substitution (CES) dairy composite. The special cases outlined above are generated by choosing appropriate values for CET parameters and the elasticity of substitution between processed dairy commodities. Grant *et al.* (2007, 2008) also use a CET function to allocate dairy production across alternative commodities. However, the authors assume that transformation possibilities are the same across alternatives and do not consider joint production. In contrast, we model joint production and allow transformation possibilities across commodities to differ. Our preferred production structure is guided by industry experts.

[1] See, for example, Francois and Wignaraja (2008), Scollay and Gilbert (2001), Rae and Strutt (2004) and Winchester (2006).

Our numerical simulations focus on New Zealand, the world's largest dairy exporter. We first tease out important disaggregation characteristics with and without joint production in an illustrative setting. We then consider the removal of US dairy tariffs on New Zealand products in a detailed analysis. Our framework can be applied to a subset of regions in a global, economy-wide model and requires a modest amount of additional data. Supplementary data include (i) output by subsector for the exporting region of interest, (ii) exports from the region of interest to destinations of interest and (iii) trade distortions imposed by destinations of interest.

This paper has three further sections. Section 2 outlines our modelling framework. Section 3 examines the impact of disaggregation and joint production in an illustrative setting. Section 4 discusses the form of our detailed analysis and reports modelling results. Section 5 concludes.

2. Model structure

Our numerical simulations employ the 'GTAP6inGAMS' model. GTAP6inGAMS draws on version six of the GTAP database (Dimaranan 2006) and is programmed using the general algebraic modelling system (GAMS). The GTAP database 'combines detailed bilateral trade, transport and protection data characterising economic linkages among regions, together with individual country input–output data bases which account for inter-sectoral linkages within regions' (Hertel 2002, pp. 1–2). Version six of the database provides a representation of the global economy in 2001. Models such as GTAP6inGAMS are widely used to investigate trade liberalisation outcomes.[2] The model is a static, perfectly competitive, multi-regional representation of the global economy that determines the production and allocation of goods. We outline salient features of the model below. Rutherford (2005) provides a detailed description.[3]

Important empirical observations not replicated in standard trade models include intra-industry trade and failure of the law of one price for traded goods. Accordingly, imports in GTAP6inGAMS are differentiated by country of origin according to a CES function (i.e. the import demand specification is separable). Composite imports are also differentiated from domestic products using a CES function following Armington (1969). Elasticity parameters for our import specification are sourced from Hertel *et al.* (2007). Specifically, the Armington composite of good i purchased in each region, DM_i, is

[2] See, for example, Anderson and van der Mensbrugghe (2007), Francois and Wignaraja (2008), Grant *et al.* (2007), Rae and Strutt (2004), Robinson and Thierfelder (2002) and Scollay and Gilbert (2000).

[3] The GTAP database is distributed with a model programmed using the General Equilibrium Modelling PACKage (GEMPACK). Readers familiar with GEMPACK should note that there are several differences between GTAP6inGAMS and the GEMPACK version of the GTAP model.

$$DM_i = \varphi^{DM}\left(\gamma^{DM} D_i^{\rho_i^{DM}} + (1-\gamma^{DM})\left(\varphi^M\left(\sum_r \gamma_r^M M_{ir}^{\rho_i^M}\right)^{1/\rho_i^M}\right)^{\rho_i^{DM}}\right)^{1/\rho^{DM}} \quad (1)$$

where D_i is the quantity of good i sourced domestically; M_{ir} denotes imports of good i from region r; φ^{DM}, φ^M, γ^{DM}, and γ_r^M are positive parameters, and $\rho_i^k = (\sigma_i^k - 1)/\sigma_i^k (k \epsilon DM, M)$, where σ_i^{DM} and σ_i^M are, respectively, elasticities of substitution between domestic production and aggregate imports, and imports from different regions.

Production technologies exhibit constant returns to scale and product and factor prices adjust to maintain zero profits. Output in each sector is governed by a Leontief nest of an intermediate input composite and a primary factor composite. The intermediate input composite is derived from a further Leontief aggregation of different products (which are themselves composites of domestic and imported varieties). Specifically, production in sector i, Y_i, is determined by:

$$Y_i = min\left\{a_{i1} Y_{i1}, \cdots a_{ij} Y_{ij}, A_i^{VA} \prod_f x_{if}^{a_{if}}\right\} \quad (2)$$

where Y_{ij} is the quantity of good j ($j \epsilon 1, \cdots, J$) used as an intermediate input into sector i, x_{if} is the quantity of factor f employed in sector i, and a_{ij}, a_i^{VA} and α_{if} are positive parameters.

As GTAP6inGAMS only identifies a single processed dairy sector, dairy producers are unable to change their product mix in response to changes in relative prices. Product-mix changes are possible when the database is disaggregated and a separate sector is included for each dairy commodity, as performed by SplitCom, but joint production is ignored. As a result, creating a separate sector for each dairy commodity overestimates product-mix changes. We modify the production function in subsequent sections to account for joint production when the dairy sector is disaggregated. We also modify assumptions regarding factor mobility. Specifically, we stipulate that agricultural land is sector specific to avoid impractical land-use changes following our trade shocks.

3. Illustrative analysis

Our numerical simulations focus on New Zealand. This is an interesting country to investigate as New Zealand is the world's largest dairy exporter, and dairy exports account for 16 per cent of this nation's total exports.[4] Version six of the GTAP database identifies 87 regions and 57 sectors,

[4] Uruguay's dairy exports contribute 4 per cent of this nation's total exports, which is the second-highest dairy export share across all regions included in the GTAP database.

including processed dairy and fluid milk. We identify two regions (New Zealand and Rest or World, RoW) and six sectors (fluid milk, processed dairy, other agriculture, resource-based sectors, manufacturing and services). In GTAP6inGAMS, the processed dairy sector uses fluid milk, other intermediate inputs and primary factors to produce a single processed dairy commodity. As mentioned previously, including a single dairy commodity ignores flexibilities in production and consumption of different dairy commodities, while specifying a separate sector for each dairy commodity ignores joint production. We investigate drawbacks associated with each disaggregation technique using a framework that nests the two approaches and a joint production specification as special cases. We begin by teasing out the important features of disaggregation and joint dairy production in a simplistic setting before considering a detailed application in Section 4.

Initially, to assist tractability, we consider disaggregation of the processed dairy sector into two commodities: butter (fat-based) and skim milk powder (SMP, protein-based). Production and consumption of New Zealand dairy in our illustrative analysis is outlined in Figure 1. We consider joint dairy production in the processing sector by allocating processed dairy, Y_D, to butter and SMP according to a CET function:[5]

$$Y_D = \left(\theta Y_D^{B^{\rho^T}} + (1-\theta) Y_D^{S^{\rho^T}}\right)^{1/\rho^T} \tag{3}$$

where Y_D^B and Y_D^S denote the production of butter and SMP, respectively, θ is a positive parameter, and $\rho^T = \frac{\sigma^T - 1}{\sigma^T}$ where σ^T is the elasticity of transformation between butter and SMP.

Our treatment of dairy purchases allows our framework to be applied without the need for data relating to New Zealand imports or RoW consumption of disaggregated dairy commodities. As illustrated in Figure 1, tariffs and transport costs are applied to disaggregated commodities. Dairy commodities are then reassembled using a CES function with elasticity parameter σ^S. The composite dairy commodity is purchased by firms and households, both domestically and abroad. Consequently, New Zealand butter and SMP do not compete directly with butter and SMP from RoW. Instead, agents choose between a New Zealand dairy composite and an aggregate dairy commodity produced by RoW. Following assignment of regional dairy expenditure, agents allocate expenditure on New Zealand dairy across butter and SMP. Specifically, RoW dairy imports from New Zealand, $M_{D,NZL}$, are captured by adding an additional CES function to the Armington specification in the base model:

[5] As pointed out by a referee, joint production could be modelled at the farm level instead of in the processing sector. Modelling joint production in fluid milk produces similar results to those above.

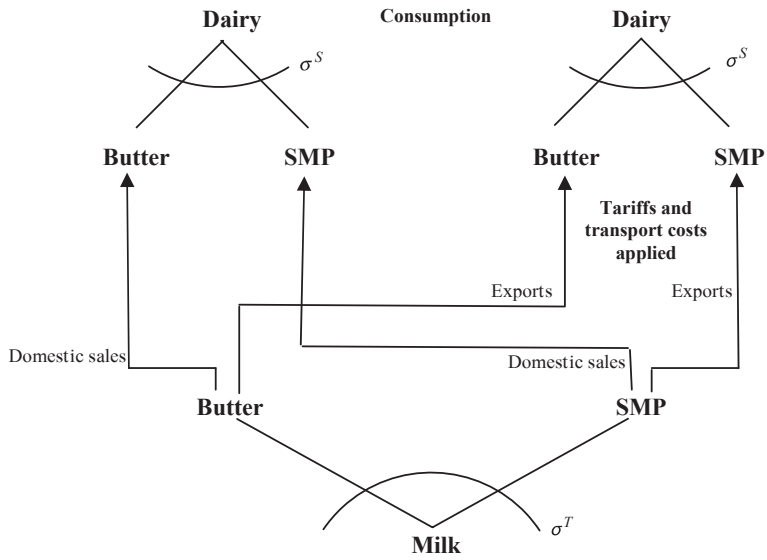

Figure 1 Illustrative dairy production structure and consumption.

$$M_{D,NZL} = \left(\gamma^D {M^B_{D,NZL}}^{\rho^s} + (1-\gamma^D){M^S_{D,NZL}}^{\rho^s}\right)^{1/\rho^s} \tag{4}$$

where $M^B_{D,NZL}$ and $M^S_{D,NZL}$ denote RoW imports of butter and SMP, respectively, from New Zealand, γ^D is a positive parameter, and $\rho^s = (\sigma^s - 1)/\sigma^s$ where σ^s is the elasticity of substitution between butter and SMP.

Our framework nests two common approaches as special cases. When $\sigma^S = 0$ and butter and SMP expenditure shares are equal across regions, the model behaves as if there is a single processed dairy sector. This is because dairy commodities are demanded in fixed proportions when $\sigma^S = 0$, independent of σ^T, so the dairy sector changes the production of both dairy commodities by the same proportion as dairy prices vary. When $\sigma^T = \infty$ and $\sigma^S > 0$, there is a separate production function for each dairy commodity, each employing identical technologies. This specification is equivalent to that produced by SplitCom when production cost shares are identical across sectors.

We assess the impact of alternative approaches on modelling outcomes by considering three alternative specifications for σ^S and σ^T. In specification (I.1), we consider a model with a single (aggregate) dairy commodity by setting $\sigma^S = 0$. Two dairy commodities produced jointly are modelled in specification (I.2) by choosing $\sigma^S = 5$ and $\sigma^T = 0$. In specification (I.3), we consider two dairy commodities with separate production functions by selecting $\sigma^S = 5$ and $\sigma^T = \infty$.

Rather than using data to complete our alternative dairy specification, we analyse results for alternative parameterisations that are consistent with aggregate dairy data in the GTAP database. This allows us to highlight

situations where accounting for joint production is important. RoW tariffs on New Zealand butter, t^B, and SMP, t^{SMP}, are, respectively, equal to $t^B = t^D \frac{\omega}{\alpha}$ and $t^{SMP} = t^D \frac{(1-\omega)}{(1-\alpha)}$, where, t^D is RoW's tariff on aggregate New Zealand dairy products, ω is the proportion of t^D attributable to t^B $(0 \leq \omega \leq 1)$, and α is the value-share of RoW butter imports from New Zealand in total dairy imports from this country $(0 < \alpha < 1)$. Initially, we make the neutral assumption that dairy production and consumption (in both New Zealand and RoW) is split evenly between butter and SMP ($\alpha = 0.5$). We also set $\omega = 1$ so as to maximise the change in the butter–SMP relative price following trade liberalisation.[6] In the GTAP database, $t^D = 0.091$, so $t^B = 0.182$ and $t^S = 0$ when $\omega = 1$ and $\alpha = 0.5$.

We report changes in New Zealand welfare, dairy production and export volumes, and real producer prices in Table 1 following the elimination of RoW tariffs on New Zealand dairy products. We measure welfare changes using the Hicksian equivalent variation in income. Welfare changes are reported in 2001 US dollars and expressed as a per cent of GDP and represent increments to welfare that can be expected in each succeeding year. Changes in New Zealand welfare and dairy production and exports are substantial but not unexpected given the size of the tariff change, the significance of the dairy sector to New Zealand's economy and the nature of the shock (which gives New Zealand dairy products preferential treatment over RoW's imports from itself).[7] The model behaves as if there is a single dairy commodity in

Table 1 Changes in New Zealand welfare, output and export volumes and prices following the removal of rest or world dairy tariffs

	(I.1)	(I.2)	(I.3)
	$\sigma^S = 0$	$\sigma^S = 5, \sigma^T = 0$	$\sigma^S = 5, \sigma^T = \infty$
Equivalent variation, US$ million	779.4	857.5	1139.1
Equivalent variation, %	1.7	1.9	2.5
Dairy output, %	66.2	67.2	87.0
Butter	66.2	67.2	206.0
Skim milk powder	66.2	67.2	−32.1
Dairy producer prices, %	7.6	7.5	10.5
Butter	14.8	25.6	10.5
Skim milk powder	0.4	−10.5	10.5
Dairy exports, %	82.9	81.0	108.9
Butter	82.9	104.6	262.2
Skim milk powder	82.9	57.4	−44.5

Note: Producer prices are deflated by a consumer price index.
Source: Simulation results as described in the text.

[6] Setting $\omega = 0$ also maximises the liberalisation-induced change in the butter–SMP relative price and, as $\alpha = 0.5$, produces symmetrical results.

[7] Rest or World includes many countries that impose tariffs on each other's exports. To maintain input–output integrity, these tariffs appear as tariffs on internal trade when these countries are aggregated together.

simulation (I.1), so production and exports of butter and SMP increase by equal proportions.

Consumers can respond to relative dairy prices but New Zealand producers must manufacture the two dairy commodities in fixed proportions in simulation (I.2). As a result, exports of both dairy commodities increase but the rise in butter exports (104.6 per cent) is larger than the increase in SMP exports (57.4 per cent). Substitution in demand away from SMP and towards butter amplifies the increase in the butter price and the decrease in the SMP price. There is also a larger increase in New Zealand welfare in (I.2) than in (I.1).

In (I.3), the increase in butter exports is substantial (262.2 per cent) and, unlike in other simulations, SMP exports decrease. Also, as SMP and butter production are no longer tied, the fall in SMP–butter relative demand results in a decline in SMP production. Proportional price changes are equal across commodities because butter and SMP technologies are identical (so cost changes are equal across commodities) and producers make zero profits.

Comparing results for (I.2) and (I.3) indicates that assumptions regarding dairy production can have a large influence on modelling outcomes when there is more than one dairy commodity. When there is joint production, output of both dairy commodities increases by 67.2 per cent. When there is a separate sector for each dairy commodity, the increase in butter production is more than three times as large as when there is joint production. Furthermore, changes in SMP output are of opposite signs in (I.2) and (I.3). Also, increases in both welfare and aggregate dairy production are about 30 per cent larger in (I.3) than in (I.2).

So far we have assumed that the aggregate dairy tariff can be attributed to a tariff applying to a single dairy commodity (and the tariff on the other dairy commodity is zero). Two other cases are possible: $t^B > t^S > 0$ (i.e. $0.5 < \omega < 1$) and $t^B = t^S$ (i.e. $\omega = 0.5$). (As the model is symmetric, we do not consider situations where $\omega < 0.5$.) When $t^B > t^S > 0$, the liberalisation-induced increase in the relative price of butter is smaller than when $t^B > 0$ and $t^D = 0$, so there is less deviation across modelling results than in Table 1 (and the model continues to behave as if there is a single dairy commodity when $\sigma^S = 0$).

When $t^B = t^S$, eliminating tariffs does not change the butter–SMP relative price, so proportional changes in production and consumption are the same for both dairy commodities. As a result (and because dairy expenditure shares are equal across countries), the model mimics the case when there is a single dairy sector irrespective of the values of σ^S and σ^T. That is, neither disaggregation nor the treatment of joint production alters modelling outcomes when tariffs are identical across commodities. Our results are also influenced by the value of α. Holding ω constant, the butter tariff increases as α decreases. Consequently, when $\omega = 1$, liberalisation-induced changes in (I.2) and (I.3) are smaller than those reported in Table 1 when $\alpha > 0.5$ and larger when $\alpha < 0.5$.

In summary, our illustrative analysis shows that joint production and disaggregation can have a large influence on quantitative assessments of the impact of trade liberalisation. Discrepancies between aggregated and disaggregated results increase as the variation of tariffs across disaggregated commodities increases.[8] Provided tariffs differ across commodities, discrepancies also increase–(i) the larger the elasticity of substitution between disaggregated commodities and (ii) the greater the transformability of dairy production across disaggregated commodities (providing $\sigma^S > 0$). Moreover, our results reveal that it is not always appropriate to use SplitCom to disaggregate sectors when a finer level of sectoral aggregation is desired. Specifically, when two commodities are produced jointly, models built on a SplitCom version of the GTAP database overestimate production changes.

4. Detailed analyses

An accurate representation of dairy production should model joint production for some processed dairy commodities (e.g. protein and fat) and account for transformation possibilities for other dairy commodities (e.g. cheese and whole milk powder (WMP)). We analyse the implications of disaggregation and joint production more comprehensively by distinguishing nine processed dairy commodities and considering the elimination of US dairy tariffs on imports from New Zealand.[9] The US is the destination for 5.5 per cent of New Zealand's dairy exports and is New Zealand's third largest overseas dairy market, behind Japan and Mexico.

New Zealand production value shares and US import value shares for dairy commodities are displayed in Table 2. The products are an aggregation of commodities at the US tariff line (HS8).[10] Our aggregation distinguishes two protein products (SMP and other protein), two fat products (butter and anhydrous milk fat, AMF) and three types of cheese (American-type, cheddar and not specifically provided for, NSPF). We also identify WMP and other products not elsewhere specified, a catch-all for less important dairy products not neatly falling within our aggregation.

Production data, where possible, are sourced from the OECD's Commodity Balance Dataset. Where it is not possible to source production data comparable to our commodity level breakdown, we use total exports to calculate production shares. We are comfortable with this approximation as < 5 per cent of New Zealand's dairy production is consumed domestically. US tariff and New Zealand export data are sourced from the WTO Integrated Data

[8] Although we eliminated tariffs that were unequal across commodities, reducing equal tariffs by different proportions produces results that are qualitatively similar to those above.

[9] In a related analysis, Alston *et al*. (2006) consider the liberalisation of dairy trade between Australia and the US.

[10] Our disaggregation routine could in principle be applied at the tariff line. We choose to work with more aggregated data for ease of exposition and because confidentiality clauses prevent us from displaying disaggregated tariff data.

Table 2 New Zealand dairy production value shares and US import value shares and tariffs

	NZ production	US imports	US AVE, %
Dairy	1.000	1.000	12.7
Protein and fat	0.497	0.766	8.9
Protein	0.359	0.694	0.1
Skim milk powder	0.148	0.004	1.9
Other protein	0.211	0.691	0.1
Fat	0.139	0.071	95.0
Butter	0.088	0.027	68.3
AMF	0.051	0.044	111.5
Whole milk powder	0.298	0.010	10.1
Cheese	0.178	0.210	27.1
American-type	0.079	0.094	44.2
Cheddar	0.037	0.043	19.0
NSPF	0.062	0.073	10.0
Other products NES	0.026	0.014	4.1

Sources: (1) production data taken from the OECD's Commodity Balance Dataset; (2) import data sourced from the WTO IDB; and (3) Tariffs are value-weighted averages of AVE estimates of tariff-line trade distortions detailed in the WTO IDB. AMF, anhydrous milk fat; AVE, ad valorem equivalent; IDB, Integrated Data Base; NES, not elsewhere specified; NSPF, not specifically provided for.

Base (IDB). The US imposes specific tariffs on 19 of 37 dairy commodities (measured at the tariff line) sourced from New Zealand. We replace these tariffs with ad valorem equivalent (AVE) tariffs sourced from the US WTO 2001 IDB submission. The US also imposes a number of tariff rate quotas (TRQs) on dairy products. Key products attracting TRQs include butter, AMF, and American-type and cheddar cheese. We determine bilateral AVEs for TRQ products following Bouët *et al.* (2006). AVE tariffs for our nine dairy commodities are value-weighted averages of estimated tariff-line AVEs.

Replacing TRQs with AVEs creates approximation errors. Grant *et al.* (2007) explicitly model dairy TRQs at the tariff line using an integrated general equilibrium–partial equilibrium model. The authors conclude that using a model with a single dairy sector and an AVE of trade restrictions produces smaller output and export responses relative to a disaggregated model that explicitly models TRQs. However, the independent effects of disaggregation and explicitly modelling TRQs are not clear. We acknowledge that the treatment of TRQs may be important but choose to use a simplified framework so as to focus our analysis on disaggregation and joint production issues.

The data in Table 2 reveal that one half of New Zealand's dairy production is allocated to the protein–fat composite, 30 per cent to WMP and 18 per cent to cheese. US dairy imports from New Zealand are dominated by protein products, which make up nearly 70 per cent of US total dairy imports from New Zealand. The average US tariff on New Zealand dairy products is 12.7 per cent, and there is considerable variation in US dairy tariffs across commodities. Other protein products face very low tariffs, while the average tariff

on fat-based products is 95 per cent and the tariff on AMF is more than 111 per cent.

To disaggregate New Zealand dairy, we impose production and import shares in Table 2 on the GTAP database and make two assignments to maintain the integrity of the database. First, we derive New Zealand and RoW expenditure shares for dairy commodities residually so that production equals total demand for each commodity. Second, we scale US tariffs reported in Table 2 so that the value-weighted average tariff on aggregate dairy products is equal to the US tariff on New Zealand dairy in the GTAP database (11.1 per cent). We aggregate the modified database into three regions (New Zealand, the US and RoW) and five sectors (fluid milk, processed dairy, other agriculture, manufacturing and services). In New Zealand, processed dairy production is disaggregated into the nine dairy commodities identified above, and there is a single dairy commodity in other regions.

The structure of New Zealand dairy production is outlined in Figure 2. The production specification was designed in consultation with Fonterra, a New Zealand-based company responsible for one-third of global dairy exports. In the first level of the production nest, dairy production is allocated across protein–fat, WMP, cheese and other dairy products according to the elasticity of transformation parameter σ^T_{MIL}. WMP and other dairy products are sold to firms and consumers. Protein and fat are divided into separate components according to the transformation parameter $\sigma^T_{P\_F}$. Further allocations of protein (to SMP and other protein products) and fat (to butter and AMF) are governed by elasticity parameters σ^T_{PTN} and σ^T_{FAT}, respectively. Cheese output is divided into three varieties (American-style, cheddar and NSPF) with transformation possibilities dictated by σ^T_{CHS}. Our production specification allows us to consider several alternative dairy production functions. On the demand side, as in our illustrative analysis, σ^S determines

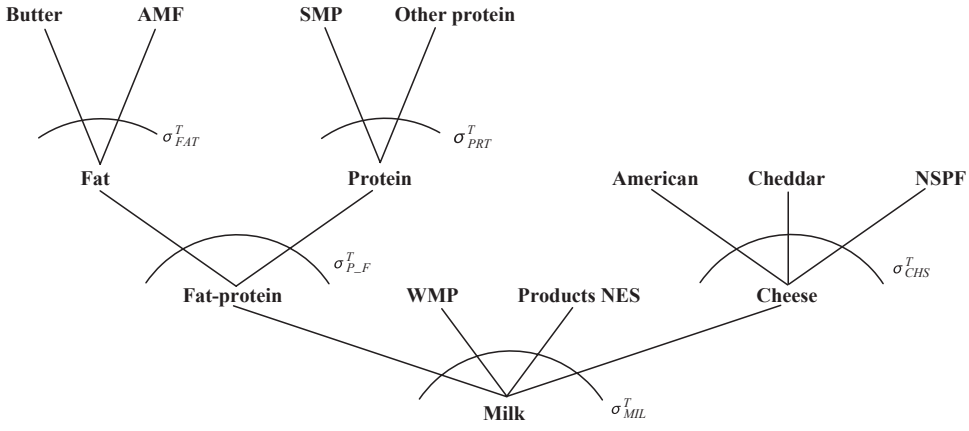

Figure 2 Detailed dairy production structure.

substitution possibilities between purchases of New Zealand dairy commodities (in both New Zealand and elsewhere).

We assume that the US and RoW each produce a single dairy commodity for simplicity and to minimise data requirements. Dairy output is a very small fraction of total output for these regions, so precise modelling of the dairy sector in the US and RoW is not required when assessing welfare implications for these regions. Additionally, New Zealand dairy products account for < 0.4 per cent of US dairy purchases, so liberalisation-induced changes in US production will be small. Aggregate commodities from the US and RoW compete with a New Zealand CES dairy composite, as in our illustrative analysis.

We consider four scenarios, which differ with respect to elasticity values, to assess the impact of alternative production and disaggregation assumptions on modelling results. Elasticity values for each scenario are gathered in Table 3. We set $\sigma^S = 0$ in scenario (D.1). Irrespective of values chosen for the elasticity of transformation parameters, this specification is similar to a model with a single processed dairy commodity.[11] Such a specification is commonly used to assess dairy liberalisation in economy-wide models. As producers and consumers are unable to respond to changes in relative dairy prices, the specification will underestimate liberalisation-induced changes in production, trade and welfare.

In scenario (D.2), we set $\sigma^S = 3$ but specify that producers must change output of all dairy commodities by equal proportions, $\sigma^T_{MIL} = \sigma^T_{P\_F} = \sigma^T_{PTN} = \sigma^T_{FAT} = \sigma^T_{CHS} = 0$. Similar to (I.2) in our illustrative analysis, this specification allows us to isolate the impact of consumer substitutability from alternative dairy production assumptions on modelling results.

In scenario (D.3), in addition to consumer substitutability, dairy producers are able to alter their product mix in response to price changes. Elasticities of transformation in (D.3) are guided by representatives from Fonterra. In the first level of the production nest, $\sigma^T_{MIL} = 3$. Further down the nest, producers are unable to alter the relative production of fat and protein, $\sigma^T_{P\_F} = 0$, but transformation within protein, fat and cheese production is possible, $\sigma^T_{PTN} = \sigma^T_{FAT} = \sigma^T_{CHS} = 5$. This is our preferred production specification as it

Table 3 Elasticities for alternative specifications

(D.1)	$\sigma^S = 0$
(D.2)	$\sigma^S = 3, \sigma^T_{MIL} = \sigma^T_{P\_F} = \sigma^T_{PTN} = \sigma^T_{FAT} = \sigma^T_{CHS} = 0$
(D.3)	$\sigma^S = 3, \sigma^T_{MIL} = 3, \sigma^T_{P\_F} = 0, \sigma^T_{PTN} = \sigma^T_{FAT} = \sigma^T_{CHS} = 5$
(D.5)	$\sigma^S = 3, \sigma^T_{MIL} = \sigma^T_{P\_F} = \sigma^T_{PTN} = \sigma^T_{FAT} = \sigma^T_{CHS} = \infty$

[11] The specification does not exactly mimic a model with a single dairy sector as, unlike in our illustrative analysis, dairy expenditure shares on disaggregated dairy commodities differ across countries.

imposes the condition that protein-based and fat-based commodities are produced jointly, but allows production transformability across commodities that are mixtures of fat and protein.[12]

Although some elasticities in (D.3) are quite large, the specification is representative of the short-medium run. This is because Fonterra plants only run at peak capacity for about 10 days per year, which allows considerable product-mix flexibility under the existing asset structure. We evaluate the appropriateness of (D.3) by simulating supply elasticities. We do this by independently increasing the price of each dairy commodity by one per cent and holding prices for other commodities fixed. Simulated elasticities range from 2.7 (for butter) to 4.8 (for WMP). Chavas and Klemme (1986) conclude that the long-run elasticity of fluid milk supply, which is a key intermediate input to dairy production, is between 3.9 and 6.7. As New Zealand dairy producers have scope to alter their product mix in response to price changes, our supply short-to-medium run dairy elasticities are not out of line with fluid milk supply elasticities estimated by Chavas and Klemme.

We set $\sigma^S = 3$ and all elasticity of transformation parameters equal to infinity in scenario (D.4) In this case, there is a separate production sector for each commodity, so (D.4) replicates a common approach used to divide a sector into two or more new sectors, including procedures that utilise SplitCom. As dairy production is perfectly transformable across commodities, the model will overestimate production responses following relative price changes induced by trade liberalisation.

Simulated changes in New Zealand welfare and dairy production volumes following the removal of US tariffs on New Zealand dairy commodities are reported in Table 4. There is a small increase in New Zealand welfare and an increase in dairy production of 1.5 per cent in (D.1). By design, the increase in the production of each dairy commodity is equal to the increase in aggregate dairy production. Results for (D.2) show that there is a larger increase in demand for New Zealand dairy products when consumer substitutability is possible than when dairy commodities are consumed in fixed proportions. This larger increase in demand ultimately results in a larger increase in New Zealand welfare in (D.2) than in (D.1). The increase in New Zealand aggregate dairy output (3.6 per cent) is also much larger in (D.2) than in (D.1).

Dairy producers are able to alter their product mix in response to relative price changes in (D.3). Changes in welfare and aggregate dairy production in (D.3) are similar to those for (D.2). However, there are large differences in results at the commodity level. This is not surprising given the changes in relative dairy prices from the removal of US tariffs. In (D.3), the largest increase in production is for AMF, which has the highest preshock tariff.

[12] Many partial equilibrium studies (e.g. Cox *et al.* 1999 and Bouamra-Mechemache *et al.* 2002) model dairy production by separating milk into fat and protein and then combining the two components to produce different commodities. Such a specification and (D.3) produce similar results.

Table 4 Changes in New Zealand welfare and dairy production volumes following the elimination of US bilateral tariffs

	(D.1)	(D.2)	(D.3)	(D.4)
Equivalent variation, US$ m	17.0	32.6	33.2	34.4
Equivalent variation, %	0.038	0.072	0.074	0.077
Dairy products, %	1.5	3.6	3.8	4.0
Protein and fat	1.5	3.6	4.9	6.3
Protein	1.5	3.6	4.9	2.3
Skim milk powder	1.5	3.6	2.3	−2.0
Other protein	1.5	3.6	6.7	5.3
Fat	1.5	3.6	4.9	16.7
Butter	1.5	3.6	−1.8	4.7
AMF	1.5	3.6	16.3	37.6
Whole milk powder	1.5	3.6	0.9	−1.9
Cheese	1.5	3.6	5.7	7.8
American-type	1.5	3.6	8.9	13.1
Cheddar	1.5	3.6	4.0	5.0
NSPF	1.5	3.6	2.6	2.8
Other products NES	1.5	3.6	1.6	−0.5

Source: Simulation results as described in the text. AMF, anhydrous milk fat; NES, not elsewhere specified; NSPF, not specifically provided for.

Interestingly, outputs of both protein products expand and butter production decreases, even though the preshock tariff on butter (68.3 per cent) is significantly higher than the corresponding average protein tariff (0.1 per cent). These changes are a direct result of our production structure. As $\sigma^T_{P\_F} = 0$, additional fat production requires additional protein production, so there is increased output of SMP and other protein. However, butter production decreases as fat is channelled into AMF production.

Relative output changes for SMP and other protein in (D.3) are also interesting. The proportional increase in SMP production is less than that for other protein, even though the US tariff on SMP (1.9 per cent) is larger than that on other protein (0.1 per cent). This is because the New Zealand producer price for each commodity is a value-weighted average of prices across destinations. As the US SMP import share is much smaller than New Zealand's SMP production share and the opposite is true for other protein (see Table 2), the relative price of SMP falls. Similarly, there is a relatively small increase in WMP production because of the small US import share for this commodity.

All elasticity of transformation parameters equal infinity and $\sigma^S = 3$ in (D.4). Comparing results for (D.4) with those for (D.3) reveals that failing to account for joint production results in unreasonable changes in protein and fat production. Protein production increases by 2.3 per cent and fat production by 16.7 per cent in (D.4), which is inconsistent with the requirement that these commodities are produced in fixed proportions. The larger increase in fat output facilitates increased production of both fat-based products. Notably, AMF production increases by 37.9 per cent in (D.4), which is nearly three

times as large as the corresponding increase in (D.3). Additionally, output changes for SMP, butter and WMP are of opposite signs in (D.3) and (D.4).

Overall, results from our detailed analysis indicate that both disaggregation and production structure have a large influence on modelling results. Our preferred production specification, (D.3), stipulates joint production for some dairy commodities but not for others. Relative to (D.3), a model that identifies a single dairy commodity underestimates production and welfare changes following trade liberalisation. Conversely, a model that includes many dairy commodities produced independently overestimates changes in welfare and aggregate dairy production. Including a separate sector for each dairy commodity can also result in output changes of unreasonable magnitudes and with incorrect signs.

5. Conclusions

This paper considered joint production and disaggregation in the dairy sector. We considered the impact of dairy liberalisation in an economy-wide setting using (i) a standard (single dairy sector) model, (ii) a model built on a conventional disaggregation procedure (SplitCom) and (iii) a model that considered both disaggregation and joint production for some or all commodities.

In an illustrative setting, we showed that the treatment of disaggregation and joint production can have a large impact on simulation results. In a detailed application, we considered the removal of US tariffs on New Zealand dairy products. In our chosen application, disaggregation of the dairy sector resulted in a welfare gain nearly twice as large as when there was a single dairy commodity. The main driver of this result is the ability of consumers to substitute between different dairy commodities. At a sectoral level, appropriately modelling dairy production is important. Failing to account for joint production not only resulted in production changes of unreasonable magnitudes but also with incorrect signs. On the other hand, production changes are underestimated when all commodities are produced jointly, as assumed in models with a single processed dairy sector. Our preferred dairy production structure includes joint production for some commodities and differs from that used in other applied trade models (e.g. Grant *et al.* 2007).

Although we focus on the dairy sector, accounting for interdependencies among disaggregated commodities is also important in other sectors. Notably, joint production of biofuels and feed by-products (such as soy and rapeseed meals) has been overlooked by CGE analyses. The exception is Taheripour *et al.* (2008), who show that studies that ignore joint production overestimate the impact of biofuel programs on agricultural markets. Although formulating detailed production specifications for other sectors requires industry guidance, our illustrative analysis is able to identify when accounting for joint production is likely to be important. Specifically, disaggregating a sector into two or more commodities and not accounting for joint production will overestimate output responses: (i) the larger the variability in

price changes across commodities, (ii) the larger the elasticity of substitution between commodities and (iii) the smaller the transformability of a sector's output across commodities.

References

Alston, J.M., Balagtas, J.V., Brunke, H. and Sumner, D.A. (2006). Supply and demand for commodity components: implications of free trade versus the AUSFTA for the US dairy industry, *The Australian Journal of Agricultural and Resource Economics* 50, 131–152.

Anderson, K. and van der Mensbrugghe, D. (2007). Effects of multilateral and preferential trade policy reform in Africa: the case of Uganda, *The Journal of International Trade & Economic Development* 16, 529–550.

Armington, P.S. (1969). A theory of demand for products distinguished by place of production, *Staff papers - International Monetary Fund* 16, 159–176.

Bouamra-Mechemache, Z., Chavas, J.P., Cox, T.L. and Requillart, V. (2002). Partial market liberalization and the efficiency of policy reform: the case of the European dairy sector, *American Journal of Agricultural Economics* 84, 1003–1020.

Bouët, A., Decreux, Y., Fontagné, L., Jean, S. and Laborde, D. (2006). Tariff data, in Dimaranan, B.V. (ed.), *Global Trade Assistance and Protection: The GTAP 6 Data Base*. Center for Global Trade Analysis, Purdue University, Chapter 16.D, 1–11.

Chavas, J.-P. and Klemme, M. (1986). Aggregate milk supply response and investment behavior on US dairy farms, *American Journal of Agricultural Economics* 68, 55–66.

Cox, T.L., Coleman, J.R., Chavas, J.-P. and Zhu, Y. (1999). An economic analysis of the effects on the world dairy sector of extending the Uruguay Round Agreement to 2005, *Canadian Journal of Agricultural Economics* 47, 169–183.

Dimaranan, B.V. (ed.) (2006). *Global Trade, Assistance, and Production: The GTAP 6 Data Base*. Center for Global Trade Analysis, Purdue University.

Francois, J.F. and Wignaraja, G. (2008) Economic implications of Asian integration, *Global Economy Journal* (Serial online), 8, Available at URL: http://www.bepress.com/gej/vol8/iss3/1 [accessed 12 November 2008].

Grant, H., Hertel, T. and Rutherford, T. (2007). Tariff line analysis of U.S. and international dairy protection, *Agricultural Economics* 37, 271–280.

Grant, H., Hertel, T. and Rutherford, T. (2008). Dairy TRQ liberalization: contrasting bilateral and most favoured nation reform options, Presented at the Eleventh Annual Conference on Global Economic Analysis, 12-14 June, Helsinki, Finland.

Hertel, T. (2002). Introduction to the GTAP Data Base, in Dimaranan, B.V. and McDougall, R.A. (eds), *Global Trade Assistance and Protection: The GTAP 5 Data Base*. Center for Global Trade Analysis, Purdue University, Chapter 1, 1–11.

Hertel, T., Hummels, D., Ivanic, M. and Keeney, R. (2007). How Confident can we be in CGE-based assessments of free trade agreements? *Economic Modelling* 24, 611–635.

Horridge, M. (2005). *SplitCom: Programs to Disaggregate a GTAP Sector*. Centre of Policy Studies, Monash University, Melbourne, Australia.

Mraz, M. and Matthews, A. (2007). Disaggregating the dairy sector in the GTAP database, Presented at the Tenth Annual Conference on Global Economic Analysis, 7–9 June 2007, Purdue University, West Lafayette, Indiana, USA.

Rae, A.N. and Strutt, A. (2004). Multilateral agricultural trade reform: potential impacts of current negotiations on New Zealand, *New Zealand Economic Papers* 38, 175–205.

Robinson, S. and Thierfelder, K. (2002). Trade liberalisation and regional integration: the search for large numbers, *The Australian Journal of Agricultural and Resource Economics* 46, 585–604.

Rutherford, T.F. (2005). GTAP6inGAMS: the dataset and static model (online), Ann Arbor, MI. Available at URL: http://www.mpsge.org/gtap6/gtap6gams.pdf [accessed 3 April 2008].

Scollay, R. and Gilbert, J. (2000). Measuring the gains from APEC trade liberalisation: an overview of CGE assessments, *World Economy* 23, 175–197.

Scollay, R. and Gilbert, J. (2001). *New Regional Trading Agreements in the Asia Pacific?* Institute for International Economics, Washington DC.

Taheripour, F., Hertel, T.W., Tyner, W.E., Beckman, J.F. and Birur, D.K. (2008). Biofuels and their by-products: global economic and environmental implications, Presented at the Eleventh Annual Conference on Global Economic Analysis, 12-14 June, Helsinki, Finland.

Winchester, N. (2006). Liberating Middle Earth: how will changes in the global trading system affect New Zealand? *New Zealand Economic Papers* 40, 45–79.

Zhu, Y., Cox, T.L. and Chavas, J.-P. (1999). An economic analysis of the effects of the Uruguay Round Agreement and full trade liberalization on the world dairy sector, *Canadian Journal of Agricultural Economics* 47, 187–200.