Estimated Contribution of Four Biotechnologies to New Zealand Agriculture

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Biotechnology is an example of a horizontal enabling technology (Ministry for Economic Development, 2003), a technology with wide application across many businesses and industries that underpins a number of specific innovations. Developments in biotechnology – the use of biological systems, living organisms or parts of them to make or modify products or processes (Organisation for Economic Co-operation and Development, 2005) – have contributed significantly to New Zealand's primary sector. Key examples of biotechnology developed in New Zealand for the primary industry include marker assisted breeding to combat footrot in sheep, clonal propagation of pine trees, soil additives to reduce nitrate leaching into rivers and lakes, and vaccines which increase lambing yield.

The New Zealand economy is strongly reliant on its primary sector. The agribusiness and forestry sectors contribute an estimated 20 per cent of real GDP, 65 percent of merchandise exports, and around 47 per cent of total exports (Ministry of Agriculture and Forestry, 2004; Ministry of Fisheries, 2004; Statistics New Zealand, 2004). Thus, governmental policy towards biotechnology can have significant impacts on New Zealand trade and growth.

In considering the effects of biotechnology on production, the potential for impacts from international price shifts needs to be analysed. New Zealand is an open economy, so the shifts in international commodity prices are transmitted directly to the farmgate (Kaye-Blake et al., 2003; Ministry of Agriculture and Forestry, 2004). Much of New Zealand's primary production is exported (about 95% in the case of dairy products (Ministry of Agriculture and Forestry, 2004)), again suggesting that international commodity prices are significant for farmgate prices. Finally, New Zealand represents a significant portion of world trade in some agricultural commodities, suggesting that its productivity might affect world prices.

This paper presents an analysis of the potential impacts of biotechnology-derived productivity on New Zealand producer prices and thus on farmgate returns. The data on productivity impacts are disaggregated at the commodity level, which allows a detailed analysis of the differential impacts across the primary sector. The paper is organised in the following way. The next section reviews prior literature on biotechnology impacts and on trade modelling. The modelling section discusses the partial equilibrium model used and the data used to inform the current modelling. There follow sections containing the results of the modelling, discussion of the results, and concluding comments.

Prior Literature

There is an extensive literature on the trade impacts of biotechnology (for example, Anderson and Jackson, 2005; Frisvold et al., 2003; Lapan and Moschini, 2002; Qaim and Traxler, 2005; Saunders and Cagatay, 2003; Stone et al., 2002). Trade analyses have focused largely on genetically modified crops (but see Frisvold, et al. (2003)), and in particular on specific crops rather than the generalised value of the underlying biotechnology. They are useful for the present research for their findings regarding impacts of productivity gains and consumer willingness to pay for enhanced agricultural products. They also provide indications of robust methodologies for estimating trade impacts.

Trade analysis has found that changes to agricultural productivity can have quite different impacts to changes in consumer demand for primary products. Increasing productivity results in greater total social welfare, which is divided amongst innovators, consumers, and producers. Innovators generally capture significant returns through appropriate licensing and pricing of biotechnological innovations (Falck-Zepeda et al., 2000; Sobolevsky et al., 2002). Consumers usually benefit from increased production: they have more food and fibre for lower prices (Frisvold et al., 2003). There are exceptions to this generalisation that arise from negative consumer reactions to genetic modification (Lapan and Moschini, 2002). Producers may or may not benefit from technology that increases agricultural efficiency. The exact impacts depend on ownership of the technology, its distribution, and trade policies (Falck-Zepeda et al., 2000; Sobolevsky et al., 2002; Lapan and Moschini, 2002). By contrast, innovations that create primary products with enhanced consumer-oriented qualities lead to benefits across the board (Saunders and Cagatay, 2003). Innovators can capture returns from the premium products, consumers gain by having more desirable products, and producers benefit from higher prices.

One tool for analysing trade impacts is a partial equilibrium (PE) model. PE frameworks are useful for quantifying the effects of changes in agricultural production. This is due to a number of factors, including the level of commodity disaggregation, the ease of traceability of interactions, the transparency of the results, the relatively small size of the models, and the low number of behavioural parameters and the methods used to obtain those parameters (Francois and Hall, 1997; Gaisford and Kerr, 2000; Roningen, 1997; van Beers and van den Bergh, 1996). An extensive programme of trade analysis for New Zealand has been conducted with the Lincoln Trade and Environment Model (LTEM), a PE model. The LTEM was initially used to simulate various scenarios relating to adoption of GM crops in NZ, including reduced costs of production, premiums for and against GM and bans for GM products in key markets Japan and the EU (Saunders and Cagatay, 2003, 2001). Further modelling work has found that for biotechnology to have positive impacts on revenues to the primary sector, New Zealand must be able to keep productivity benefits for itself and/or the GM product must attract a higher price in world markets (Saunders et al., 2003).

Another tool for analysing trade impacts is a computable general equilibrium (CGE) model. These models, which can be much larger and more complex than PE models, quantify linkages between different parts of the economy. There have been some CGE modelling activities in the Australian context that have relevance to New Zealand. A Productivity Commission Report (Stone et al., 2002) used the Global Trade Analysis Project (GTAP) model (Hertel, 1997) to examine potential impacts of GM technology on Australia’s trade in non-wheat grains and oilseeds. The results of the three scenarios in this report demonstrated that very small absolute changes would occur in Australia’s import and export flows. Rather, regions with currently significant GM sectors, which did not include New Zealand, received the most substantial impacts to trade and income.

Empirical Methods and Data

LTEM: The Trade Model

For the present research, the preferred method of analysis is a PE model. The ability to considered commodities at a disaggregated level is a key consideration for modelling the impacts of the biotechnologies in this report. Furthermore, the relative ease and transparency of the modelling make the final impacts easy to understand and interpret. Linkages beyond the agricultural sector may be quantified with supplemental analysis, with such as with multipliers derived from input-output tables.

The trade modelling framework is the Lincoln Trade and Environment Model (LTEM), an agricultural multi-country, multi-commodity trade model that uses a PE framework to analyse the impact of changes in agricultural productivity and domestic agricultural and trade policies. The model is based on VORSIM, which evolved from SWOPSIM and its associated trade-database used to conduct analyses during the Uruguay Round of General Agreement on Trade and Tariffs (GATT) negotiations (Roningen, 1986; Roningen et al., 1991). It has been used to analyse trade policies, climate change policies, and markets for organically grown and genetically modified products.

The LTEM embodies all the advantages of PE trade models. An additional strength of the LTEM is its explicit modelling of the dairy sector at a disaggregated level. Dairy products are New Zealand’s largest single agricultural commodity, and nearly all the country’s production goes to export markets, making it the largest agricultural export. Because dairy markets are under the influence of various domestic and border policies, explicit modelling of supply and demand behaviour is essential in order to quantify the impacts of productivity changes.

The LTEM includes 19 agricultural commodities (seven crop and 12 livestock products) and 17 countries. The linkages of the agricultural sector with other industries and factor markets are not considered. The commodities included in the model are treated as homogeneous with respect to the country of origin and destination, and with respect to the physical characteristics of the product. Therefore commodities are assumed to be perfect substitutes in consumption in international markets. Importers and exporters are assumed to be indifferent about their trade partners.

The LTEM is a synthetic model whose parameters are adopted from the relevant literature. Interdependencies between primary and processed products and between substitute or complementary products are reflected by cross-price elasticities. The model is then used to quantify the price, supply, demand and net trade effects of policy changes. The model is used to derive the medium- to long-term policy impact in a comparative static fashion. The base year the model works from is 2000. The present research models impacts up to 2005 to determine present price effects.

In the general LTEM framework, there are seven endogenous variables in the structural-form of the equation set for a commodity under each country, made up of six behavioural equations and one economic identity. There are four exogenously determined variables, but the number of exogenous variables in the structural-form equation set for a commodity varies based on cross-price and cross-commodity relationships. The behavioural equations are: (i) domestic supply, (ii) demand, (iii) stocks, (iv) domestic producer price, (v) consumer price, and (vi) trade price. The economic identity is a net trade equation, which is equal to excess supply or demand in the domestic economy. For some products, the number of behavioural equations may change as the total demand is disaggregated into food, feed, and processing industry demand. This is determined endogenously.

Model inputs

Research into commercialised applications of four biotechnologies across the whole primary sector, reported in Kaye-Blake et al. (2005), calculated the productivity impacts of novel products or applications. The data was collected through surveying key informants about the production impacts of the technology, the available alternatives to biotechnological innovations, and the rates at which innovations had been adopted by primary producers. It focused on four specific modern biotechnologies:

- Clonal propagation/cell manipulation,
- Bio-control agents, or bio-pesticides,
- Enzyme manipulation, and
- Marker-assisted selection or breeding.

The major quantitative findings are given in table 1. The total net benefit of these innovations to the primary sector was estimated to be $266 million per year in 2005. The contribution of these biotechnologies to the different subsectors is apparent in these figures. Dairy production benefited the most from these innovations, which is not surprising given that dairy production is the largest of the subsectors. Other pastoral agriculture also benefited, with impacts on sheep production larger than those on beef and veal production. The horticulture subsector showed significant benefits, with some crops heavily reliant on biotechnology and other barely affected. The dollar value of impacts in arable crops was relatively small, but this was a function of the size of the subsector. Finally, impacts were relatively small for forestry as only one of the biotechnologies had commercial application, and they were nil for seafood production.

Table 1. Summary of direct impacts of four biotechnologies

Subsector	Value of clonal propagation / cell manipulation (NZ$000's)	Value of biocontrol agents (NZ$000's)	Value of enzyme manipulations (NZ$000's)	Value of marker assisted selection (NZ$000's)	Total (NZ$000's)
Dairy	74,914	19,893	3,791	nil	98,598
Beef and veal	20,890	772	nil	nil	21,662
Sheep (meat and wool)	35,287	41,353	nil	770	77,410
Forestry	16,976	nil	nil	nil	16,976
Horticulture and floriculture	32,995	small value	9,960	nil	42,955
Arable crops	8,220	nil	nil	nil	8,220
Seafood	nil	nil	nil	nil	0
Total	189,282	62,018	13,751	770	265,821

The figures shown in table 1 contain an important assumption: that the changes in production had no impact on farmgate prices. Biotechnology was shown in Kaye-Blake et al. (2005) to increase the production of several important commodities, but no adjustment was made for possible price impacts. By incorporating the above figures into the LTEM, it is possible to estimate the price impacts associated with productivity gains. These prices changes can then be used to estimate the net impact on the agricultural sector.

One key input into the trade model is the uptake rates of new technologies. A major factor affecting the aggregate impacts of an innovation on the primary sector is the proportion of producers who have adopted it. Uptake or adoption rates were not found to be uniform across innovations or across subsectors. However, in the LTEM, the commodities produced are assumed to be homogenous. As a result, it is possible to express the aggregate impact of a biotechnology as a percentage of production. The production impact can be measured at the commodity level and then a single shift in production modelled for each commodity. Because of commodity homogeneity, the production impact is the same regardless of whether it is modelled as technology uptake by specific producers or simple commodity-wide productivity shifts. One drawback to this method, however, is that it cannot account for uneven impacts in the primary sector from uneven adoption of innovations.

A second key input is the effects of biotechnology on the productivity of the primary sector. Three different scenarios were modelled. The first scenario is the base case, primary production as it currently happens. This is modelled by using the base data for 2000 and modelling expected production up to 2005. No shifts in productivity are modelled in the first scenario. The other two scenarios model production in New Zealand in the absence of the biotechnology-derived production shifts in table 1. This absence is modelled as a proportional reduction in primary sector productivity. The modelled production shifts are given in table 2. In this table, the negative signs indicate that production would be lower without biotechnology. Demand and supply equations in the LTEM are assumed to have constant elasticity functional form and exogenous shocks to this model arising from biotechnology are assumed to shift demand and supply by a constant percentage of price for all levels of production, so that pivotal shifts are assumed. These are similar to the shifts described in Frisvold et al. (2003) in their work on returns to technological advancements.

The two alternative scenarios have one key difference. For the first one, the productivity reductions affect all countries: the innovations are removed from the primary sectors everywhere. This scenario examines the impact of an absence of biotechnology with the assumption that all countries have benefited equally from these innovations. For the second scenario, several of the innovations are removed from the primary sector only in New Zealand. This scenario is considered because of the New Zealand-specific application of some innovations. For example, some endophyte technology specific to New Zealand pasturage has been extensively adopted domestically, but less extensively adopted elsewhere.

Table 2. Productivity impacts for modelling

Trade commodity	Change in productivity	Alternative scenario 1 Production systems affected	Alternative scenario 2 Production systems affected
Wheat	- 5.1%	All countries	All countries
Coarse grains	- 5.1%	All countries	All countries
Beef, veal	- 1.9%	All pastoral	NZ only
Sheepmeat	- 3.9%	All pastoral	NZ only
Wool	- 3.9%	All pastoral	NZ only
Milk, raw	- 2.3%	All pastoral	NZ only
Apples	nil	n/a	n/a
Kiwifruit	nil	n/a	n/a

Detailed modelling of the dairy complex is a key strength of the LTEM. In particular, the model separates production into extensive (e.g., pastoral) systems and intensive (e.g., feedlot) systems. This is an important distinction when modelling biotechnological innovations, because several innovations in use in New Zealand affect only pastoral systems. Feedlot production would not be improved by innovations in pasture quality. In order to reflect the differences among raw milk physical production systems in terms of the differences in nitrogen fertilizer and feed concentrates use, the countries Australia, EU, New Zealand and USA were separated into three regions and supply responses in these regions were modelled explicitly.

The major dairy producing trading blocs were each sub-divided into regions (defined as in table 3) to reflect internal heterogeneity with respect to dairy production systems and environmental conditions. These divisions were based on observed variation in, for example, yields, stocking rates and drainage characteristics as well as the nitrogen fertilizer and feed concentrate use. The divisions are incorporated into the LTEM through the regional domestic raw milk supply equations. Data on production systems were taken from a number of sources, including farm advisory recommendations, census and survey reports, and field trials.

Table 3. Heterogeneity in the dairy production system amongst regions

Region	Production per cow (litres)	Average stocking rate (per ha)	Area (000ha)
EU (15) :			
West EU	5310	2.4	3174.8
East EU	4680	1.8	6639.6
Other EU	4991	2.3	3302.2
Australia:			
Victoria	4715	1.0	1267.9
NSW	4972	0.5	504.0
Rest of Australia	4608	0.5	1046.0
USA:	7238		
California	8439	10.0	149.2
WI, MI, MN, PA, NY	7182	3.0	1251.2
Rest of USA	6770	2.7	1727.8
New Zealand:			
Auckland	3278	2.8	494.6
South Island	3874	2.6	274.8
Rest of NZ	3300	2.0	570.4

The final key input is consumer willingness to pay for differentiated products, such as organically grown or genetically modified food. The LTEM can simulate different willingness to pay for segmented commodity products. For example, an enzyme biotechnology that produces superior meat characteristics could lead to higher export prices for adopting producers. This capability of the LTEM was not used for the modelling. For most commodities, there were no biotechnological innovations that altered product qualities and led to premium prices. For horticultural products, some innovations were identified that led to premium prices, but those products are not included in the LTEM. The main horticultural products in the model, apples and kiwifruit, were not affected by quality-enhancing biotechnologies. As a result, no demand shifts were modelled.

Results

Trade models by their nature produce a range of outputs: consumer and producer prices, quantities produced, quantities traded, and more. The information of importance here is the price change for each commodity as a result of lower production. For each commodity in the model whose production was affected by biotechnology, the difference in producer prices and quantities produced between production with biotechnology and production without biotechnology was calculated. The changes in both price and quantity were used to calculate the changes to gross producer returns. These calculations were made for both scenarios and are presented in table 4.

Table 4. Results of modelling

Trade commodity	Change in productivity	Alternative scenario 1 World-wide impacts		Alternative scenario 2 Some NZ-only impacts	
		Change in NZ producer price (%)	Change in NZ producer returns (%)	Change in NZ producer price (%)	Change in NZ producer returns (%)
Wheat	- 5.1%	5.4	3.6	5.5	0.2
Coarse grains	- 5.1%	4.1	1.6	4.3	0.2
Beef, veal	- 1.9%	2.6	0.6	1.0	-2.0
Sheepmeat	- 3.9%	4.6	1.9	1.0	-6.3
Wool	- 3.9%	3.1	-0.6	1.0	-4.1
Milk, raw	- 2.3%	1.8	-1.2	1.1	-1.4

The results for the first scenario indicate the impact on New Zealand producers had biotechnology not led to productivity gains anywhere in the world. When the impact of a worldwide reduction in productivity in the primary sector is modelled, market prices adjust upward in response to the reduction in supply. Trade also adapts to account for the change in productivity. As a result, the net change in producer returns for New Zealand is positive for wheat, coarse grains, beef and veal, and sheepmeat, and negative for wool and dairy. That is, higher prices and in some case higher quantities demanded lead to gains to arable crops, sheepmeat and beef (marginal). On the other hand, the higher price is not enough to offset the drop in production in the dairy sector, and producer returns fall.

For Scenario 2, the price impacts are smaller for several commodities, those outside the arable crop subsector. These commodities were modelled as having improvements that applied only to the New Zealand primary sector, so that production in other countries was unaffected. Thus, the absence of biotechnology in New Zealand alone has smaller price impacts on international commodity markets. The net impact on producer returns is essentially nil for wheat and coarse grains and negative for all other commodities. The reduction of New Zealand production and exports is enough to increase international prices slightly, but the rise is not sufficient to offset the losses in production.

To calculate the dollar value of these impacts, data on the revenues for these commodities was adjusted to account for the results from the trade modelling. The gross margins were then calculated to make the results comparable to the net impacts shown in table 1. Table 5 presents the results for the first alternative scenario, and table 6 presents those for the second. For these calculations, changes to forestry, horticulture, and seafood are not included, as they are not part of the trade model.

The net, price-adjusted direct economic impact as calculated in table 5 was the reduction in producer returns (after variable costs) that arose from an absence of biotechnologies. This result suggests that by using the biotechnological innovations identified in this research, and assuming that all other countries had access to the same technology, the New Zealand primary sector had a direct economic benefit of $19 million dollars, excluding forestry and horticulture. By contrast, the direct economic benefit, without accounting for price shifts, for these subsectors was calculated shown in table 1 to be $206 million.

Table 5. Alternative scenario 1: impact of absence of biotechnologies

Subsector	Revenues with biotechnology ($000's) a	Change in producer returns (%)	Change in producer returns ($000's)	Gross margin ($ per dollar of revenue) b	Net impact of absence of biotechnology ($000's)
Dairy	5,312,500	-1.2	-64,169	0.79	-50,694
Beef and veal	1,300,320	0.6	7,539	0.90	6,785
Sheep (meat and wool) c	2,824,090	1.1	29,827	0.70	20,879
Arable crops d	364,187	2.2	7,856	0.45	3,535
Total					-19,494

a Kaye-Blake et al., 2005; Ministry of Agriculture and Forestry, 2004; Statistics New Zealand, 2004.

b Burtt, 2004; Kaye-Blake et al., 2005.

c The change in producer returns is calculated as the average of the Sheepmeat and Wool impacts in table 4, weighted by the amount of revenue in Lamb, Mutton and Wool in (Ministry of Agriculture and Forestry, 2004).

d The change in producer returns is calculated as the average of the Wheat and Coarse grains change in producer returns in table 4, weighted by the amount of revenue for each arable crop as shown in (Kaye-Blake et al., 2005).

The value calculated in table 6 indicates how much lower direct economic impacts in the primary sector would be in the absence of specific biotechnologies. These are New Zealand-specific biotechnologies that increase the productivity of the pasture-based parts of the primary sector. In this scenario, some biotechnologies, such as those in arable crops, were simply not available worldwide. Other biotechnologies were removed only from New Zealand commodity production. These were biotechnological innovations in dairy, meat and wool production. The reduction in direct impacts was $191 million, which was very nearly identical to the direct economic benefit for these subsectors in table 1, $206 million.

Table 6. Scenario 2: impact of absence of NZ biotechnologies*

Subsector	Revenues with biotechnology ($000's)	Change in producer returns (%)	Change in producer returns ($000's)	Gross margin ($ per dollar of revenue)	Net impact of absence of biotechnology ($000's)
Dairy	5,312,500	-1.4	-73,774	0.79	-58,281
Beef and veal	1,300,320	-2.0	-25,911	0.9	-23,320
Sheep (meat and wool)	2,824,090	-5.5	-156,377	0.7	-109,464
Arable crops	364,187	0.2	707	0.45	318
Total					-190,747

* See notes from table 5.

Discussion of modelling results

The results from the trade analysis provide important information regarding the impacts of biotechnology. The two alternative scenarios modelled present two different pictures of biotechnology in New Zealand. The first alternative models the primary sector without the innovations based on the four biotechnologies mentioned above. Many examples of these biotechnologies, particularly those that are clonal or cell technologies, are widely used. If these biotechnologies had not been developed, then they would not have affected production anywhere in the world. The difference between the world with biotechnology, the base case, and the world without the identified innovations, is measured by the first alternative. For those sectors in the LTEM, considering the combination of price and quantity effects, the difference between using and not using biotechnology in New Zealand is $19 million in direct economic impacts. This is about 9.2% of the calculated impacts that do not account for price shifts (table 1). This result suggests that New Zealand gains little from the worldwide use of these biotechnologies, because the price decreases nearly cancel out the increased quantity from productivity gains.

The second scenario is slightly different. For this modelling, dairy, meat and wool productivity were reduced only in New Zealand (arable crop productivity was reduced for all countries). The second scenario considers a world in which biotechnological innovations with application specifically to New Zealand environments had not been developed. Without these innovations boosting New Zealand production, the primary sector would lose direct economic impacts of $191 million. This figure is about 92.7% of the constant-price calculations, suggesting that innovations that are specific to New Zealand do contribute significantly to agricultural sector revenues.

The trade model can also provide results for each subsector. For dairy products, loss of biotechnology reduced producer revenues for both alternative scenarios. New Zealand's dairy industry clearly gains from biotechnology, whether it is adopted just in New Zealand or more globally. For the meat subsectors, the results of the two alternatives are rather different. The results for beef and veal suggest that worldwide loss of biotechnology does not have much impact on New Zealand, but the sheepmeat sector would have greater revenues with lower productivity. However, both sectors are smaller with the loss of New Zealand-specific innovations, with sheepmeat having the highest impact of any subsector.

The differences in impacts across subsectors suggest that the economic impacts of biotechnology on New Zealand, a small, open economy, are affected by the markets with which the country trades. Productivity gains by themselves are not the whole story. Issues like market structure, trade policies, and domestic production in overseas markets, which are captured by using a trade model, all affect the net economic impact from innovations.

The results, taken together, also suggest that biotechnology is another element in an agricultural technology treadmill. Early adoption of innovations can lead to economic gains, but once those adoptions are widespread the gains to the agricultural sector are small. However, if the innovations are not available to or not adopted by a specific country, then its agricultural sector could face large losses as its competitors become more efficient.

Conclusion

This trade modelling contributes to the literature on biotechnology. Most research on the trade impacts of biotechnology has had to rely on ad hoc assumptions regarding productivity impacts due to lack of data. The present research has used data on actual productivity impacts of commercialised biotechnology products in New Zealand. These impacts were then incorporated into a model of international trade. This analysis of trade impacts thus provides an analysis of what has actually occurred in New Zealand agriculture.

The analysis demonstrates the net impact of changing productivity. The data from Kaye-Blake et al. (2005) assumed that the price elasticity of demand for agricultural commodities was practically infinite: the New Zealand primary sector was a price-taker on world commodity markets, too small to make a difference. The trade analysis makes some adjustment to this picture. By considering the impact that New Zealand can have on commodity markets, especially in dairy products and meat, it provided a different result and indicated differences amongst subsectors.

Which of the two alternative scenarios more accurately portrays the New Zealand situation is uncertain. Clearly, adopting biotechnology is important. It increases productivity, which either allows New Zealand to have a competitive advantage in certain commodities or keeps the country in line with its rivals. If the former is true, that is, if biotechnology research has produced innovations that preferentially benefit New Zealand, then the contribution of biotechnology is closer to the absolute value of the estimate in the second alternative. In this case, the New Zealand agricultural sector may be about NZ$200 million larger because of these biotechnologies. If the latter is true, then the net impact on producer returns from using these biotechnologies, given that everyone else has adopted similar innovations, too, is closer to the estimate in the first alternative. The net gain to New Zealand agriculture in that case may be more on the order of NZ$20 million.

This research has also suggested areas for further investigation. Because this trade model assumes commodities are homogeneous, the impacts on different producers of the same commodity were not estimated. With uneven uptake of innovations, differences within a subsector would be expected. These differences could be analysed with a more disaggregated model. A second area not explored here was the impact of quality changes that affect consumers' willingness to pay for commodities. Price differentials based on specific quality enhancements would be an important area for future research, in particular if they could be modelled alongside productivity changes.

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Appendix

The Trade Model

This appendix provides a brief description of the Lincoln Trade and Environment Model (LTEM). Included in this description are the equations in the model and the method of determining prices and quantities.

Each country in the LTEM has its own set of behavioural equations for each commodity. In general there are six behavioural equations and one economic identity for each commodity in each country, i.e. there are seven endogenous variables in the structural-form of the equation set. These behavioural equations are domestic supply, demand, stocks, domestic producer and consumer prices and a trade price equation. The economic identity is the net trade equation, representing the excess supply or demand in each country. There is some variation between countries and commodities based on the levels of disaggregation. The following section explains the functional form and variable specification for the behavioural equations.

Domestic Supply

The type of supply equation used in the LTEM is known as a directly estimated partial supply response model (Colman, 1983). The equation is a function of own- and cross-prices, with an ad hoc theoretical background. The equations use the Cobb-Douglas (CD) constant elasticity functional form, specified at the level of the variables. The general form of the supply equations for the commodities is presented below:

$$qs_{it} = \alpha_0 pp_{it}^{\alpha_1} \prod_j pp_{jt}^{\alpha_j} \; ; \qquad \alpha_1 > 0 , \alpha_j < 0$$

where:

i = own commodity

j = substitutes

qs = domestic supply

pp = producer price

t = time period.

Domestic Demand

Demand is simulated in the LTEM using a uniform CD aggregate domestic demand function, again for each country and commodity. The demand relationship is derived from the consumers' utility maximisation behaviour under perfect competition assumption. Demand is therefore specified as a function of the own- and substitute prices, per capita income and the population growth rate. Income and population are exogenous to the model. The general form of the demand equations is:

$$qd_{i,fot} = \beta_0 pc_{it}^{\beta_1} pinc_t^{\beta_2} pop_t^{\beta_3} \prod_j pc_{jt}^{\beta_j} \; ; \qquad \beta_1 < 0 , \beta_2 > 0 , \beta_3 > 0 , \beta_j > 0$$

$$qd_{i,fet} = \beta_0 pc_{it}^{\beta_1} \prod_j \prod_q pc_{jt}^{\beta_j} qs_{qt}^{\beta_q} \; ; \qquad \beta_1 < 0 , \beta_j > 0 , \beta_q > 0$$

where:

pc = consumer price

pinc = per capita income

pop = population

qd_{fe} = domestic feed demand

qd_{fo} = domestic food demand

Stocks

Stocks are modelled using the theory of inventory demand (FAPRI, 1989). The main motive for the stock demand is transaction rather than speculation. The equations are shown below:

$$qe_{it} = \varphi_0 qs_{it}^{\varphi_1}; \qquad \varphi_1 > 0$$

$$qe_{it} = \varphi_i qd_{it}^{\varphi_1}; \qquad \varphi_1 > 0$$

where:

qd = domestic demand (can be food, feed or processing)

qe = stocks

Net Trade

As mentioned previously, net trade in the LTEM is an economic identity based on the difference between domestic supply and the sum of various demand amounts as well as stocks. Stocks are incorporated as a change from the previous year. The net trade equation is shown below:

$$qt_{it} = qs_{it} - (qd_{i,fot} + qd_{i,fet} + qd_{i,prt}) - (\Delta qe_{it})$$

where:

qt = quantity traded

qd_{pr} = quantity processed

Raw milk is not traded as its supply is assumed to be completely exhausted in the production of the other dairy products.

Prices

Domestic consumer and producer prices in the LTEM are determined by the world trade prices for each commodity, as well as the domestic and border policies applied in each country. Equations 19 and 20 illustrate this price transmission mechanism. The trade price of a commodity is determined by the world market price of that commodity, as shown in equation 18. Producer and consumer support and subsidy measures are incorporated into the price equations through the use of commodity based price wedge variables, which differentiate the domestic and trade prices of each commodity. These variables may include per unit direct payments, inputs subsidies, general services expenditures and other market subsidy payments to producers, as well as a consumer market subsidy, as shown in equations 21 and 22. These policies are all calculated per tonne of production and consumption, following the concept of producer and consumer subsidy equivalents (PSE and CSEs) (Cahill and Legg, 1990).

$$pt_{it} = \left(\frac{WDp_{it}}{ex} \right)^{\varepsilon_\tau}$$

$$pp_{it} = pt_{it} + tp_{it} + tc_t \quad ; \qquad tc = 0$$

$$pc_{it} = pt_{it} + tc_{it} + tc_t \quad ; \qquad tc = 0$$

$$pp_{it} = (pt_{it} + tp_{it} + sd_{it} + si_{it} + sg_{it} + sm_{it})$$

$$pc_{it} = pt_{it} + tc_{it} + cm_{it}$$

where:

cm = consumer market subsidy

ex = exchange rate

pt = trade price

sd = direct payments

sg = general services expenditure

si = input subsidy

sm = other producer market subsidy

tc_i = export subsidies

tc = transportation costs

tp_i = import tariffs

WD_p = world price

The model works by simulating the commodity-based clearing price in world markets on the domestic quantities and prices, which may or may not be under the effect of policy changes, in each country. Excess domestic supply or demand in each country spills over onto the world market to determine world prices. The world market-clearing price is determined at the level that equilibrates the total excess demand and supply of each commodity in the world market, by using a non-linear optimisation algorithm (Newton's global or search algorithm).

All prices in the LTEM are in US dollars, removing any exchange rate effects.