The 84th Annual Conference of the Agricultural Economics Society

Edinburgh

29th to 31st March 2010

Modelling Climate Change Impacts on Agriculture and Forestry with the Extended LTEM (Lincoln Trade and Environment Model)

Caroline Saunders
William Kaye-Blake

Abstract

In the land-based sectors, agricultural production generally is a source of carbon, while forestry may be thought to act as a sink. This paper focuses on new research examining the interaction of the two. The core of the research is the Lincoln Trade and Environment model (LTEM), a partial equilibrium model which links trade in NZ with the main trading countries overseas, through to production and associated environmental consequences . This paper reports on research expanding the model to include forestry from incorporating the capabilities of the Global Forest Products Model (GFPM) into the LTEM and hence producing an integrated model of agricultural and forestry land-uses for NZ and overseas. The paper extends the environmental modelling capabilities of the LTEM to include the impacts of climate change. The paper thereby reports on the development of a model of international trade that encompasses major agricultural commodities and forestry, complete with linkages and feedback with the environment and differentiated international markets. The paper then presents results of scenarios around changes in consumer behaviour and production using the new model.

Introduction

This paper focuses on extending the modelling capability to include forestry in an agricultural partial equilibrium trade model. The core of the research is the Lincoln Trade and Environment model (LTEM), a partial equilibrium model which links trade in NZ with the main trading countries overseas, through to production and associated environmental consequences. This paper discusses the issues, methodology and results from research expanding the model to include forestry. This was done by incorporating the capabilities of the Global Forest Products Model (GFPM) into the LTEM and hence producing an integrated model of agricultural and forestry land-uses for NZ and overseas. The paper thereby reports on the development of a model of international trade that encompasses major agricultural commodities and forestry, complete with linkages and feedback with the environment and differentiated international markets.

This paper initially considers the issues around gathering the necessary data and parameter values to extend the LTEM to include the forestry sector, incorporate mitigation efforts and technologies, and account for change in consumption related to climate change. It then details the processes involved to include adding new variables to account for the commodities, new parameters to account for specific features of forestry and the forestry-agriculture interactions, and modifications to the equation structure to accommodate the new sector.

Finally, results from the updated model to investigate specific scenarios relating to climate change, market reactions, mitigation efforts, and policies are presented. Scenarios were developed based on various estimates of changes in agricultural production due to impacts of climate change, based on the review of research in Kaye-Blake et al (2009). Some scenarios also included potential changes in consumer behaviour in various markets in response to climate change.

Main characteristics of LTEM

The LTEM is a partial equilibrium model of international trade in the agricultural sector, with exogenous links to other industries, factor markets, and the macroeconomy. The LTEM is a multi-country, multi-commodity model with a high degree of commodity disaggregation: the dairy market is divided into five traded products and the oilseed complex is represented by three commodities. The model quantifies price and quantity impacts on production, consumption, and trade, and allows calculation of revenue and welfare impacts. The model links through to the environment via production functions and then through to environmental consequences. Currently, the model links through to groundwater nitrates, greenhouse gas emissions, and energy.

The LTEM is a synthetic model since the parameters are adopted from the literature. The symmetry condition holds for the supply and demand elasticities, therefore own- and cross-price elasticities are consistent. The model is used to quantify the price, supply, demand and net trade effects of various policy changes. The policy parameters and/or variables and non-agricultural exogenous variables are listed in Table 1. The model is used to derive the medium- to long-term policy impact in a comparative static fashion from the base year of 2004.

Table 1: Policy variables/parameters and non-agricultural exogenous variables

Policy Variables-Domestic Market	*Policy Variables-Border*	*Non-Agricultural Exogenous Variables*
Land set-aside	Import tariff	Gross domestic product
Production quota	Export subsidy	Country price index
Support/minimum price	Trade quota	Population
Producer market subsidy	In-quota tariff	Exchange rate
Producer input subsidies	Out-quota tariff	
Producer direct payments	Export tax	
Producer general services		
Consumer market subsidy		

The LTEM includes 22 commodities and 18 countries or regions. These are presented in Tables 2 and 3. The dairy sector is modelled as five commodities, raw milk is defined as the farm gate product and is then allocated to the liquid milk, butter, cheese, whole milk powder or skim milk powder markets depending upon their relative prices, subject to physical constraints. The meat sector is disaggregated into sheepmeat, beef and pig meat, and the poultry sector (poultry meat and eggs) and wool are also modelled explicitly. There are eight crop products (wheat, maize, sugar, other grains, rice, oilseeds, oil meals, oil) in the LTEM.

Table 2: Country coverage of the LTEM

Argentina	India	Russian Federation
Australia	Japan	South Africa
Brazil	Korea	Switzerland
Canada	Mexico	Turkey
China	New Zealand	United States
European Union (25)	Norway	Rest of World
		World (data, market clearing equations

Table 3: Commodity coverage of the LTEM

Wheat	Oilseed meals	Poultry meat	Cheese
Maize	Oils	Eggs	Whole milk powder
Other grains	Beef and Veal	Raw milk	Skim milk powder
Sugar (refined)	Pig meat	Liquid milk	Apples
Rice	Sheep meat	Butter	Kiwifruit
Oilseeds	Wool		

A final general characteristic of the LTEM is that each commodity can appear in two different forms. This allows researchers to model quality-differentiated products, such as two types of wheat or two types of butter. The quality differentiation is linked to production methods. It is thus capable of linking consumer preferences for specific production methods to the supply of the products. The technique can be used for endogenising consumer demand for organically grown food, genetically modified crops, or low-GHG emissions production.

Basically, the model works by simulating the commodity based world market clearing price 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. The LTEM is described in more detail in Cagatay and Saunders et al (2003) and Saunders, et al and Cagatay et al (2003).

In general, there are six behavioural equations and one economic identity for each commodity under each country in the LTEM framework. Therefore, there are seven endogenous variables in the structural-form of the equation set for a commodity under each country[1]. There are four exogenously determined variables, but the number of exogenous variables in the structural-form equation set for a commodity varies, based on the cross-price, cross-commodity relationships. The behavioural equations are domestic supply, demand, stocks, domestic producer and consumer price functions and a trade price equation. The economic identity is the 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, processing industry demand, and are determined endogenously.

To simulate the impact of changing market conditions on production and thus the environment, the factors affecting greenhouse gas emissions have been specified separately and for the purpose of this study, emissions from beef and dairy cattle and sheep are taken into account[2]. The principal determinants of gas from this source are livestock numbers, feed intake and type per head (Lassey *et al*., 1992). Most animal waste decomposes aerobically on pasture in New Zealand, resulting in relatively low levels of methane emissions from manure management for this country (MfE, 2000). Lassey *et al*. (1992) also assesses emissions from animal wastes, and from effluent processing plants such as abattoirs and dairy factories to be of relatively minor importance.

The challenge of incorporating methane and nitrous oxide into the LTEM model is to produce an equation (an environmental sub-module) which links all agricultural sources of these greenhouse gases to domestic production, and measures the methane and nitrous oxide emissions in physical terms. Therefore emission factors are crucial in this process, as well as the effect of different production systems, domestic and border policies. The IPCC in its guidelines produces default emission factors for different sources of gases, for a maximum of eight regions of the world[3]. Greenhouse gases (GHG) are incorporated into the model through the equation 32. In this equation *GHG* emissions from raw milk production is specified as a function of applied nitrogen fertilizer (n_a) and number of animals (Na_a) which are endogenous to the model. The CH_4 and N_2O emission factors are implicit in the coefficients (ξ, ζ) and values of these coefficients are provided by Clough and Sherlock (2001), equation 15. The CH_4 and N_2O emissions from these sources are converted to their CO_2 equivalents by multiplying with their respective weights (21 and 310) to give CO_2 equivalents[4].

$$GHG_{amt} = \xi Na_{amt} + \varsigma(n_{at}, Na_{at}) \qquad 32$$

The calculation of coefficients for methane and nitrous oxide production from livestock systems is based on the IPCC methodology for greenhouse gas inventories[5]. Methane and

[1] The extended LTEM, including forestry, contains 4,767 equations, with each country having between 228 and 302 equations, depending on its primary sector.

[2] In New Zealand, around 57 percent of methane emissions are from sheep and lambs, 27 percent from beef cattle, and 17 percent from dairy cattle (MAF, 2001).

[3] Naturally therefore, these values will vary considerably within each region, and New Zealand, as have many other countries, has carried out in-depth research to provide more accurate emission factors.

[4] The same equation is used to measure nation level emissions from beef and sheep also.

[5] For details on these guidelines, see www.ipcc.org for 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook'

nitrous oxide are separated into their sources. Default emission factors provided by the IPCC are used for the calculation of coefficients in most countries. In the case of nitrous oxide production in New Zealand, the emission factors are based on recent research, and differ from the default IPCC values. For the purposes of the model used in this study, coefficients representing the total methane and nitrous oxide produced from all livestock sources, for each animal type were calculated. Clough & Sherlock (2001) combined the emission factors for the various sources into one coefficient for the production of nitrous oxide and one for the production of methane per animal. A single coefficient for the nitrous oxide emitted from nitrogen fertilizer was also calculated, constant across animals and countries.

Global Forest Products Model[6]

The Global Forest Products Model (Buongiorno et al. 2003) is an economic model of the global forest sector. The general principle of the model is that global markets optimise the allocation of resources in the short-run (within one year). In the long-run resource allocation is governed partly by market forces, as in trade, and also by external forces, such as waste paper supply determined by environmental policy, tariffs by trade policy, and techniques of production by technological progress.

The Global Forest Products Model deals with 180 countries (Appendix, Table 1), each of which produces, consumes, imports, or exports at least one of 14 wood products (Appendix, Table 2). The source of the base year production, consumption, trade, and price data for these countries and products is the Food and Agriculture Organization online database FAOStat (FAO 2008). These data are collected from individual country statistics, which it is recognised, contain potential inaccuracies. However, the FAO is the only source of internationally comparable country data. Furthermore, the calibration of the Global Forest Products Model base year data (Buongiorno et al. 2001, Turner et al. 2005) addresses some of the inaccuracies in the FAO data. While most trade data are left intact by the calibration procedure, the production data are modified to ensure feasibility and consistency. For example, consumption cannot be negative. Furthermore, the amounts of materials used in a country and the amounts of products manufactured must be consistent with *a priori* knowledge regarding the inputs needed per unit of output.

Because domestic price data are scarce for most countries, the market-clearing price in countries that were net exporters of a product was assumed to be the world average export unit value[7]. For net importers, the price was the world export price plus the freight cost and import tariff for a particular country (Buongiorno et al. 2003, p. 75). Also needed for the base year were country forest stock and forest area – from the Forest Resources Assessment 2005 (FAO 2005) – and GDP per capita – from the World Development Indicators database (World Bank 2005).

From the base year, the Global Forest Products Model makes projections of forest resources, and wood product prices and quantities to 2030. To make these projections the model requires parameters describing the four main components of the wood-based sector: final demand, raw material supply, manufacturing activities, and international trade. Demand for final products and supply of raw materials are represented by econometric equations, which relate demand

[6] For a detailed mathematical description of the Global Forest Products Model refer to Buongiorno et al. (2003) Chapter 3.

[7] The value of world exports divided by the volume of world exports for a product.

and supply volumes to product prices and gross domestic product. Manufacturing activities are represented by input-output coefficients and manufacturing costs covering labour, energy and capital. Transport cost depends on freight rates and import tariffs.

Each of the four components has a static and a dynamic element. The static part describes each year's competitive equilibrium – where the price of each product in each country is solved so that consumption equals production plus imports minus exports. The dynamic element is governed by endogenous changes – determined within the model – or exogenous changes – determined outside of the model.

Demand for final products – fuelwood, other industrial roundwood, sawnwood, veneer and plywood, particleboard, fibreboard, newsprint, printing and writing paper, and other paper and paperboard – is represented by econometric equations (Buongiorno et al. 2003). These equations relate the demand for each product to national income – measured by real gross domestic product – and real product price – in U.S. dollars. The price and income elasticities of demand – the percentage change in quantity demanded for a one percent change in product price or country income – are in Table 3 in the Appendix. The Global Forest Products Model determines real product price changes endogenously, that is simultaneously with the quantities supplied, demanded, and traded. Country income changes – represented by the rate of growth of real gross domestic product from World Bank (2008), OECD (2004) and EIA (2004) reported in Turner et al. (2006) – are exogenous, reflecting assumptions regarding the future economic growth of each country.

The supply, or harvest, of wood – fuelwood, industrial roundwood, and other industrial roundwood[8] – is also represented by econometric equations (Turner et al. 2006a). These equations relate wood supply to each country's income per capita – measured by real gross domestic product per capita –, forest stock, and wood price. The price, income per capita, and forest stock elasticities – the percentage change in quantity supplied for a one percent change in each explanatory variable – are in Table 4 in the Appendix. Wood price changes are determined endogenously by the Global Forest Products Model so that they balance supply and demand. The growth rates of country income per capita are exogenous, based on assumptions regarding future economic and demographic growth (United Nations, 2005). In the Global Forest Products Model they are meant to reflect the increase in wood supply due to improvements in infrastructure and technology. Forest stock changes are determined endogenously by the Global Forest Products Model, and reflect the harvest capacity of a country.

The forest stock of a country is predicted with a growth-drain equation, where next year's stock equals the current stock plus the annual changes in forest stock due to forest area change and to forest growth or decay on a given area, minus harvests. Stock change due to growth or decay is a function of forest density – stock per unit area. Base year forest stock growth rates are from FAO (2005).

Forest area change is a function of country income per capita, following the environmental Kuznets curve for forestry. This suggests an increase in country income results in a declining rate of deforestation at incomes below $9,000 per person. Above this income, as country income grows there is an increasing rate of afforestation until an income of $21,000 per person, after which the rate of afforestation declines until it is zero at $33,000 per person. The theory upon which this representation of forest area change is based is sufficiently general to

[8] Industrial roundwood and other industrial roundwood in the GFPM are not separated into softwoods and hardwoods.

cover the economic situations of many countries, while being simple enough to implement empirically with the scarce international data. Base-year forest area change rates are from FAO (2005). The environmental Kuznets curve for each country is adjusted so that the predicted forest area change rate for 2006 is equal to the observed.
The supply of waste paper is related to national income – measured by real gross domestic product – and its real price – in U.S. dollars. Reflecting the availability of recovered paper, there is an upper bound on waste paper supply, which is determined by a country's paper consumption and recycling rate. This upper bound shifts over time due to endogenous changes in paper consumption, and exogenous changes in the maximum recycling rate.

The assumed waste paper recovery rates were such that the world recovery rate would rise to around 45 percent by 2030, from 39 percent in 2002 (Cesar 1995, Mabee and Pande 1997). The supply of other fibre pulp – fibre from non-wood sources such as straw and bagasse – is also related to national income and price.

The manufacture of wood products – sawnwood, veneer and plywood, particleboard, fibreboard, mechanical and chemical pulp, newsprint, printing and writing paper, and other paper and paperboard – is represented by input-output coefficients and associated manufacturing costs. Input-output coefficients describe how raw materials are utilised in production – the amount of input per unit of output – and differ among wood products and countries. These data were estimated with the methods described in Buongiorno et al. (2001). The manufacturing cost is the cost of the inputs – labour, energy, capital, etc. – not explicitly recognized in the model. The manufacturing cost is an increasing function of the level of production, described by an elasticity. For most manufacturing activities a one percent increase in production results in a 0.10 percent increase in the cost of manufacture, apart from the cost of wood and fibre inputs.

In the projections, manufacturing technology – represented by the input-output coefficients – was held constant at its 2006 level, except for newsprint, printing and writing paper, and other paper and paperboard. For these products the utilisation of waste paper in manufacture was assumed to increase gradually, with a corresponding decrease in the amount of wood pulp used, between 2006 and 2030. The estimated changes in waste paper utilisation were made by extending historical trends and adjusting these trends according to expert opinion (Ince 1994, Cesar 1995, Mabee and Pande 1997). It was also assumed that more wastepaper would be utilised in regions where more wastepaper is recovered. The resulting increase in the wastepaper utilisation rate was high – 0.70 percent per annum – in Asia and Oceania; medium – 0.35 percent to 0.50 percent per annum – in Europe, South America, former USSR, and North America; and low – 0.20 percent per annum – in Africa. For countries with already low levels of wood pulp utilisation the anticipated increase in waste paper utilisation was slower.

The Global Forest Products Model predicts trade flow volumes – between each country and the world market – for all wood products, except other industrial roundwood. Predicted trade flows are influenced by the cost of transportation, which includes the cost of freight and import tariffs. Freight costs are those reported in Turner and Buongiorno (2001). Import tariff data for 2006 were from the APEC[9] and UNCTAD TRAINS[10] databases (Turner et al. 2006b).

[9] www.apectariff.org
[10] www.unctad.org/trains

Using the GPFM to expand the LTEM

As the above descriptions indicate, the GFPM and LTEM are structurally similar, although they focus on different commodities and countries. The similarities between the two models made them ideal for combining into a single model. The LTEM was chosen as the framework for the combined model, and it was expanded using material from the GFPM. This chapter discusses how that was done.

The LTEM contains several different equation structures for different commodities. Field crops, for example, are treated differently from livestock production. For the present work, the structure of the livestock equations was used, for two reasons. First, forestry is most likely to compete with pastoral agriculture for land use. Secondly, both livestock and forestry have current production levels that depend on available stock, and thus on prior production levels. The general form of the forestry equations are shown in equations 43 and 44:

$$qd_{i,ft} = \beta_0 pc_{it}^{\beta_1} pinc_t^{\beta_2} pop_t^{\beta_3} \prod_j pc_{jt}^{\beta_j}\ ; \qquad \beta_1 < 0\,, \beta_2 > 0\,, \beta_3 > 0\,, \beta_j > 0 \qquad 43$$

$$qs_f = \theta_{f0} pp_f^{\theta_{ff}} \prod_k pp_j^{\theta_{fj}}\ ; \qquad \theta_{ff} > 0\,,\ \theta_{fj} < 0 \qquad 44$$

The demand for forestry products is a function of the price, as well as personal income, population, and the prices of other products. The supply of forestry products is a function of its own price, the prices of other forestry products, and the prices of agricultural products. The responsiveness is a function of the elasticities, given as β and θ.

The GFPM is highly disaggregated by country and forestry product. For the purposes of examining the impact of climate change on New Zealand, a more aggregated description of the forestry sector was sufficient. The number of forestry products was reduced from 14 to four: firewood, roundwood, panelwood, and paper and pulp. Table 4 provides the mapping from the GFPM products to the extended LTEM products.

Table 4: Mapping of GFPM Products to LTEM Commodities

GFPM Product	LTEM Product (Code)
Fuelwood and charcoal	Firewood (FWD)
Industrial roundwood	Roundwood (RWD)
Other industrial roundwood	Roundwood (RWD)
Sawnwood	Panelwood (PWD)
Plywood	Panelwood (PWD)
Particleboard	Panelwood (PWD)
Fibreboard	Panelwood (PWD)
Mechanical pulp	Paper and pulp (PPP)
Chemical pulp	Paper and pulp (PPP)
Other fibre pulp	Paper and pulp (PPP)
Waste paper	Paper and pulp (PPP)
Newsprint	Paper and pulp (PPP)
Printing and writing paper	Paper and pulp (PPP)
Other paper and paperboard	Paper and pulp (PPP)

Quantities produced were calculated for each of the four aggregate products. Prices were calculated as weighted averages of the prices of the constituent products in the GFPM. These quantities and prices were then used for the equations described above.

Some countries are present in both the GFPM and the LTEM. Data from these countries were added to the database for the LTEM. Other countries in the GFPM are either part of regions in the LTEM, or included in the Rest of the World (ROW). For these countries, production data were summed and transferred to the LTEM. Price data were aggregated with weighted averages and then transferred to the LTEM database.

Finally, the data on trade policies in the GFPM was also incorporated into the LTEM. The GFPM uses producer subsidy equivalents (PSEs) to model the impact of trade policies, and these can be incorporated multiplicatively into supply equations in the LTEM. The PSEs are also used to calculate consumer subsidy equivalents (CSEs) for the LTEM, to maintain the domestic balance between the producer and consumer prices in the model.

Many of the equations in the LTEM use elasticities to model the reaction of a dependent variable to changes in an independent variable. For example, price elasticities of demand are used to model the change in consumption that results from a given change in price. The GFPM similarly contains elasticities for supply, demand, and other equations. Some of these elasticities translated directly into model inputs for the LTEM. Other elasticities required calculation, and these were generally calculated by finding weighted averages of elasticities across the products and countries that were be aggregated. Finally, some of the calculated elasticities were adjusted before they were included in the LTEM. The supply and demand equations in the LTEM are somewhat different from the input-output structure of manufactured forestry products in the GFPM. Price elasticities of demand in the LTEM were thus constrained to be less than -0.20 (that is, greater than an absolute value of 0.20), which allowed the model sufficiently flexibility to find solutions to the climate change scenarios.

Cross-elasticities are also used in the LTEM to model the interaction between commodities. In the original LTEM, for example, the supply of beef is influenced by the price of sheep and milk. The responsiveness is a function of the size of the cross-elasticity.

Data were sought from the literature on land use change, particularly in New Zealand, in order to understand the interaction between agricultural and forestry products. The researchers also consulted with colleagues at Motu Economic and Public Policy Research in Wellington and the office of the Parliamentary Commissioner for the Environment. The results of empirical work in New Zealand conducted by Suzi Kerr and Jo Hendy suggest that the elasticity of supply of forestry products with respect to the price of agricultural commodities is quite low, and the same is true for the supply of agricultural commodities with respect to the price of forestry products[11]. In order to incorporate these interactions, therefore, low cross-price elasticities were included in the extended LTEM.

The material from the GFPM was incorporated into the LTEM by using the existing LTEM equation structure, aggregating data from the GFPM and adding them to the LTEM, and including supply and demand elasticities, and cross-elasticities in the equations.

Scenario Descriptions

The expanded LTEM was used to model several different scenarios. These scenarios were designed around the two goals of the research: developing a new model to assess climate change, and investigating the impact of climate change and reactions to it. To help develop the model, scenarios were designed to test the expanded model, to investigate how it reacts to different types of inputs, and to identify areas of future work to improve results and their applicability. To provide information about potential impacts of climate change, inputs from the literature on climate change, carbon emissions, and evolving market trends were incorporated into scenarios.

The scenarios were designed around four dimensions. The first dimension was the presence of climate change. Some scenarios included impacts of climate change estimated from the IPCC scenario A2. However, there are significant uncertainties around future climate change and the impacts on agricultural productivity. Some scenarios without climate change impacts were thus included. This approach allows the results to be used more widely for understanding potential impacts of policy and market trends, holding the level of climate change constant. To model climate change effects, the productivity impacts described in Kaye-Blake, et al. (2009) were used to modify the supply shift parameters, which is shf_{qs} in equations 38 and 39.

The second dimension considered in the modelling was the extent of policies to curb greenhouse gas emissions. A number of policy tools have been discussed in the literature, including carbon taxes and cap-and-trade policies. These policies all have the impact of placing a direct or implicit price on carbon. They can all be modelled similarly, that is, as an increase in the cost of production that is proportional to the amount of GHG emissions. They were therefore modelled as changes to the supply shift parameter in equations 38 and 39. The impact on productivity was calculated based on emissions from beef, sheep, and dairy in the different countries and a price of US$25 per tonne of CO_2 equivalents. This productivity impact was then used to calculate a new supply shift parameter. The policies were further divided into two possibilities. One possibility is that all Annex 1 countries include agriculture in greenhouse gas emissions policies, and Non-Annex 1 countries are exempt. The second possibility is that New Zealand includes its agricultural sector in its ETS, but no other country

[11] Pers. Comm., Jo Hendy, 6 November 2009, and Wei Zhang, 5 November 2009.

follows suit. Both of these possibilities have been modelled. For all policies, forestry products were modelled as carbon-neutral, and therefore not affected directly by GHG policies.

The third dimension that formed part of the scenario development was the use of mitigation technologies. As discussed in Kaye-Blake, et al. (2009), there are techniques and technologies with the potential to reduce greenhouse gas emissions from agriculture. If these technologies are implemented, there are two impacts. They reduce the potential liability from GHG policies, reducing the added costs that the primary sector would incur from such policies. In addition, they reduce the amount of GHG emitted per unit of production. In the present research, mitigation technologies were modelled alongside GHG policies, to investigate the joint impacts of technological improvements and price signals. Around one-half of New Zealand production was modelled as having no reductions in emissions, while the other half was modelled was having a 30 per cent reduction. This level of reduction is based on the scientific research discussed in Kaye-Blake, et al. (2009), and represents some of the highest levels of reduction. This mitigation level may therefore represent the potential of current research, rather than mitigation that is actually achievable on-farm.

For the scenarios presented in this paper, the split-commodity capability of the model was employed. The production in every country was divided evenly between standard production and low-emissions production. Between the two methods of production, each commodity was highly substitutable to avoid constraining production of one type or the other. The standard production method produced the current (2004) level of greenhouse gases. The low-emissions method produced 30 per cent less GHG emissions per unit of production. This difference was modelled by adjusting the supply shift parameters so that the low-emissions product had a 30 per cent lower shift than the conventional product.

The final dimension considered in the scenarios was consumer demand for lower-emissions methods of production. In some scenarios, low-emissions product did not attract a price premium and were not preferred by consumer. Other scenarios included a 10 per cent shift in demand for low-emissions products, representing a price premium that consumers would be willing to pay for production method with lower GHG emissions. The premium was modelled with the demand shift parameter, shf_{qd} in equation 42. For the low-emissions product, the parameter was set at 1.10, while it was set at 1.00 for the standard product.

Altogether, the results of 15 scenarios are included in this paper. They are summarised in Table 5, which includes the scenario code and ticks indicating which element or elements were included in the scenario. As the table indicates, GHG policies could be enacted either by all Annex 1 countries or just New Zealand, and mitigation technologies could appear alongside GHG policies.

Table 5: Scenarios modelled

		-- GHG policies --			
Scenario code	Climate change	All Annex 1	NZ only	Mitigation technologies	Low-emissions demand
01		✓			
02		✓		✓	
03	✓				
04	✓	✓			

05	✓	✓		✓	
06			✓		
07			✓	✓	
08	✓		✓		
09	✓		✓	✓	
10					✓
12		✓		✓	✓
13	✓				✓
15	✓	✓		✓	✓
17			✓	✓	✓
19	✓		✓	✓	✓

Results

The model was used to investigate the impact of several different future scenarios on the agricultural and forestry sectors in New Zealand. The results of modelling these different scenarios are presented below. Two summary measures are used to describe the impact of each scenario. The first is a financial measure: the net change in producer returns. Producer returns indicate the total revenue earned by a sector, and are calculated by multiplying the amount of a commodity produced in New Zealand by its price. The second measure is the change in greenhouse gas emissions. The model focused on the production of methane and nitrous oxide from animal production, as well as total greenhouse gas emissions from agriculture. The change in emissions from animals is based on the number of animals produced and the uptake of emissions-reducing techniques and technologies.

Scenarios with climate change

The first set of scenario results are based on the climate change scenarios developed for IPCC research. The trade model was modified to reproduce the productivity impacts expected under climate change scenario A2. These impacts affected both agricultural and forestry commodities, and have been estimated for several regions and many specific countries, including New Zealand. The productivity impacts were then placed alongside other potential changes in the agricultural and forestry sectors, and the net results calculated.

The results from these scenarios are presented in two tables. Table 6 presents the percentage changes in producer returns expected under the different scenarios. The producer returns are presented for all New Zealand agriculture, and then for the separate industries of beef, sheepmeat, and dairy. The final column provides the impact on producer returns for roundwood production.

The first scenario examined the expected impacts on New Zealand of worldwide climate change under IPCC climate scenario A2, and is scenario code 03. With climate change, production in some regions and countries declines, while in others, production increases. New Zealand productivity declines, but not as much as in some other countries. Reduced quantities of commodities also lead to higher prices. The net result is that a scenario including only climate change and no policy or market impacts produces an increase in producer revenues in the New Zealand primary sector. Beef revenues decline slightly, as a result of higher impacts on dryland pastures in New Zealand and productivity gains overseas, such as in the United States. Sheepmeat and dairy revenues increase, a combination of domestic productivity impacts, overseas climate changes, and New Zealand’s contribution to international trade of these commodities. Forestry production also increases, as a result of increased productivity.

The second scenario in Table 6 includes both the climate change impacts as well as implementation of GHG policies in all Annex 1 countries at US$25 per tonne. The policies are modelled in the LTEM as affecting the cost of production and thus reducing the productivity of farmers: increased inputs are required to produce the same level of outputs. As a result, greenhouse gas policies reinforce the impacts of climate change. Production becomes more expensive, commodity prices increase, and the primary sector producer revenues increase. Producer returns in forestry are constant. Forestry products are modelled as ‘carbon neutral’ and thus not affected directly by GHG policies. The indirect impacts from land use change are not large enough to affect overall producer returns.

Table 6: Percentage changes in New Zealand producer returns, climate change scenario A2

Scenario (code)	All agriculture	Beef	Sheepmeat	Dairy	Roundwood
Climate change only (03)	14.6	-0.9	18.2	21.5	9.2
With worldwide GHG policy (04)	31.0	2.2	32.2	55.2	9.2
With worldwide GHG policy and mitigation (05)	28.3	1.7	29.8	49.6	9.2
With NZ-only ETS (08)	7.6	-8.0	13.5	18.3	9.1
With NZ-only ETS and mitigation (09)	8.6	-7.1	14.2	18.7	9.1

The second scenario in Table 6 includes both the climate change impacts as well as implementation of GHG policies in all Annex 1 countries at US$25 per tonne. The policies are modelled in the LTEM as affecting the cost of production and thus reducing the productivity of farmers: increased inputs are required to produce the same level of outputs. As a result, greenhouse gas policies reinforce the impacts of climate change. Production becomes more expensive, commodity prices increase, and the primary sector producer revenues increase. Producer returns in forestry are constant. Forestry products are modelled as ‘carbon neutral’ and thus not affected directly by GHG policies. The indirect impacts from land use change are not large enough to affect overall producer returns.

The third scenario in Table 6 shows the impact of including mitigation efforts in the model alongside worldwide GHG policies and climate change. Mitigation reduces some of the impacts of GHG policies: producers become more ‘carbon efficient’ and therefore have lower costs associated with the policies. As a result, their productivity relative to other producers is increased and price are lower on average. For agricultural products, the net result is a decrease in producer returns relative to a scenario with no mitigation, but the returns are higher than in a scenario with no GHG policies at all. Roundwood again shows no change.

The fourth and fifth scenarios in Table 6 indicate the impacts on New Zealand from global climate change, but only a domestic GHG policy, such as the ETS. Other Annex 1 countries, in these two scenarios, exempt their agricultural sectors from GHG policies. In addition, the fifth scenario also includes mitigation technologies, which have economic impacts only in New Zealand. Under these conditions, New Zealand does gain in relation to the baseline, as a result of higher prices and lower worldwide production brought about by climate change. However, relative to other climate change scenarios, New Zealand primary sector producers have lower revenues. The difference relative to the scenario with no GHG policies at all is a seven per cent reduction in producer returns across agriculture (forestry is essentially unchanged, although results suggest downward pressure on the industry). With mitigation, agriculture is able to regain one percentage point of the difference, but is still below the no-policies scenario. Of the livestock sectors, dairy is the least affected.

The model also allowed calculation of the impact on GHG emissions from agriculture and forestry of the different scenarios. The results are presented in Table 7. The scenarios are the same as those discussed with the previous table.

Table 7: Percentage changes in New Zealand methane and nitrous oxide emissions, climate change scenario A2

	All livestock	Beef	Sheepmeat	Dairy
Climate change only (03)	0.1	-9.8	0.9	5.8
With worldwide GHG policy (04)	-1.3	-18.6	-1.2	10.2
With worldwide GHG policy and mitigation (05)	-14.3	-28.4	-14.6	-4.6
With NZ-only ETS (08)	-7.4	-16.6	-7.0	-1.6
With NZ-only ETS and mitigation (09)	-18.8	-26.8	-18.9	-13.4

Climate change is expected to reduce agricultural production in general, and regional variation is also expected. The impact on New Zealand is partially bio-physical, that is, the amount of production that could be sustained given soils, climate, etc. The impact is also partially a result of changes to production that flow through to international markets. If production falls overseas for commodities of which New Zealand is a major supplier, then the country is likely to see a large impact. If other suppliers of a commodity are not significantly affected, or even see increases in production (such as are predicted for some regions in some climate change projections), then New Zealand production could even decline.

The results presented in Table 7 indicate that these different pressures on production and markets will have uneven impacts across New Zealand agriculture. For example, climate change scenario A2, when modelled with the LTEM, led to increases in dairy production and thus increased GHG emissions, nearly constant production in the sheep sector, and decreases in beef production with accompanying falls in emissions.

The unevenness of the impacts is exacerbated by worldwide GHG policies. Implementation of policies leads to general decreases in New Zealand emissions from livestock. However, the beef sector reduces emissions by nearly 20 per cent, while the dairy sector actually increases its emissions by over ten per cent. If mitigation technologies are implemented worldwide alongside carbon charges and climate change, then New Zealand beef and sheep producers have large decreases in emissions, while dairying has smaller reductions.

The general pattern is repeated in the scenarios in which only New Zealand implements GHG policies. Emissions fall, mirroring the fall in producer returns discussed above, but fall the most in the beef sector and least in dairy. Mitigation technologies reduce emissions even more, with the livestock sectors showing an overall decrease of nearly 20 per cent. Once again, these decreases are achieved unevenly across the sectors.

In all of the above scenarios, no consumer reaction was included. As discussed above, other scenarios modelled with the expanded LTEM also included a ten per cent demand premium for low-emissions products. This premium was applied in several cases, and the results are presented in Table 8.

Table 8: Percentage changes in New Zealand producer returns with demand for lower-emissions products

	All agriculture	Beef	Sheepmeat	Dairy	Roundwood
Demand plus climate change (13)	51.1	14.0	52.0	72.7	20.9
Demand plus climate change, GHG policies, and mitigation (15)	70.0	17.3	67.0	113.2	20.9
Demand plus climate change, NZ-only ETS and mitigation (19)	43.7	7.1	47.6	69.7	20.8

The first possibility considered was that the response to climate change would be left to the market. If consumers were concerned about their impacts on GHG emissions from agricultural production, then they could pay more for low-emissions production methods. In combination with climate change, the demand premium led to an overall increase in agricultural producer returns of 51.1 per cent. The dairy sector saw the largest increase, while the beef sector had the smallest. Returns for roundwood production also increased, by over 20 per cent. Simply put, increased demand overseas for desirable primary products created significant increases primary sector revenues.

The impact of GHG policies were also considered, both policies implemented by all Annex 1 countries and a New Zealand-only policy. In both cases, primary sector producer returns increased, and they increased more than in any of the scenarios in which consumer responses were not considered. When the GHG policies are implemented worldwide, New Zealand gains significantly from the decreased productivity and increased demand. If New Zealand is alone in implementing such policies, then the gains are not as large. As with the earlier scenarios, the results are spread unevenly across the three livestock sectors.

The changes to GHG emissions in these scenarios were also calculated, and they are presented in Table 8. For all scenarios, the combination of climate change and demand for lower-emissions products leads to a general reduction in agricultural GHG emissions. However, emissions from dairy tend to increase, except in the case in which New Zealand is the only country implementing a GHG policy. Emissions from beef decline significantly, and emissions from the sheep sector also decrease.

Comparing this to Table 7 indicates an interesting result. With no policy in place regarding emissions or mitigation, consumer demand for lower-emissions production leads to lower emissions. Emissions are reduced by about six per cent overall, while climate change alone did not reduce emissions. However, the reduction in emissions is actually lower in the other two scenarios than in their counterparts in Table 7. The reason for this result is that the increase in demand for lower-emissions products leads to a net increase in production and thus in emissions.

Table 9: Percentage changes in New Zealand methane and nitrous oxide emissions, with demand for lower-emissions products

	All livestock	Beef	Sheepmeat	Dairy
Demand plus climate change (13)	-5.8	-25.1	-5.1	6.2
Demand plus climate change, GHG policies, and mitigation (15)	-6.8	-31.6	-7.1	9.9
Demand plus climate change, NZ-only ETS and mitigation (19)	-11.9	-30.1	-11.6	-0.2

Scenarios without climate change

Another set of scenarios removed the impacts of climate change. These results indicate the impacts of GHG policies, mitigation, and consumer reactions, without the additional impacts of climate change.

Table 10 provides the changes to New Zealand producer returns under four different scenarios. The first scenario is the implementation of GHG policies in all Annex 1 countries. These policies increase the cost of producing agricultural products, reducing production. The result is an increase in market prices. The net impact on New Zealand agriculture is an increase in producer returns. For forestry, GHG policies are modelled as neutral so there is no impact on forestry returns.

Table 10: Percentage changes in New Zealand producer returns, climate change impacts removed

	All agriculture	Beef	Sheepmeat	Dairy	Roundwood
With worldwide GHG policy (01)	13.5	3.5	11.5	26.6	0.0
With worldwide GHG policy and mitigation (02)	11.2	2.9	9.5	22.1	0.0
With NZ-only ETS (06)	-5.9	-6.5	-3.8	-2.6	-0.1
With NZ-only ETS and mitigation (07)	-5.1	-5.6	-3.3	-2.2	-0.1

The second scenario in Table 10 combines Annex 1 GHG policies with mitigation technologies. This combination leads to increased producer returns in agriculture, with large gains for dairy and lower returns for beef and sheepmeat. The increases are somewhat lower than in the previous scenario, as mitigation technologies reduce the costs of GHG policies.

The next two scenarios examine the impacts of a GHG policy implemented only in New Zealand. In both scenarios, the producer returns in New Zealand are reduced. Returns for beef fall the most, while returns in the dairy industry fall least. The forestry sector remains essentially unchanged, with a margin impact from interactions with other commodities. With mitigation technologies, the reduction in producer returns is lessened as a result of lower costs for GHG emissions.

The impact on GHG emissions were also calculated for these scenarios, and reported in Table 11. With GHG policies in all Annex 1 countries, emissions are somewhat reduced overall, but the impacts are uneven. Emissions from dairy increase, as New Zealand increases its production to replace reduced production overseas. Emissions from beef and sheep production in New Zealand decline. With mitigation included alongside the GHG policies, emissions fall for all the commodities.

Table 11: Percentage changes in New Zealand methane and nitrous oxide emissions, climate change impacts removed

	All livestock	Beef	Sheepmeat	Dairy
With worldwide GHG policy (01)	-1.4	-9.2	-1.7	4.0
With worldwide GHG policy and mitigation (02)	-14.4	-20.1	-15.0	-9.9
With NZ-only ETS (06)	-7.0	-6.9	-7.3	-6.8
With NZ-only ETS and mitigation (07)	-18.6	-18.4	-19.2	-18.0

The second two scenarios in Table 11 examine the impact of a New Zealand-only GHG policy. For the first of the two, mitigation is not included. With the policy, emissions are reduced from all the commodities. The reduction in emissions is increased by the addition of mitigation policies. The reductions are fairly even across all the commodities.

The impact of consumer demand for low-emissions products was also considered in this set of scenarios. Table 12 presents the results for three scenarios that include a price premium. The first scenario has the price premium alone, which leads to a large increase in producer returns. All four commodities have increased returns, but they have different levels of increases. A second scenario includes Annex 1 GHG policies as well as mitigation technologies, and this leads to even larger increases in producer returns. In the third scenario, only NZ implements a GHG policy. All commodities still have increases in producer returns, although these increases are lower than in the other two scenarios. For all scenarios, dairy has the largest increase in returns, while forestry and beef have the lowest returns.

Table 12: Percentage changes in New Zealand producer returns with demand for lower-emissions products

	All agriculture	Beef	Sheepmeat	Dairy	Roundwood
Demand impacts only (10)	31.6	15.1	28.5	43.0	10.7
Demand plus GHG policies and mitigation (12)	47.1	18.6	40.8	74.9	10.7
Demand plus NZ-only ETS and mitigation (17)	25.3	8.7	24.9	40.6	10.6

Table 13 presents the impact on GHG emissions from these same three scenarios. When demand for low-emissions products is considered by itself, it leads to a general reduction in GHG emissions. However, emissions from dairy increase as a result of increased production to supply demand. In the scenario including both Annex 1 GHG policies and mitigation, there is again a general decline in New Zealand emissions from livestock, but an increase in emissions from dairy. In the final scenario, the New Zealand-only GHG policy and mitigation lead to reduced emissions from a combination of the mitigation technologies and lowered production.

Table 13: Percentage changes in New Zealand methane and nitrous oxide emissions, with demand for lower-emissions products

	All livestock	Beef	Sheepmeat	Dairy
Demand impacts only (10)	-6.2	-16.8	-6.0	0.6
Demand plus GHG policies and mitigation (12)	-7.3	-23.5	-7.6	3.9
Demand plus NZ-only ETS and mitigation (17)	-11.9	-21.9	-11.9	-5.3

Conclusion

This research created a model of international trade with unique capabilities. It extended the LTEM, an existing model of trade in agricultural commodities that includes modules for assessing GHG emission and energy, by incorporating data and parameters from the GFPM, and international model of trade in forestry products. This extended LTEM allows the impact of commodity price fluctuations on switching between agricultural and forestry production to be endogenised in a single model, and the impact on prices, production, and GHG emission to be assessed at the commodity and country levels.

The extended LTEM was then used to model 15 scenarios regarding the potential impacts of climate change, GHG policies in Annex 1 countries and New Zealand, emissions mitigation efforts in New Zealand, and consumer reactions to products produced with lower emissions. Scenarios were developed that examine each of these items alone as well as in combinations. These scenarios were modelled, and the impacts on producer returns and GHG emissions were calculated for New Zealand agriculture and for the three livestock sectors, beef, sheep, and dairy.

The results suggest that net impacts may be negative or positive for New Zealand, depending on the actual effects of climate change, the policies enacted, and efforts at mitigation emissions and linking emissions reductions to the market. In general, the results suggest five tentative conclusions:

1. Climate change and worldwide GHG policies may improve returns for New Zealand's primary sector. These changes will reduce agricultural productivity abroad, increasing worldwide prices and potentially increase demand for exports from New Zealand.
2. An ETS *of itself* may have a small impact on GHG emissions. The cost of carbon credits is a small fraction of the total income from agriculture, so the reduction in production is likely also to be small.
3. An ETS may be effective in reducing emissions if combined with support for mitigation or marketing. The greatest benefit of an ETS may be in enabling and promoting efforts to link emissions reductions to payments and premium markets.
4. Mitigation may be effective, and may benefit from government support. This research modelled emissions mitigation that is experimentally possible but may not have been achieved on farm. The impacts on total emissions were significantly larger than without mitigation efforts.

5. Promoting New Zealand products as low-emissions products is likely to improve producer returns in New Zealand. Achieving higher price for primary sector products means higher producer returns, lower emissions, and greater productivity in the sector.

A large part of this research has been focused on developing the new model and working through various issues that arose in combing the two models. These issues point to elements of uncertainty regarding the modelling to date and the results presented, and indicate a number of areas for future work.

- **Sensitivity analysis.** With any new model, it is important to identify the key variables or parameters that have large effects on the results, and then to determine the sensitivity of the model to the initial values. In particular, it would be important to investigate the equations and parameters that link the forestry products to the rest of the model. There are also several parameters that affect some of the modelling results presented here, such as the substitutability of different commodities. Some sensitivity analysis of the model would allow researchers and policy-makers to understand the areas where results are particularly robust, as well as areas where additional primary research is needed to increase the certainty about model inputs.

- **Land use change.** The original LTEM is a synthetic model, and relies on estimated parameters to control the switching between commodities in production. Because of the amount of work on this topic, it is possible to have relatively robust results. The topic of land use, land use change, and forestry (LULUCF) is quite important when discussing climate change and the carbon economy. Now that forestry is included in the extended LTEM, it is possible to model LULUCF more directly, rather than using the indirect approach.

- **Price of GHG emissions.** The present research used one single price for GHG emissions, US$25 per tonne of CO_2-equivalent. There are a number of questions that can now be investigated further. First, it would be interesting to investigate the impact of the price level in combination with the other impacts included in the model. Secondly, the impact of differential pricing by country, region, commodity, or production method could be studied using the model, and may provide useful results for understanding the potential impacts of different policies.

- **Mitigation.** The technique for modelling mitigation in the present research demonstrated the model capability, but it would be possible to develop more sophisticated techniques. Such techniques could link the structure of production, land use, policy, and markets.

- **Biofuels.** The original LTEM has already been used to model biofuels, both bioethanol and biodiesel, and the impact of biofuel policy on New Zealand agriculture. With the earlier addition of sugar and now the extension to included forestry products, it would be possible to investigate the impacts of biofuel policy that included several different feedstocks. In addition, the linkage to the energy markets and GHG emissions would allow a full investigate of the impact of new technologies and policies on production, energy prices, and GHG emissions.

- **Different GHG policies.** One of the core capabilities of the LTEM is modelling domestic and international policies. For the present research, one type of policy – a direct or indirect price on carbon – was considered. However, there are greater capabilities in the model for investigating a number of policies, including countervailing carbon tariffs, domestic subsidies for emissions reduction, and more. By comparing these methods for reducing emissions, the impacts and unintended consequences of policy can be investigated.

This research demonstrates both the difficulties and value of economic modelling for understanding complex systems and the combinations and shocks and policies that affect them. Although the two models, the GFPM and the LTEM, are both partial equilibrium trade models, differences in specifications created considerably difficulty in incorporating the one into the other. However, having done that, it was possible to model a number of scenarios and estimate some initial results. The results, described above, will hopefully be useful in designing New Zealand's responses to climate change and international policy developments.

References

Buongiorno, J., C.S. Liu, and J. Turner. 2001. Estimating international wood and fiber utilization accounts in the presence of measurement errors. *Journal of Forest Economics* 7(2): 101-124.

Buongiorno, J., S. Zhu, D. Zhang, J.A. Turner, and D. Tomberlin. 2003. The Global Forest Products Model: Structure, Estimation and Applications. Academic Press, San Diego. 301 pp.

Cesar, M. 1995. Global outlook for recovered paper. *In* Tappi Global Fiber Supply Symposium, Tappi Press, Atlanta, GA. pp. 81-94.

Energy Information Administration (EIA). 2004. Energy Outlook Study 2004. Department of Energy, Energy Information Administration, Washington D.C.

Food and Agriculture Organisation (FAO). 2005. Forest Resource Assessment 2005. Food and Agriculture Organization of the United Nations, Rome. www.fao.org/forestry/site/fra/en (Accessed 14 November 2005).

Food and Agriculture Organisation (FAO). 2008. Online FAO Yearbook of Forest Products, FAOSTAT statistics database. Food and Agriculture Organization of the United Nations, Rome. http://apps.fao.org/ (Accessed 16 May 2008)

Ince, P.J. 1994. Recycling and long-range timber outlook. General Technical Report GTR-RM-242. USDA Forest Service. 23 pp. Mabee, W.E. 1998. The importance of recovered fibres in global fibre supply. Unasylva 49(193): 31-36.

Kaye-Blake, W., Greenhalgh, S., Turner, J., Holbek, E., Sinclair, R., and Matunga, T. 2009. A Review of Research on Economic Impacts of Climate Change. AERU Research Report #314. Lincoln, NZ: Agribusiness and Economics Research Unit, April.

Mabee, W.E., and H. Pande. 1997. Recovered and non-wood fiber: Effects of alternative fibers on global fiber supply. Working Paper GFSS/WP/04. Food and Agriculture Organization of the United Nations.

Organization for Economic Cooperation and Development (OECD). 2004. OECD Economic Outlook No. 76, January 2005. Organization for Economic Cooperation and Development, Paris.

Cagatay, S., Saunders, C. M. and Wreford, A. 2003. Lincoln Trade and Environment Model (LTEM): Linking Trade and Environment. AERU Research Report No. 263, Lincoln University, NZ.

Cagatay, S.and Saunders, C. 2003. Lincoln Trade and Environment Model (LTEM): An Agricultural Multi-Country, Multi-Commodity Partial Equilibrium Framework. AERU Research Report No. 254, Lincoln University, NZ.

Simangunsong, B., and J. Buongiorno. 2001. International demand for forest products: A comparison of methods. *Scandinavian Journal of Forest Research* 16: 155-172.

Turner, J., and J. Buongiorno. 2001. International freight rates for forest products: Structure, past trends and forecasts. *International Forestry Review* 3(2): 136-145.

Turner, J.A., J. Buongiorno, S. Zhu, and R. Li. 2005. Calibrating and updating the Global Forest Products Model (GFPM version 2005). Staff Paper Series #57. Department of Forest Ecology and Management, University of Wisconsin-Madison. Madison, WI.

Turner, J.A., J. Buongiorno, and S. Zhu. 2006a. An economic model of international wood supply, forest stock and forest area change. *Scandinavian Journal of Forest Research* 21: 73-86.

Turner, J.A., J. Buongiorno, F. Maplesden, S. Zhu, S. Bates, and R. Li. 2006b. World Wood Industries Outlook: 2005-2030. *Forest Research Bulletin 230*. Ensis, Rotorua, New Zealand. 84 p. ISBN 0-478-11014-6.

United Nations. 2004. World Population Prospects: The 2004 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. http://esa.un.org/unpp, (Accessed 14 June 2005).

United Nations. 2005. World Economic Situation and Prospects 2005. Department of Economic and Social Affairs, United Nations, New York.

United Nations Economic Commission for Europe/ Food and Agriculture Organization (UNECE/FAO). 2002. Forecasts of the Economic Growth in OECD Countries and Central and Eastern European Countries for the Period 2000-2040. United Nations, New York.

World Bank. 2005. World Development Indicators online database. World Bank, Washington, D.C.

Appendix

Table 1: Country codes in GFPM[12]

Code	Country	Code	Country	Code	Country	Code	Country
	AFRICA		**N/C AMERICA**		**ASIA**		**EUROPE**
A0	Algeria	F0	Bahamas	I5	Afghanistan	N5	Albania
A1	Angola	F1	Barbados	I6	Bahrain	N6	Austria
A2	Benin	F2	Belize	I7	Bangladesh	N7	Belgium
A3	Botswana	F3	Canada	I8	Bhutan	N8	Bosnia and Herzegovina
A4	Burkina Faso	F4	Cayman Islands	I9	Brunei Darussalam	N9	Bulgaria
A5	Burundi	F5	Costa Rica	J0	Cambodia	O0	Croatia
A6	Cameroon	F6	Cuba	J1	China	O1	Czech Republic
A7	Cape Verde	F7	Dominica	J2	Cyprus	O2	Denmark
A8	Central African Republic	F8	Dominican Republic	J3	Hong Kong	O3	Finland
A9	Chad	F9	El Salvador	J4	India	O4	France
B0	Congo, Republic of	G0	Guatemala	J5	Indonesia	O5	Germany
B1	Côte d'Ivoire	G1	Haiti	J6	Iran, Islamic Rep of	O6	Greece
B2	Djibouti	G2	Honduras	J7	Iraq	O7	Hungary
B3	Egypt	G3	Jamaica	J8	Israel	O8	Iceland
B4	Equatorial Guinea	G4	Martinique	J9	Japan	O9	Ireland
B5	Ethiopia	G5	Mexico	K0	Jordan	P0	Italy
B6	Gabon	G6	Netherlands Antilles	K1	Korea, Dem People's Rep	P1	Macedonia, The Fmr Yug Rp
B7	Gambia	G7	Nicaragua	K2	Korea, Republic of	P2	Malta
B8	Ghana	G8	Panama	K3	Kuwait	P3	Netherlands
B9	Guinea	G9	Saint Vincent/Grenadines	K4	Laos	P4	Norway
C0	Guinea-Bissau	H0	Trinidad and Tobago	K5	Lebanon	P5	Poland
C1	Kenya	H1	United States of America	K6	Macau	P6	Portugal
C2	Lesotho		**SOUTH AMERICA**	K7	Malaysia	P7	Romania
C3	Liberia	H2	Argentina	K8	Mongolia	P8	Slovakia
C4	Libyan Arab Jamahiriya	H3	Bolivia	K9	Myanmar	P9	Slovenia
C5	Madagascar	H4	Brazil	L0	Nepal	Q0	Spain
C6	Malawi	H5	Chile	L1	Oman	Q1	Sweden
C7	Mali	H6	Colombia	L2	Pakistan	Q2	Switzerland
C8	Mauritania	H7	Ecuador	L3	Philippines	Q3	United Kingdom
C9	Mauritius	H8	French Guiana	L4	Qatar	Q4	Serbia and Montenegro
D0	Morocco	H9	Guyana	L5	Saudi Arabia		**FORMER USSR**
D1	Mozambique	I0	Paraguay	L6	Singapore	Q5	Armenia
D2	Niger	I1	Peru	L7	Sri Lanka	Q6	Azerbaijan, Republic of
D3	Nigeria	I2	Suriname	L8	Syrian Arab Republic	Q7	Belarus
D4	Réunion	I3	Uruguay	L9	Thailand	Q8	Estonia
D5	Rwanda	I4	Venezuela, Boliv Rep of	M0	Turkey	Q9	Georgia
D6	Sao Tome and Principe			M1	United Arab Emirates	R0	Kazakhstan
D7	Senegal			M2	Viet Nam	R1	Kyrgyzstan
D8	Sierra Leone			M3	Yemen	R2	Latvia
D9	Somalia				**OCEANIA**	R3	Lithuania
E0	South Africa			M4	Australia	R4	Moldova, Republic of
E1	Sudan			M5	Cook Islands	R5	Russian Federation
E2	Swaziland			M6	Fiji Islands	R6	Tajikistan
E3	Tanzania, United Rep of			M7	French Polynesia	R7	Turkmenistan
E4	Togo			M8	New Caledonia	R8	Ukraine
E5	Tunisia			M9	New Zealand	R9	Uzbekistan
E6	Uganda			N0	Papua New Guinea		
E7	Congo, Dem Republic of			N1	Samoa	ZY	Dummy Region
E8	Zambia			N2	Solomon Islands	ZZ	World
E9	Zimbabwe			N3	Tonga		
				N4	Vanuatu		

[12] The listed countries are default countries in GFPM. To add or remove countries, see Zhu et al. (2008).

Table 2: Wood products in the Global Forest Products Model (GFPM)

Commodity Aggregate (used in the GFPM)	Constituent Commodities
Fuelwood and charcoal	Wood fuel
	Wood charcoal
Industrial roundwood	Chips and particles (imports and exports only)
	Pulpwood
	Sawlogs
Other industrial roundwood	Other industrial roundwood
Sawnwood	Sawnwood
Plywood	Plywood
	Veneer sheets
Particleboard	Particleboard
Fibreboard	Fibreboard
Mechanical pulp	Mechanical wood pulp
Chemical pulp	Chemical wood pulp
	Semi-chemical wood pulp
Other fibre pulp	Other fibre pulp
Waste paper	Recovered paper
Newsprint	Newsprint
Printing and writing paper	Printing and writing paper
Other paper and paperboard	Other paper and paperboard

Table 3: Price and income elasticities of demand for final products

Commodity	Wealth - Region	Price	Income
Fuelwood	High income[1]	-0.62	-1.50
	Low income[2] – Africa	-0.10	0.40
	Low income – Other regions	-0.10	0.15
Other industrial roundwood	High income	-0.05	-0.58
	Low income	-0.37	0.19
Sawnwood	High income	-0.16	0.32
	Low income	-0.21	0.46
Plywood and veneer	High income	-0.13	0.10
	Low income – Europe	-0.22	1.20
	Low income – Other regions	-0.22	0.74
Particleboard	High income	-0.24	1.25
	Low income	-0.05	0.65
Fibreboard	High income	-0.52	0.82
	Low income – Asia, Europe	-0.52	1.50
	Low income – Other regions	-0.52	1.10
Newsprint	High income	-0.05	0.21
	Low income – Asia, Europe	-0.18	1.05
	Low income	-0.18	0.21
Printing and writing paper	High income	-0.15	0.80
	Low income	-0.37	1.11
Other paper and paperboard	High income	-0.06	0.65
	Low income	-0.14	0.92

[1] Australia, Austria, Belgium-Luxembourg, Canada, Denmark, Finland, France, Germany, Ireland, Israel, Italy, Japan, Kuwait, Netherlands, Norway, New Zealand, South Africa, Spain, Sweden, Switzerland, United Kingdom, and the USA
[2] Rest of the world
Modified from Buongiorno et al. (2003, Table 4.5).

Table 4: Equation parameters for fuelwood and industrial roundwood supply in the Global Forest Products Model.

	Fuelwood Supply		Industrial Roundwood Supply	
	Low income	High income	Low income	High income
Price	1.00	2.00	0.40-1.57[1]	0.70-1.57
GDP per capita			0.90	0.90
Forest stock	1.00	1.50	1.60	0.50

[1]The price elasticity of industrial roundwood supply depends on the proportion of country forest in public ownership; with supply from public forests less price elastic than supply from private forests.

Table 5: Supply shift parameters for GHG policy scenarios

Commodity	Australia	Canada	European Union	Japan	New Zealand	Norway	Russia	Switzerland	Turkey	USA
Wheat	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Other grains	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Maize	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Rice	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Sugar	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Oilseed	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Oilseed meal	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Oil	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Beef	0.74	0.87	0.92	0.87	0.93	0.87	0.87	0.87	0.87	0.89
Pork	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Sheepmeat	0.78	0.86	0.87	0.86	0.91	0.86	0.86	0.86	0.86	0.90
Wool	0.78	0.86	0.87	0.86	0.91	0.86	0.86	0.86	0.86	0.90
Poultry	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Eggs	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Raw milk	0.88	0.93	0.96	0.93	0.92	0.93	0.93	0.93	0.93	0.96
Liquid milk	0.88	0.93	0.96	0.93	0.92	0.93	0.93	0.93	0.93	0.96
Butter	0.88	0.93	0.96	0.93	0.92	0.93	0.93	0.93	0.93	0.96
Cheese	0.88	0.93	0.96	0.93	0.92	0.93	0.93	0.93	0.93	0.96
Whole milk powder	0.88	0.93	0.96	0.93	0.92	0.93	0.93	0.93	0.93	0.96
Skim milk powder	0.88	0.93	0.96	0.93	0.92	0.93	0.93	0.93	0.93	0.96
Apples	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Kiwifruit	1.00	0.96	0.95	0.96	0.94	0.96	0.96	0.96	0.96	0.94
Firewood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Roundwood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Panelwood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Paper and pulp	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6: Supply shift parameters for mitigation scenarios

Commodity	Australia	Canada	European Union	Japan	New Zealand	Norway	Russia	Switzerland	Turkey	USA
Wheat	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Other grains	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Maize	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Rice	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Sugar	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Oilseed	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Oilseed meal	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Oil	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Beef	0.82	0.91	0.94	0.91	0.95	0.91	0.91	0.91	0.91	0.92
Pork	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Sheepmeat	0.84	0.90	0.91	0.90	0.94	0.90	0.90	0.90	0.90	0.93
Wool	0.84	0.90	0.91	0.90	0.94	0.90	0.90	0.90	0.90	0.93
Poultry	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Eggs	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Raw milk	0.91	0.95	0.97	0.95	0.94	0.95	0.95	0.95	0.95	0.97
Liquid milk	0.91	0.95	0.97	0.95	0.94	0.95	0.95	0.95	0.95	0.97
Butter	0.91	0.95	0.97	0.95	0.94	0.95	0.95	0.95	0.95	0.97
Cheese	0.91	0.95	0.97	0.95	0.94	0.95	0.95	0.95	0.95	0.97
Whole milk powder	0.91	0.95	0.97	0.95	0.94	0.95	0.95	0.95	0.95	0.97
Skim milk powder	0.91	0.95	0.97	0.95	0.94	0.95	0.95	0.95	0.95	0.97
Apples	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Kiwifruit	1.00	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96
Firewood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Roundwood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Panelwood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Paper and pulp	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 7: Supply shift parameters for climate change scenarios

Commodity	Argentina	Australia	Brazil	Canada	China	EU	India	Japan	Korea	Mexico	New Zealand	Norway	Russia	South Africa	Switzer-land	Turkey	USA	ROW
Wheat	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Other grains	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Maize	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Rice	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Sugar	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Oilseed	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Oilseed meal	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Oil	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Beef	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.93	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Pork	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Sheepmeat	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.93	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Wool	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.93	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Poultry	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Eggs	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Raw milk	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Liquid milk	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Butter	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Cheese	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Whole milk powder	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Skim milk powder	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Apples	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Kiwifruit	0.96	0.99	0.96	1.01	0.93	0.99	0.93	0.99	0.99	1.01	0.96	0.99	0.93	0.96	0.99	0.99	1.01	0.96
Firewood	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01	1.01	1.11	1.02	1.01	1.01	1.01	1.01	1.02	1.01
Roundwood	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01	1.01	1.11	1.02	1.01	1.01	1.01	1.01	1.02	1.01
Panelwood	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01	1.01	1.11	1.02	1.01	1.01	1.01	1.01	1.02	1.01
Paper and pulp	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01	1.01	1.11	1.02	1.01	1.01	1.01	1.01	1.02	1.01