MODELLING THE IMPACT OF THE EXOTIC FOREST PEST NECTRIA ON THE NEW ZEALAND FOREST SECTOR AND ITS MAJOR TRADING PARTNERS

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ABSTRACT

The possible impact of *Nectria fuckeliana* Booth on the forests and forest industries of New Zealand, a significant exporter of industrial roundwood, was estimated for different scenarios of the spread of the fungal pest and trade measure responses in export markets. An economic model was used to assess the direct effect of the pest and the potential impact of trade bans and phytosanitary regulations to prevent pest arrival in New Zealand's major export markets — China, Japan, and South Korea. Depending on the assumed area affected by *N. fuckeliana*, the net present value of New Zealand's forest sector gross revenue was US$34 million to US$612 million lower, due to reduced harvest and log exports, even without foreign trade measures. A possible measure, requiring the debarking of New Zealand log exports, would reduce the present value of New Zealand growers' revenues by US$1,200 million, even if *N. fuckeliana* were confined to the already

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affected area. If China, Japan, and South Korea banned imports of New Zealand logs altogether, and the pest continued to spread at historical rates, the present value of New Zealand growers' revenues would decrease by US$8,200 million. Estimated losses to growers could be, to varying extents, offset by increased domestic production of processed wood products, under both trade measures. The debarking and import ban policies would increase gross revenues for producers in China and South Korea, but also increase the cost to consumers of wood products.

Keywords: exotic forest pests; international trade; phytosanitary regulations; forest sector model.

BACKGROUND

New Zealand's wood product exports were worth US$1,551 million at year end February 2006, accounting for 9.2% of all exports by value (Statistics New Zealand 2006). These exports are based on highly productive plantation forests of *Pinus radiata* D. Don and *Pseudotsuga menziesii* (Mirb.) Franco (Brown 1997), which face a significant threat from exotic forest pests, such as Nectria disease caused by the fungus *Nectria fuckeliana*.

More than 400 pest threats known to affect *P. radiata* are currently not present in New Zealand (Flux *et al*. 1993), but the growth of global trade is increasing the risk of unintentional introductions (Tkacz 2002). The severe threat that exotic pests pose to forest ecosystems has led to a variety of measures, such as phytosanitary regulations — fumigation and heat treatments, debarking, visual inspections, phytosanitary certificates — or import bans, to reduce the risk of importing pests (Powell 1997; New Zealand Forest Research Institute 1999; Roberts 1999; Roberts *et al*. 1999).

These trade measures can affect domestic and foreign wood product industries and consumers in numerous ways. There are clear benefits from reducing the risk of damage to forest resources and hence loss of production and exports (Rose 1983; USDA Forest Service 1991; Pimentel *et al*. 2000; Turner *et al*. 2004). However, trade regulations have a cost. Exporting countries may lose access to markets. Importing countries may have to forego cheaper foreign products and raw materials (Roberts *et al*. 1999; Mumford 2002).

The full economic impact of regulations to prevent the importation of exotic pests can be assessed by measuring price and quantity changes for producers and consumers along the wood product value chain from the forest to the end consumer, through various stages of manufacture. At each stage, consumer and producer surplus should be assessed, to the extent possible.

To capture these various effects Roberts *et al*. (1999) suggested an economic framework (1) which is easily understood, (2) is comprehensive enough to represent a range of trade measures, and (3) into which empirical data on trade regulations and exotic pest impacts can be incorporated for the estimation of trade, production, consumption, and welfare effects. To this list we would add, (4) the ability to represent the temporal effect of exotic pests on forest resources — because forest pests are biological organisms that grow, reproduce, multiply, actively and passively disperse, interact with ecosystems in unpredictable ways, and randomly evolve (Powell 1997) — and (5) the ability to represent complex interactions, through trade, among countries. This is necessary to determine how regulations in a particular country or its trading partners affect their forest sector. It depends on how world prices are affected by the regulation and whether the affected exporter is able to sell in other markets (Roberts *et al.* 1999).

Market equilibrium models have been a fruitful approach for predicting the effects of regulations to reduce the risk of importing exotic pests (Beghin & Bureau 2001). They have the characteristics necessary to fully assess the main impacts, and they have already been applied successfully to policy analysis.

Studies of the economic and trade effects of phytosanitary regulations in the agricultural sector (Roberts *et al.* 1999) commonly conclude that the short- and long-run effects of pests, and policies to reduce the risk of their import, are to lower aggregate wealth and to redistribute it within a country and beyond its borders. In the country imposing the policy consumers pay higher prices, while producers benefit. In the exporting country, producers experience production losses.

Krissoff *et al.* (1997) and Calvin & Krissoff (1998) examined technical regulations imposed on United States apple exports to Japan, South Korea, and Mexico. Sumner & Lee (1997) determined the cost of complying with Asian regulations on vegetable imports from the United States. Orden & Romano (2006) estimated the effect of production losses in the United States avocado industry resulting from the possibility of pest infestation from Mexican imports. They measured the benefits to United States producers of a ban on avocado imports from Mexico, as well as the cost to United States consumers. Roberts *et al.* (1999) assessed the economic effects of easing the United States ban on the importation of avocados from Mexico, distinguishing between regulatory protection, supply-shift, and demand-shift effects.

Paarlberg & Lee (1998) calculated the “optimum tariff” on imports of beef from regions with foot-and-mouth disease. The “optimum tariff” was set to maximise the difference between the consumers’ gains from trade and the costs to the domestic industry from the spread of the disease. James & Anderson (1998) assessed the costs and benefits of quarantine restrictions in Australia while explicitly taking into account the probability of contamination.

Past analyses of the impact of exotic pests on the forest sector (Kuchler & Duffy 1984; Holmes 1991; USDA Forest Service 1991; Turner *et al.* 2004) have not considered phytosanitary regulations. Prestemon *et al.* (2006) seem to have made the only attempt to determine the full costs and benefits of regulations on United States imports of softwood logs from Russia, which potentially carry the Asian gypsy and nun moths. They used the Global Forest Products Model (Buongiorno *et al*. 2003) to simulate different interventions — phytosanitary, direct trade barriers, and detection and control — by the United States and to assess their cost and efficacy, and hence their effect on producers and consumers.

The objective of this study was to predict the potential economic impact of the fungus *Nectria fuckeliana*, which has been found in exotic timber plantations in the South Island of New Zealand (Wang & Thode 2004; Dick *et al*. 2006). Both the direct effect of the pest, in terms of forest loss, and the indirect effect due to trade measures imposed by importers of New Zealand logs were considered. By studying New Zealand we assessed the implications of forest pests and phytosanitary regulations from the perspective of a significant exporter of industrial roundwood, while Prestemon *et al*. (2006) focused on the United States as an importer. The implications in terms of aggregate timber production, prices, consumption, and net trade are, therefore, likely to be very different. Below, we discuss first the economic model, outline the alternative pest spread and policy scenarios, and then describe in detail the results and their implications.

METHODS AND MATERIALS

Economic Model

The impact of *N. fuckeliana* on wood product production, trade, and prices, and on forest resources in New Zealand, its markets, and competitors was predicted from 2002 to 2030 with the Global Forest Products Model (Buongiorno *et al*. 2003). The GFPM has previously been used to forecast forest sector development (Turner, Buongiorno, Maplesden, Zhu, Bates & Li 2006) and to study issues such as the effects of accelerated tariff liberalisation (Zhu *et al*. 2001) and of trade agreements on the New Zealand forest sector (Turner *et al*. 2001), the global impact of waste paper recycling in the United States (Zhu & Buongiorno 2002), effects of illegal logging on the United States forest sector (Seneca Creek 2004), and the impact of the Free Trade Area of the Americas on forest resources (Turner *et al*. 2005).

The GFPM is a dynamic market equilibrium model that integrates wood supply, processing industries, product demand, and trade. Wood producing, consuming, and manufacturing activities are modelled with supply and demand equations, and activity analysis. Countries are linked by trade. Inter-temporal linkages are exogenous, as for changes in techniques of production in pulp and paper, or endogenous, as for shifts in wood supply and changes in forest area and forest stock*.

* The mathematical specification of the GFPM is given in Appendix A. Turner, Buongiorno, Zhu & Li (2006) have provided a complete description of model assumptions. Model assumptions specific to New Zealand are given in Appendix B. Model data are available from the authors upon request.

Forest resources and harvests are represented in the GFPM by equations describing the annual roundwood harvest, and the changes of forest stock and forest area (Turner, Buongiorno & Zhu 2006). The harvest volume is a function of prices, forest stock (endogenous), and gross domestic product per capita (exogenous).

Forest stock evolves according to a growth-drain equation (Brooks 1987):

$$I_{i,t+1} = (1 + g^{a}_{it} + g^{u}_{it})I_{it} - S_{it} \qquad [1]$$

where S_{it} is the total roundwood harvest in country i and year t, g^{a}_{it} is the rate of change in forest stock (I_{it}) due to forest area change (afforestation/deforestation), g^{u}_{it} is the rate of forest growth on a given area, without harvest and under normal conditions — in particular without exotic forest pests.

The annual relative change of forest area in all countries (except for New Zealand in this study, see below) is a function of income per capita (*Y/N*), as in the environmental Kuznets curve for forestry (Vincent *et al.* 1997):

$$g^{a}_{it} = \alpha_0 + \alpha_1 \, (Y_{it} \,/\, N_{it}) + \alpha_2 \, (Y_{it} \,/\, N_{it})^2 \qquad [2]$$

The annual relative change of forest stock due to growth is an inverse function of forest density – stock per unit area, *I/A* (Oliver & Larson 1996):

$$g^{u}_{it} = \gamma_0 (I_{it} \,/\, A_{it})^{-a} \qquad [3]$$

The effect of an invasive species was represented by reducing this rate of growth of forest stock by various amounts, $g^{u}_{it}*$, over time, to simulate different rates of pest spread. These changes in forest stock would then affect future harvests and growth via the wood supply equation and Equation [3].

New Zealand's industrial roundwood harvests are almost entirely from plantations; 0.1% of harvests in 2005 were from native forests (NZFOA 2006). Thus, only the planted forest estate was considered in this study. In 2003 New Zealand had 1.83 million ha of planted forest with a volume of 398 million m^3 (NZFOA 2005), growing at 18 to 24 m^3/ha per year (Brown 1997) — or g^u = 8.3% per year of the current growing stock. Estimates of new plantings are 30 100 ha in 2002 and 22 100 ha in 2003 (NZFOA 2005). For the projections we assumed a long-run average planting rate of 20 000 ha per year (NZMAF 2000) — equivalent to g^a = 1.09% per year addition to the plantation estate (Table B.3).

Impacts of Nectria

Nectria fuckeliana is found in New Zealand; it is found in Scandinavia, Northern Europe, and North America generally at latitudes greater than 50ºN, although it has been recorded in Oregon and Northern California. In New Zealand the fungus commonly, but not exclusively, enters trees through the pruning stub and this leads to stain and decay within the stem (Dick *et al.* 2006), affecting the most valuable section of the tree, the pruned log (NZFOA 2005).

Nectria may have arrived in New Zealand in the late 1980s or early 1990s, according to anecdotal reports. The first formal collection was made in 1996, and by the end of 2005 targeted surveys had demonstrated that the fungus was present throughout the wood supply regions of Southland and Otago, and occurred in parts of Canterbury (Waimate, Timaru, and Mackenzie territorial authorities). Those regions contain 34 million m^3 — 8.6% — of New Zealand's total forest stock (NZMAF 2004). Further surveys were carried out in Canterbury in 2006 and 2007. By April 2007, the northernmost find was at Banks Peninsula, approximately 140 km from the nearest known location recorded in April 2004.

Regional incidence surveys carried out in Southland and Otago in 2006 showed 20% of the trees were affected to some extent. Wang & Thode (2004) suggested 4 to 39%. The volume loss per tree could be 5 to 10%, given that 8% of trees were assessed as having medium damage and 5% were assessed as having severe damage, but as Nectria affects the most valuable section of the stem*, we assumed a volume loss of 10%. Taken together, the assumptions imply a reduction in New Zealand's total forest stock of 0.172% (8.6% × 20% × 10%). The assumed pattern of stock reduction was 0.109% in 2003, reflecting the stock lost from 1990 to 2003, an additional stock reduction of 0.028% in 2004, 0.036% in 2005, and no further reduction from 2006 to 2030.

If Nectria's spread continued at historical rates — approximately 100 km every 2 years — the fungus could affect Southland, Otago, and Canterbury by 2008, and all of the South Island (excluding the West Coast) by 2014. This study also considered the possibility of Nectria establishing itself, by either natural or unnatural means, in the North Island. It was assumed that the disease would arrive in the North Island in 2007 and be completely established by 2011 (Fig. 1). This rate of spread was assumed to be more rapid than in Canterbury and Nelson, due to the more favourable climate in the central North Island and the abundance of suitable host material. The rate of stock reduction under this scenario is shown in Fig. 2.

Log Importer Policy Response

Of the 8.3 million m^3 of logs exported by New Zealand in 2002, 20% went to the People's Republic of China, 18% to Japan, and 48% to South Korea (FAO 2005). We assumed that these countries might respond to the spread of Nectria in New Zealand in three ways (G. Hosking, Hosking Forestry, pers. comm.): (1) do nothing, (2) allow imports of debarked roundwood only, or (3) ban all industrial roundwood imports from New Zealand. These represent the range of possible responses. Others include inspections, certification in New Zealand, or fumigation,

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* 60% of the tree value is in the pruned log of 27-year-old *P. radiata* grown on a direct sawlog regime (NZFOA 2005)

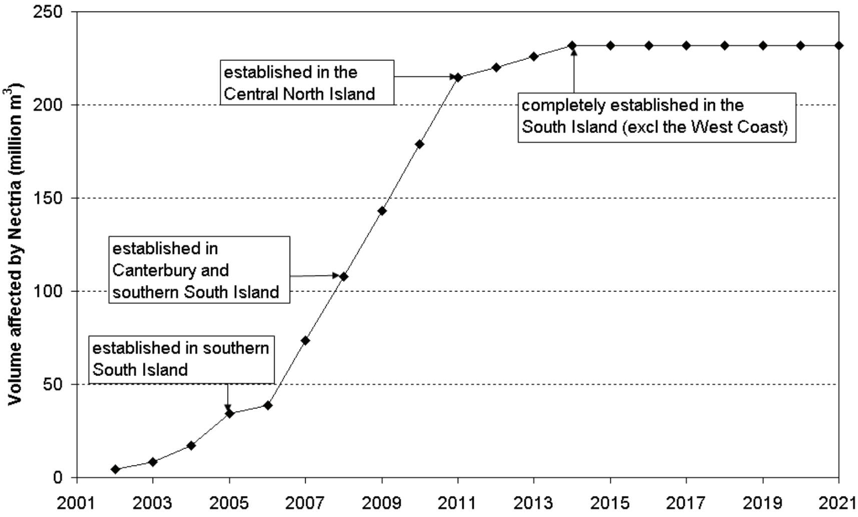

FIG. 1–Assumed volume of New Zealand's plantation forest affected by the spread of Nectria.

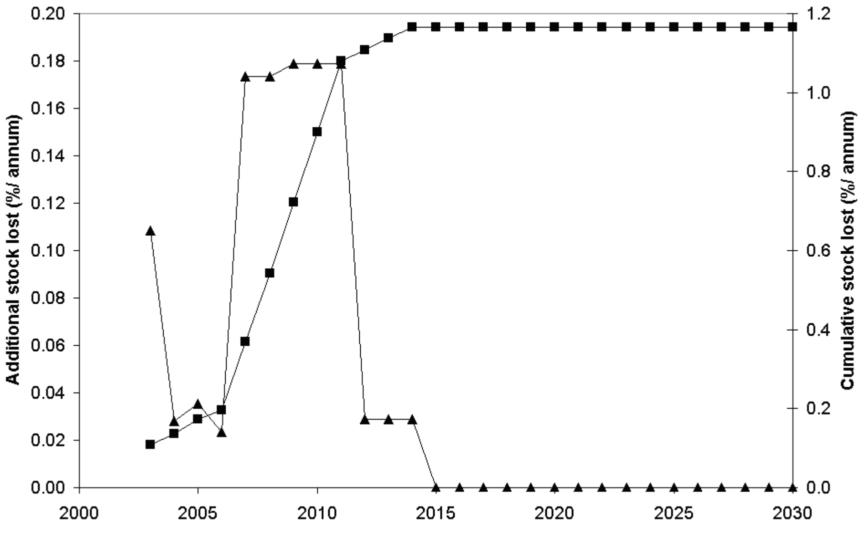

FIG. 2–Annual additional (▲) and cumulative (■) New Zealand forest stock lost due to Nectria spread to all of the South Island (excluding the West Coast) and the North Island.

which, like debarking, add to varying degrees to the cost of freight for New Zealand industrial roundwood.

Each response was analysed under two levels of Nectria invasion — staying confined to its current area, or spreading to all of the South Island (excluding the

West Coast) and the central North Island (Fig. 2). While it is likely that the fungus will spread throughout the North Island, we confined the response analysis to the central North Island on the conservative assumption that the disease would not cause significant damage in other regions due to climatic factors. Each of the six response-spread scenarios was compared with the status quo scenario in which there would be no Nectria in New Zealand and thus no need for a response by China, Japan, and South Korea.

Debarking was estimated to cost US$4.42/m^3, based on costs of NZ$4.27/m^3 to NZ$6.39/m^3 in 1988 New Zealand dollars (W.Blundell & G.Murphy unpubl. data), adjusted to 2005 US dollars using the New Zealand consumer price index and a New Zealand to US dollar exchange rate of 0.55 in 2005. The cost includes log handling, which is 40 to 60% of the total cost. This cost of debarking was modelled as an increase in the level of the industrial roundwood freight cost (Equation A.11) for New Zealand log exports to China, Japan, and South Korea.

RESULTS AND DISCUSSION

No Response by China, Japan and South Korea

For no policy action by China, Japan, and South Korea, depending on the extent of Nectria spread, New Zealand forest stock was predicted to be 200 000 m^3 to 20 million m^3 lower in 2030 than without the pest (Table 1). From 2002 to 2030, the average annual harvest was 20 900 m^3 to 1.3 million m^3 per year lower, 0.1 to 4.5% (Table 2). This reduction in New Zealand harvests led to substantially lower industrial roundwood exports — a 1.4 million m^3 per year or 7.0% reduction were Nectria to spread beyond its current extent. There were modest changes in New Zealand's production and net trade (exports minus imports) of all other wood products — less than 4% — with larger reductions for sawnwood, wood-based panels, and wood pulp than for paper products (Table 2).

Total net imports of industrial roundwood by China, Japan, and South Korea were unchanged – less than 1% per year difference (Table 2) – because reduced imports from New Zealand were replaced by imports from Brazil (8% per year increase) and Chile (1% per year increase) (Table 3). New Zealand industrial roundwood exports to China, Japan, and South Korea were barely affected by Nectria at its current extent (Table 4) and, as a result, harvest and stock in China, Japan, and South Korea were unchanged (Tables 1 and 2). However, were Nectria to spread throughout the South Island and central North Island, industrial roundwood exports to Japan and the rest of the world would be lower by 252 000 m^3 per year and 1.4 million m^3 per year, respectively (Table 4). Log exports to China would remain unchanged, reflecting China's strong demand for wood driven by rapid economic growth and the relatively small increase in the price of New Zealand industrial roundwood (Fig. 3).

TABLE 1–Impact of Nectria on forest stock (million m^3 and %) in 2030.

	Do nothing		NZ debarks log exports		CJK* ban NZ logs	
	(million m^3)	(%)	(million m^3)	(%)	(million m^3)	(%)
Nectria confined to current area						
New Zealand	–0.2	–0.1	41.5	6.0	319.7	46.1
China	0.0	0.0	0.0	0.0	–55.4	–0.8
Japan	0.1	0.0	–0.8	0.0	–1.5	0.0
South Korea	0.0	0.0	–0.6	–0.2	–25.4	–9.4
Nectria at maximum spread						
New Zealand	–20.4	–2.9	16.4	2.4	253.4	12.5
China	0.0	0.0	0.0	0.0	–55.4	–0.8
Japan	–0.3	0.0	–1.3	0.0	–1.4	–0.0
South Korea	0.1	0.0	–0.8	–0.3	–25.4	–9.4

* CJK = China, Japan, and South Korea

Unexpectedly, New Zealand's log exports to South Korea were predicted to be slightly higher — 5000 m^3 to 219 000 m^3 per year, depending on the extent of Nectria spread (Table 4). This was due to the dynamics of the impact of the stock loss on New Zealand industrial roundwood prices, harvests, and log exports. The initial effect was to increase industrial roundwood prices (Fig. 3), reducing demand for New Zealand roundwood exports, and increasing harvests in South Korea. As

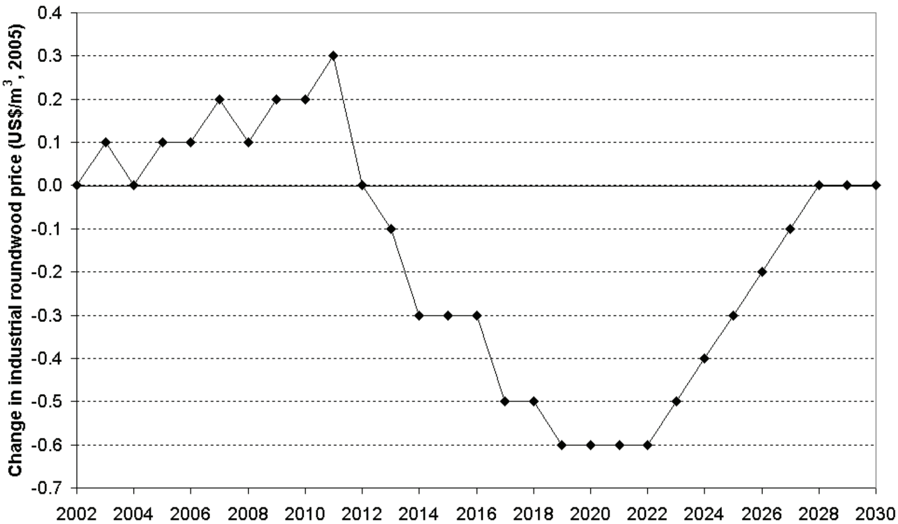

FIG. 3–Change in New Zealand industrial roundwood price (US$/m^3, 2005) due to spread of Nectria through the South Island and central North Island of New Zealand.

TABLE 2–Percentage change of average annual production and net trade volume due to Nectria in New Zealand with three policy responses, from 2002 to 2030.

Product	Country	Do nothing		NZ debarks log exports		CJK ban NZ logs	
		Production	Net trade	Production	Net trade	Production	Net trade
Nectria confined to current area							
Industrial roundwood	New Zealand	-0.1	-0.1	-3.9	-14.7	-31.3	-62.3
	China	0.0	0.0	0.0	0.0	2.3	-5.8
	Japan	0.0	0.0	0.1	-0.9	0.2	-0.9
	South Korea	0.0	0.1	1.4	-0.7	78.7	-21.8
Sawnwood	New Zealand	-0.1	-0.4	21.5	79.1	32.0	115.3
	China	0.0	0.0	0.0	0.0	-2.5	0.0
	Japan	0.0	0.0	-0.2	0.6	-0.4	0.9
	South Korea	0.0	0.0	-0.3	0.3	-11.4	0.6
Wood-based panels	New Zealand	-0.2	-0.3	6.9	15.1	14.3	30.4
	China	0.0	0.0	0.0	0.0	-1.6	0.0
	Japan	0.0	0.0	-0.4	0.4	-0.8	0.7
	South Korea	0.2	-0.1	-1.1	0.6	-15.6	2.0
Wood pulp	New Zealand	-0.1	-0.2	43.2	125.4	71.5	186.0
	China	0.0	0.0	0.0	0.0	-2.1	0.0
	Japan	0.0	0.0	-0.7	4.1	-0.4	1.7
	South Korea	0.0	0.0	-0.2	0.0	-14.0	-5.3
Paper & paper board	New Zealand	0.0	0.1	1.1	9.7	15.3	129.9
	China	0.0	0.0	0.0	0.0	-0.4	0.7
	Japan	0.0	0.0	0.0	1.1	-0.1	2.0
	South Korea	0.0	0.0	0.0	0.0	-5.8	-30.9

TABLE 2–cont.

Product	Country	Do nothing		NZ debarks log exports		CJK ban NZ logs	
		Production	Net trade	Production	Net trade	Production	Net trade
Nectria at maximum spread							
Industrial roundwood	New Zealand	-4.5	-7.0	-7.9	-17.8	-31.3	-62.3
	China	0.0	0.0	0.0	0.0	2.3	-5.8
	Japan	0.1	0.0	0.2	-0.6	0.2	-0.9
	South Korea	-0.3	0.7	1.9	-0.8	78.7	-21.8
Sawnwood	New Zealand	-0.2	-0.7	15.2	57.4	31.9	115.3
	China	0.0	0.0	0.0	0.0	-2.5	0.0
	Japan	0.0	0.0	-0.2	0.5	-0.4	0.9
	South Korea	0.1	-0.1	-0.4	0.4	-11.4	0.6
Wood-based panels	New Zealand	0.7	1.5	4.8	10.5	14.2	30.3
	China	0.0	0.0	0.0	0.0	-1.6	0.0
	Japan	-0.1	0.1	-0.5	0.4	-0.7	0.7
	South Korea	1.6	-0.9	-1.2	0.6	-15.6	2.0
Wood pulp	New Zealand	1.4	3.8	32.0	94.9	70.5	185.8
	China	0.0	0.0	0.0	0.0	-2.1	0.0
	Japan	0.1	-0.4	-0.3	1.7	-0.4	1.7
	South Korea	0.1	0.0	-0.2	0.0	-14.0	-5.3
Paper & paper board	New Zealand	0.1	1.0	1.0	8.3	14.1	119.3
	China	0.0	0.0	0.0	0.0	-0.5	0.7
	Japan	0.0	0.0	0.0	0.9	-0.1	2.1
	South Korea	0.0	0.0	0.0	0.0	-5.8	-30.9

TABLE 3–Percentage change of average annual industrial roundwood net-trade in major countries due to Nectria in New Zealand with three policy responses, from 2002 to 2030

Country/Region	Do nothing	NZ debarks log exports	CJK* ban NZ logs
Nectria confined to current area			
AFRICA	0.03	1.05	1.71
South Africa	0.02	1.89	3.53
N&C AMERICA	0.04	0.14	2.56
Canada	-0.14	-0.29	-7.97
United States	0.00	0.00	0.01
SOUTH AMERICA	-0.06	2.85	4.63
Brazil	-0.30	6.65	14.57
Chile	-0.03	2.16	2.90
ASIA	0.00	-0.42	-6.58
Malaysia	0.01	0.68	1.13
OCEANIA	-0.02	-7.17	-29.70
Australia	0.01	0.48	0.94
EUROPE	0.03	6.29	9.77
Finland	-0.06	-4.44	-6.13
Russian Federation	0.00	0.00	0.00
Sweden	-0.02	-0.83	-2.08
Nectria at maximum spread			
AFRICA	0.38	1.39	1.74
South Africa	0.59	3.02	3.34
N&C AMERICA	0.01	0.25	2.57
Canada	0.09	-0.89	-7.99
United States	0.00	0.01	0.00
SOUTH AMERICA	2.09	4.05	4.45
Brazil	7.98	10.88	13.49
Chile	1.02	2.92	2.82
ASIA	-0.02	-0.39	-6.57
Malaysia	0.36	0.91	1.11
OCEANIA	-3.28	-8.61	-29.71
Australia	0.25	0.79	0.93
EUROPE	3.30	7.58	9.85
Finland	-1.96	-4.91	-6.18
Russian Federation	0.00	0.00	0.00
Sweden	-2.02	-1.90	-2.15

* CJK = China, Japan, and South Korea

New Zealand harvests decreased, due to reduced demand, the stock loss due to Nectria was partially recovered (Fig. 4). This increased the potential supply of New Zealand industrial roundwood and lowered its price (Fig. 3). At the same

TABLE 4–Effect of Nectria on New Zealand average annual exports of industrial roundwood, by destination, from 2002 to 2030

	Do nothing		NZ debarks log exports		CJK* ban NZ logs	
	(10^3 m^3)	(%)	(10^3 m^3)	(%)	(10^3 m^3)	(%)
Nectria confined to current area						
China	0	0.0	0	0.0	–4710	–86.2
Japan	–5	–0.2	–1521	–49.3	–2476	–86.2
South Korea	5	0.1	–2907	–35.4	–6459	–86.2
Rest of the world	–10	–0.2	1212	18.1	1229	18.4
Nectria at maximum spread						
China	0	0.0	0	0.0	–4710	–86.2
Japan	–252	–9.7	–1496	–48.7	–2476	–86.2
South Korea	219	2.3	–2707	–33.2	–6459	–86.2
Rest of the world	–1361	–27.5	278	1.7	1229	18.4

* CJK = China, Japan, and South Korea

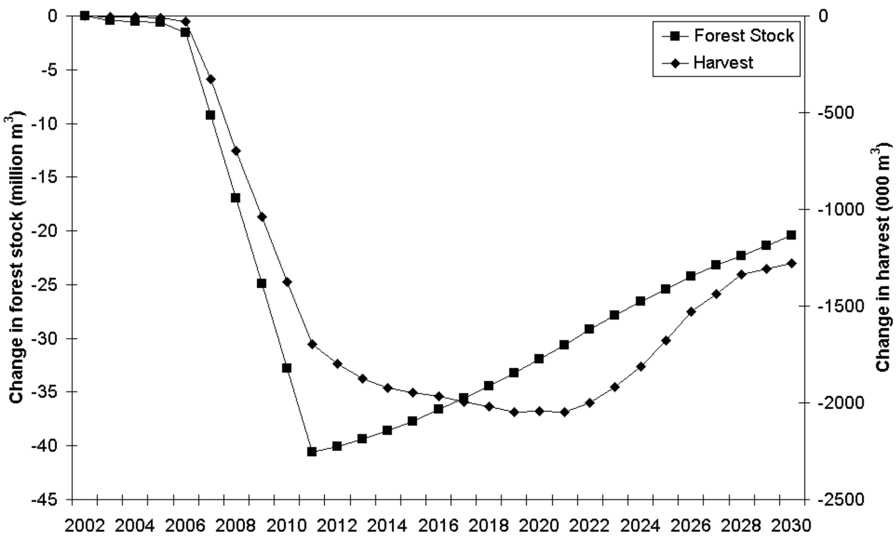

FIG. 4–Change in New Zealand plantation forest stock and industrial roundwood harvests due to spread of Nectria through the South Island and central North Island of New Zealand.

time South Korea's industrial roundwood price increased because of its more expensive domestic harvests. In response, South Korea increased its imports of New Zealand industrial roundwood in the 2020s.

Depending on the extent of Nectria spread, the net present value — at an 8% discount rate — of New Zealand producers' gross revenue* would decrease by US$34 million to US$612 million (Table 5). The gross revenue loss to industrial roundwood producers was US$9 million to US$746 million (Table 6). Most of the reduction in harvests went to a reduction in industrial roundwood exports. New Zealand consumption of industrial roundwood was unchanged.

Producer revenue in New Zealand's markets increased slightly due to some production moving to these countries. World producer revenue increased as other countries increased their production to replace New Zealand's exports to China, Japan, and South Korea.

TABLE 5–Gains and losses† in different countries due to Nectria and countervailing trade measures

	Do nothing		NZ debarks log exports		CJK‡ ban NZ logs	
	Producers	Consumers	Producers	Consumers	Producers	Consumers
Nectria confined to current area						
New Zealand	-34	4	1,654	-110	-5,100	-985
China	-5	-2	-29	-7	17,321	12,101
Japan	0	1	-415	19	-228	67
South Korea	20	0	75	230	2,195	11,149
World	45	42	-1,197	121	19,118	22,683
Nectria at maximum spread						
New Zealand	-612	88	239	0	-4,644	-824
China	31	10	21	9	17,317	12,105
Japan	96	47	-113	73	-236	63
South Korea	166	-8	133	311	2,204	11,152
World	1,525	668	962	879	19,604	22,911

† Net present value of producers' revenue and consumers' expenditure, in US$ million 2005, with an 8% per year discount rate
‡ China, Japan, and South Korea

Debarking of Log Exports Required

The imposition of a debarking requirement by China, Japan, and South Korea further reduced New Zealand harvest and log exports. Lower industrial roundwood prices — 4.1% to 4.3% on average between 2002 and 2030, depending on the extent of Nectria spread (Table 7) – contributed to harvests which were 1.2 million m^3 to 2.4 million m^3 (4–8%) per year lower on average (Table 2).

* Gross revenue is the value of production — quantity produced multiplied by price per unit— ignoring changes in the cost of raw material inputs to production.

TABLE 6–Gains and losses* of different sub sectors in New Zealand due to Nectria and countervailing trade measures

	Do nothing		NZ debarks log exports		CJK† ban NZ logs	
	Producers	Consumers	Producers	Consumers	Producers	Consumers
Nectria confined to current area						
Industrial roundwood	–9		–1,202		–8,222	
Sawnwood	–12	0	1,087	–49	797	–440
Wood based panels	–10	0	368	–31	482	–47
Wood pulp	–6		1,395		1,618	
Paper and paperboard	0	0	24	–11	408	–119
Nectria at maximum spread						
Industrial roundwood	–746		–1,687		–7,979	
Sawnwood	–25	–2	669	–42	873	–403
Wood based panels	27	–1	222	–27	523	–226
Wood pulp	38		938		1,647	
Paper and paperboard	2	0	18	–10	384	–108

* Net present value of producers' revenue and consumers' expenditure, in US$ million 2005, with an 8% per year discount rate.
† China, Japan, and South Korea

Japan's and China's industrial roundwood harvests were almost unchanged, but South Korea's yearly harvest was 14 800 m^3 to 20 400 m^3 (1.4–1.9%) higher (Table 2), in accord with a 1.2–1.6% average increase in the price of industrial roundwood. The reduction in New Zealand's harvest offset the loss of forest stock due to Nectria, so that by 2030 New Zealand's forest stock was 41.5 million m^3 (6%) higher (Table 1), with Nectria confined to its current extent. Were Nectria to spread throughout the South Island and central North Island the increase in New Zealand's forest stock would be less — 16.4 million m^3 higher (2%) by 2030.

The extent to which such a gain in forest stock would occur depends on how New Zealand land use changes due to the lower wood price. It is possible that existing plantation forests may be converted to agriculture due to lower returns from land in forestry.

New Zealand industrial roundwood exports to China were unchanged, reflecting China's strong demand for wood. However, New Zealand exports to Japan and South Korea were significantly lower — 1.5 million m^3 (49%) and 2.8 million m^3 (34%) on an average year, respectively (Table 4) — regardless of the extent of Nectria spread. These countries replaced imports from New Zealand, predominantly with imports from other countries, particularly Brazil (7–11% per year) and Chile (2–3% per year) (Table 3).

TABLE 7–Percentage change of average prices due to Nectria in New Zealand, with three policies, from 2002 to 2030

Product	Do nothing	NZ debarks log exports	CJK* ban NZ logs
Nectria confined to current area			
Industrial roundwood	0.0	–4.3	–30.2
Sawnwood	0.0	–1.3	–9.7
Veneer & plywood	0.0	–0.8	–5.5
Particleboard	0.0	–1.2	–8.8
Fibreboard	0.0	–0.7	–5.0
Mechanical pulp	0.0	–0.9	–6.9
Chemical pulp	0.0	–0.9	–7.5
Newsprint	0.0	–0.2	–0.6
Printing & writing paper	0.0	0.0	–0.3
Other paper and paperboard	0.0	–0.4	–3.1
Nectria at maximum spread			
Industrial roundwood	–0.3	–4.1	–27.6
Sawnwood	–0.1	–1.2	–8.8
Veneer & plywood	–0.1	–0.7	–5.0
Particleboard	–0.1	–1.2	–8.0
Fibreboard	0.0	–0.6	–4.6
Mechanical pulp	–0.1	–0.9	–6.2
Chemical pulp	–0.1	–0.9	–6.9
Newsprint	0.1	–0.1	–0.5
Printing & writing paper	0.0	0.0	–0.3
Other paper and paperboard	0.0	–0.4	–2.8

* CJK = China, Japan, and South Korea

The reduction in New Zealand roundwood exports to the major markets due to the debarking requirement was partly offset by increased exports to the rest of the world (Table 4), due to increased demand for New Zealand industrial roundwood in these markets because of its lower price (Table 7). With Nectria confined to its current extent, exports to the rest of the world were 1.2 million m^3 per year higher (Table 4). However, were Nectria to spread further, the greater reduction in industrial roundwood harvests would limit the growth in exports to the rest of the world to 278 000 m^3 per year (Table 4). Overall, New Zealand's industrial roundwood exports were 3.2 million m^3 to 3.9 million m^3 per year lower, depending on the extent of Nectria spread.

New Zealand production and net-export of processed wood products — particularly sawnwood, wood-based panels, and wood pulp — were higher (Table 2), due to the availability of cheaper industrial roundwood (Table 7). However, this increase would not be as large were Nectria to spread throughout the South Island and central North Island (Table 2), due to the greater reduction in industrial roundwood harvests and less price decline with the greater Nectria spread.

The prices of all New Zealand wood products were slightly lower with this scenario, generally less than 1% from 2002 to 2030, with slightly larger reductions in sawnwood and particleboard prices (Table 7). These lower prices were offset by increased production, so that the present value of gross revenue to New Zealand's manufacturing industries increased (Table 6) — US$669 million to US$1,087 million for sawnwood, US$222 million to US$368 million for wood-based panels, and US$938 million to US$1,395 million for wood pulp, depending on the spread of Nectria. Industrial roundwood producer gross revenue decreased by US$1,202 million to US$1,687 million. These changes led to a gross revenue increase for the entire sector of US$239 million to US$1,654 million (Table 5). The gain of producers was smaller if Nectria spread widely because the attendant reduction in stock reduced domestic supply by more than the reduction of log exports, so that domestic production and revenues were curtailed.

World producer revenue was lower, as New Zealand production and net exports of processed wood products led to lower prices and production in other countries, especially United States, Brazil, Finland, and Sweden. However, New Zealand's lower production were Nectria to spread further meant that world producer revenue was higher due to less competition from New Zealand exports.

Log Import Ban

A ban on imports of New Zealand logs by China, Japan, and South Korea would have a significant negative impact on the New Zealand forest sector, regardless of the extent of Nectria spread.

The loss of exports to China, Japan, and South Korea was partly compensated for by higher exports to the rest of the world, 1.2 million m^3 per year (Table 4). Nevertheless, there would be an overall decrease of 12.4 million m^3 per year (62%) from 2002 to 2030. The higher exports to other markets were partly due to the lower price of New Zealand industrial roundwood, 28–30% on an average year (Table 7).

As a result of the ban on roundwood imports from New Zealand, domestic harvests would increase in China, Japan, and South Korea (Table 2). Reflecting the importance of New Zealand logs to South Korea (44% of South Korea's log imports in 2002) its annual harvest was 79% higher on average. This resulted in 9% less forest stock in South Korea by 2030 (Table 1). The impact on China's and Japan's harvests was less significant, and the impact on their forest stock was negligible (Table 1), as these countries increase industrial roundwood imports from other countries, particularly Brazil (13–15% per year) and Chile (3% per year) (Table 3).

Lower industrial roundwood prices contributed to New Zealand harvests being 9.1 million m^3 (31%) lower per year (Table 2). This decrease completely compensated for the loss of forest stock due to Nectria, so that New Zealand's forest stock was 253 million m^3 to 320 million m^3 (13–46%) higher in 2030, depending on the extent of Nectria (Table 1).

New Zealand production and net exports of processed wood products — particularly sawnwood, wood-based panels, and wood pulp — were higher (Table 2), due to the cheaper industrial roundwood. The prices of all New Zealand wood products were lower, generally 5–10% between 2002 and 2030 (Table 7).

The ban on New Zealand log imports by China, Japan, and South Korea resulted in their slightly lower production of sawnwood, wood-based panels, and wood pulp (Table 2). South Korea's industries were the most affected, due their current reliance on New Zealand logs.

The large reduction in New Zealand harvests and prices decreased the forest growers' net present gross revenue by US$8,222 million, regardless of the spread of Nectria (Table 6). Increases in gross revenue for New Zealand's other wood product industries — due to increased production — failed to compensate for the loss to the growers, resulting in total gross revenue losses of US$5,100 million (Table 5).

The imposition of debarking or a ban on log imports from New Zealand generally increased gross revenues for producers in China and South Korea, but also increased consumer expenditures (Table 5). This fits with the general finding that "consumers pay for quarantine in higher prices and that domestic producers benefit" (Mumford 2002). In New Zealand instead, both producer's gross revenue and consumer's expenditures* were lower (Table 5), due to lower wood product prices.

The increase in consumer expenditures in China and South Korea due to the log import ban needs to be weighed against the potential loss to producers that would arise were Nectria to become established. To estimate this potential loss requires estimates of the likelihood of establishment and potential forest loss (Prestemon *et al.* 2006) in these countries.

CONCLUSION

The economic impact of Nectria on the New Zealand forest sector, a significant exporter of industrial roundwood, was studied for a scenario confining the pest to the current area, and another where it spread at historical rates to affect the South Island and central North Island of New Zealand.

If the main importers of New Zealand logs — China, Japan, and South Korea — did nothing and Nectria were confined to the current area, the net present value

* Consumer expenditure is the value of consumption, quantity consumed multiplied by price per unit.

of New Zealand's forest sector gross revenues would be US$34 million lower over the period 2002 to 2030. Were Nectria to spread throughout the South Island and the central North Island of New Zealand, the gross revenue loss could reach US$612 million.

Nectria alone would leave New Zealand's production of processed wood products relatively unaffected, regardless of its spread. Most of the change would be in lower industrial roundwood exports because of lower harvests tied to the stock reduction due to Nectria.

Trade measures imposed by the main importers of New Zealand logs in response to the presence of *N. fuckeliana* in New Zealand would have an impact on the New Zealand forest sector well beyond the direct effect of the pest on the volume of growing stock. If debarking of logs or another costly phytosanitary measure was imposed by importers, or if they banned New Zealand logs altogether, New Zealand growers could lose US$1,202 million to US$8,222 million, depending on the extent of *N. fuckeliana* spread and on the response of importers. Nevertheless, these losses to growers would be partly, and in some cases more than totally, offset by increased domestic production of processed wood products due to the lower cost of industrial roundwood.

Overall, the predicted changes to forest sector gross revenue varied from a loss of US$4,644 million for the scenario where Nectria spread throughout the South Island and the central North Island and New Zealand logs were banned by China, Japan, and South Korea, to a gain of US$1,654 million when Nectria was confined to its current area and China, Japan, and South Korea demanded that logs be debarked.

For producers in New Zealand and consumers in importing countries the best trade measure, in terms of changes in producer revenues and consumer expenditures, is debarking. The imposition of a debarking requirement by New Zealand's export markets would have less impact on the New Zealand total sector, and on forest grower producer revenue, than a ban. Producers in the export markets would benefit more from a ban, in terms of both increased producer revenue and reduced likelihood of forest loss due to establishment of Nectria. Consumers in export markets, however, would be worse off with the imposition of any trade measure.

In interpreting these results it must be remembered that the analysis involves a number of assumptions about disease behaviour and impact that may not necessarily be fulfilled. Currently there is no evidence that Nectria has spread by unnatural means beyond the current infected area, nor that the disease will be vectored on logs. A study is under way at present to determine fungal survival on forest produce and debris. Also, the analysis does not allow for the impact of disease management strategies that are being developed under a research programme currently under way (Dick *et al.* 2006).

Nonetheless, this assessment provides information about the possible long run effects on producers and consumers, considering trade policy responses by New Zealand's principal trading partners. This information will be helpful in deciding how much to spend to manage pest spread. The estimated effects of Nectria — US$34 million to US$612 million depending on the extent of the spread, even without reaction from importers of New Zealand logs — suggests that research aimed at reducing Nectria spread and impact, such as tree selection, planting alternative species, or modified silvicultural treatments, could yield significant benefits.

The study findings also contribute to assessment of possible trade measure responses by New Zealand's export markets, by determining the costs and benefits to producers and consumers of wood products in New Zealand and in its export markets China, Japan, and South Korea. To identify the best policy response, however, would require additional technical information on the efficacy of alternative phytosanitary regulations, the likelihood of Nectria establishment, and magnitude of potential forest loss associated with establishment in the export markets.

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Appendix A

GFPM MATHEMATICAL FORMULATION

Spatial Global Equilibrium

(All variables refer to one specific year)

Objective function

The objective function of the Global Forest Products Model follows Samuelson (1952), identifying production, consumption, and trade flows so that producer plus consumer surplus minus transfer costs is a maximum:

$$\text{(A.1)} \quad \max = Z \sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})\, dD_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik}) dS_{ik} - \sum_i \sum_k Y_{ik} m_{ik}(Y_{ik}) - \sum_i \sum_j \sum_k c_{ijk} T_{ijk}$$

where i,j = country, k = product, P = price in U.S. dollars of constant value, D = final product demand, S = raw material supply, Y = quantity manufactured, m = cost of manufacture, T = quantity transported, c = cost of transportation.

End product demand

$$\text{(A.2)} \quad D_{ik} = D^*_{ik} \left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\delta_{ik}}$$

where D^* = current demand at last year's price $P_{-1,}\delta$ = price elasticity of demand (Table B.1). D^* depends on last year's demand, and country GDP growth (A.7).

Primary product supply

$$\text{(A.3)} \quad S_{ik} = S^*_{ik} \left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\lambda_{ik}}$$

where S^* = current supply at last year's price, λ = price elasticity of supply (Table B.2). S^* depends on last year's supply, and on exogenous or endogenous supply shifters (A.8 and A.9).

For recycled paper, $S_{ik} \leq S_{ik}{}^U$, where S^U = upper bound on supply, which depends on domestic paper consumption in the previous year (A.10).

Country total wood supply is $S_i = S_{ir} + S_{in} + \theta_i S_{if}$, where r = industrial roundwood, n = other industrial roundwood, f = fuelwood, θ = fraction of fuelwood that comes from the forest (Table B.3). $S_i \leq I_i$ where I_i = forest stock.

Material balance

$$\text{(A.4)} \quad \sum_j T_{jik} + S_{ik} + Y_{ik} - D_{ik} - \sum_n a_{ikn} Y_{in} - \sum_j T_{ijk} = 0 \qquad \forall\ i, k$$

where a_{ikn} = input of product k per unit of product n (Table B.4). The shadow prices of the material balance constraints give the market clearing prices, P.

Trade inertia

(A.5) $T^L_{ijk} \leq T_{ijk} \leq T^U_{ijk}$

where the superscripts *L* and U refer to lower and upper bounds, respectively (see Equation A.12).

Manufacturing cost

Manufacturing is represented by input-output coefficients and a manufacturing cost (Table B.4). The latter is the cost of the inputs not recognised explicitly by the model (labour, energy, capital, etc.):

(A.6) $$m = m^*_{ik} \left(\frac{Y_{ik}}{Y_{ik,-1}}\right)^{s_{ik}}$$

where m^* = current manufacturing cost at last year's output, s = elasticity of manufacturing cost with respect to output (Table B.4). m^* depends on last year's manufacturing cost.

Market Dynamics

(Unless otherwise indicated, variables and parameters refer to one country, one commodity, and one year)

Shifts of demand

(A.7) $D^* = D_{-1}(1 + \alpha_y g_y)$

where g_y = GDP annual growth rate, α = elasticity (Table B.1).

Shifts of supply

Industrial roundwood and fuelwood:

(A.8) $S^* = S_{-1}(1 + \beta_I g_I + \beta_{y'} g_{y'})$ for $k = r,n,f$

where g_I = rate of change of forest stock (Equation 1), $g_{y'}$ = GDP per capita annual growth rate, β = elasticity (Table B.2).

Waste paper and other fibre pulp (Table B.2):

(A.9) $S^* = S_{-1}(1 + \beta_y g_y)$

The upper bound on waste paper supply shifts according to:

(A.10) $S^U = \sum_k r_k D_{k,-1}$

where r_k is the maximum possible recovery rate for paper of grade k, which may change exogenously over time.

Changes in manufacturing coefficients

The input-output coefficients, the a_{ikn}'s in (A.4), may change exogenously over time, in particular to reflect increasing use of recycled paper in paper manufacturing (Table B.4).

Changes in freight cost and tariff

The transport cost for commodity k from country i to country j in any given year includes the cost of freight, import tariff (applied to the c.i.f. price), and export tariff:

(A.11) $c_{ijk} = f_{ijk} + t^{I}_{jk}\,(f_{ijk} + P_{ik,-1}) + t^{X}_{jk}P_{ik,-1}$

where c = transport cost, per unit of volume, f = freight cost, per unit of volume, t^I = import *ad valorem* tariff (Table B.5), P_{-1} = last year's equilibrium export price, and t^X = export *ad valorem* tariff.

Changes in trade inertia bounds

(A.12) $$T^L = T_{-1}(1 - \varepsilon)$$ $$T^U = T_{-1}(1 + \varepsilon)$$

ε = upper or lower bound on relative change in trade flow (Table B.5).

Appendix B

GFPM PARAMETERS FOR NEW ZEALAND

TABLE B.1–Elasticity of demand with respect to price and GDP

Product	Price	GDP
Fuelwood	–0.62	–1.50
Other industrial roundwood	–0.05	–0.58
Sawnwood	–0.16	0.32
Veneer and plywood	–0.13	1.20
Particleboard	–0.24	1.25
Fibreboard	–0.52	0.82
Newsprint	–0.05	0.21
Printing and writing paper	–0.15	0.80
Other paper and paperboard	–0.06	0.65

TABLE B.2–Elasticity of supply with respect to price, GDP per capita, and forest stock

Product	Price	GDP per capita	Forest stock
Fuelwood	2.00	0.00	1.50
Industrial roundwood	1.39	0.90	1.00
Other industrial roundwood	1.39	0.90	1.00
Other fibre pulp	0.80	1.00	
Waste paper	0.80	1.00	

TABLE B.3–Forest resource data and parameters

Parameter	Unit	Value
Forest stock	(10^6 m^3)	398
Forest stock growth rate	(% per year)	8.30
Forest area	(10^3 ha)	1827
Rate of forest area change	(% per year)	1.09
Fraction of fuelwood from forest		1.00

TABLE B.4–Manufacturing parameters

Input product	Manufactured product	Coefficient (m^3/m^3, m^3/t or t/t)	Change in coefficient (t/t)	Manufacturing cost* (US$/$m^3$ or US$/t)	Output elasticity of manufacturing cost
Industrial roundwood	Sawnwood	1.00		126.00	0.10
Industrial roundwood	Veneer and plywood	1.19		317.46	0.10
Industrial roundwood	Particleboard	0.80		116.20	0.10
Industrial roundwood	Fibreboard	0.72		214.48	0.10
Industrial roundwood	Mechanical pulp	1.07		209.28	0.10
Industrial roundwood	Chemical pulp	1.65		285.93	0.10
Mechanical pulp	Newsprint	0.58	0.000	177.56	3.00
Chemical pulp		0.30	–0.002		
Other fibre pulp		0.00	0.000		
Waste paper		0.12	0.002		
Mechanical pulp	Printing and writing paper	0.24	0.000	584.35	0.10
Chemical pulp		0.51	–0.001		
Other fibre pulp		0.00	0.000		
Waste paper		0.16	0.001		
Mechanical pulp	Other paper and paperboard	0.49	0.000	348.69	0.10
Chemical pulp		0.44	0.000		
Other fibre pulp		0.00	0.000		
Waste paper		0.08	0.000		

* Labour, capital, energy, and materials, exclusive of the cost of wood and fibre input.

TABLE B.5–Trade parameters*

Product	*Ad valorem* tariff (%)	Tariff reduction (% per yr)	Freight cost (US$/m^3 or US$/t)	Trade bounds (ε)
Industrial roundwood	0.0	0.0	12	0.030
Sawnwood	5.0	0.0	21	0.050
Veneer and plywood	2.0	0.0	16	0.052
Particleboard	5.0	0.0	7	0.069
Fibreboard	5.0	0.0	10	0.060
Chemical pulp	0.0	0.0	32	0.045
Printing and writing paper	7.0	–2.0	46	0.030
Other paper and paperboard	6.0	–1.0	40	0.051

* The trade bounds (or trade inertia) parameter, ε in Equation A.12 (Appendix A), is a bound on relative change in trade flow for a particular product, and is set at three times the standard error of the mean percentage change of world imports and exports of that product from 1970 to 1997 (Buongiorno *et al*. 2003).