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2008-02

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An Economic Analysis of Mountain Pine Beetle Impacts in a Global Context

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January 2008

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An economic analysis of mountain pine beetle impacts in a global context.

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December 18, 2007

Abstract

The economic effects of the mountain pine beetle outbreak in British Columbia are simulated using a multi-region spatial price equilibrium model coupled with a stochastic dynamic updating procedure. The simulation captures expected changes in the B.C. timber supply, growth of plantation forests in the southern hemisphere and an escalating Russian log export tax. The results indicate lumber and log prices will rise in B.C., offsetting some of the economic loss to timber producers. However, on net producers in the B.C. forest industry will experience a decrease in economic surplus.

JEL Classifications: C67, F14, F17.

Keywords: Mountain pine beetle; spatial price equilibirum; trade modeling.

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1 Introduction

In this paper we analyze the impact that the mountain pine beetle (MPB) will have on the British Columbia forest industry. The B.C. Ministry of Forests and Range (2007) forecasts that, as a result of the mountain pine beetle outbreak, the annual allowable cut (AAC) will be reduced by approximately 12 million m^3 below pre-outbreak levels. The 2006 harvest was 8.7 million m^3 above pre-outbreak AAC levels, due to increased salvage harvesting, indicating an expected drop of 20.1 million m^3. The drop below current (2006) harvest will amount to approximately 20% of B.C., 4.5% of North America and 1.5% of world softwood timber supply.

The B.C. government's pine beetle action plan (2006) stipulates that $50 million per year will be contributed to re-forestation until serious timber supply problems are eliminated. It has identified that $800 million to $1 billion dollars is needed for intensive silviculture to provide fertilizer, fast growing species, and product research. These large amounts of money are intended to alleviate the timber supply shortfall and reduce the economic harm to those dependent on the forest industry. The action plan does not specify the anticipated economic losses that justify those subsidies.

A simplified view of the situation, similar to Wright (2007), would project a provincial decrease in manufacturing activity of approximately $2.5 billion, a loss of 27,000 direct jobs, and a loss of some $250 million in government stumpage and royalty revenues, based on a 25% decrease in available fibre (Council of Forest Industries 2004). This outcome is based on the unlikely assumption that pine lost to the MPB is valued the same as other B.C. timber. It also assumes that the prices of logs and other forest products will be unaltered by the beetle-induced supply reduction, or any other factor.[1] It is generally true that a substantial reduction in supply, such as will occur in B.C.,

[1] It is traditional to refer to standing trees as timber, and harvested trees that are traded as logs. For the purposes of this study they are generally interchangeable.

will cause market prices to rise. In this study, we consider the magnitude of the price changes that can be expected to occur, and use these to predict the changes in economic surplus that can be anticipated.

Projecting prices in the forest industry over the next thirty years is not particularly easy, as many factors in addition to those taking place in B.C. must be considered. Two that are given considerable attention in this study are the introduction of rather large log export taxes in Russia and growth in the scope and productivity of plantation forests in southern regions. It is not readily obvious what the net impact of these global changes will be. The increasing timber production from plantations will push down the price of timber and hurt the B.C. industry. The Russian log export tax has less obvious implications, but Roberts (2007) suggests that it will create opportunities for forest companies over the five to six years following the implementation of the 80% export tax in 2009. The tax should raise world prices, which will be opportune for struggling B.C. firms. However, with anticipated timber shortages, it is not clear they will be able to stake out new market opportunities.

A dynamic two-commodity spatial price equilibrium model is developed in this study to analyze the problem. While not a true dynamic optimization, our model is dynamic in the sense that the parameters are time dependent. The model is used to simulate global forest product changes up to 2035. In the model, the world is divided into 21 regions to provide sufficient detail. Production, consumption and trade in saw logs and lumber are projected, although only a subset of results is presented.

The remainder of this paper is as follows: section two introduces the theoretical model that is the basis for the computational model, section three describes the computational methodology, section four presents computational results and section five discusses and concludes. The appendix provides a detailed description of the data.

2 Integrated Forest Sector Model

The forest industry is modeled by representative firms in the lumber and timber sectors. Lumber is denoted by y and timber (logs) by x, with $y = f(x)$ a function mapping raw logs into lumber. It is assumed that $f(0) = 0$ and $f'(x)$ is a constant recovery rate (ratio of m^3 lumber output to m^3 log input). The lumber producer sells y for a price p_y and buys x for p_x in competitive markets. In addition to log input costs, production costs are given by a convex monotonically increasing function $c(y)$. The lumber producer's profit maximization problem is,

$$\max_{x} \quad \pi(x) = p_y f(x) - p_x x - c(f(x)).$$

Assuming the second-order condition holds (which can easily be verified), the necessary condition for profit maximization is,

$$p_y = \frac{p_x}{f'(x)} + c'(y). \tag{1}$$

Equation (1) requires that marginal benefit equals marginal cost. Rearranging (1) gives the lumber producer's inverse demand for timber:

$$p_x = f'(x) \left[p_y - c'(f(x)) \right], \tag{2}$$

which can be shown to be downward sloping by differentiating with respect to x.

The inverse log supply function is obtained by solving the timber producing firm's problem, which, in the case of B.C., would be the government (but not in other jurisdictions). Decreasing returns to scale are assumed. Let $C(x)$ denote the cost of producing timber, so the timber producer's profit function is $\psi(x) = p_x x - C(x)$. The profit maximizing solution gives the inverse timber supply curve $p_x = C'(x)$.

To complete the model we assume a downward sloping inverse lumber demand curve $D^{-1}(y)$. Using this and the timber producer's supply curve, the lumber market clearing condition can be written as,

$$D^{-1}(f(x^*)) = \frac{C'(x^*)}{f'(x)} + c'(f(x^*)), \tag{3}$$

where x^* is the market clearing amount of logs sold. The market clearing quantity of lumber supplied, y^*, is then determined by the production function. The equilibrium prices are determined as follows:

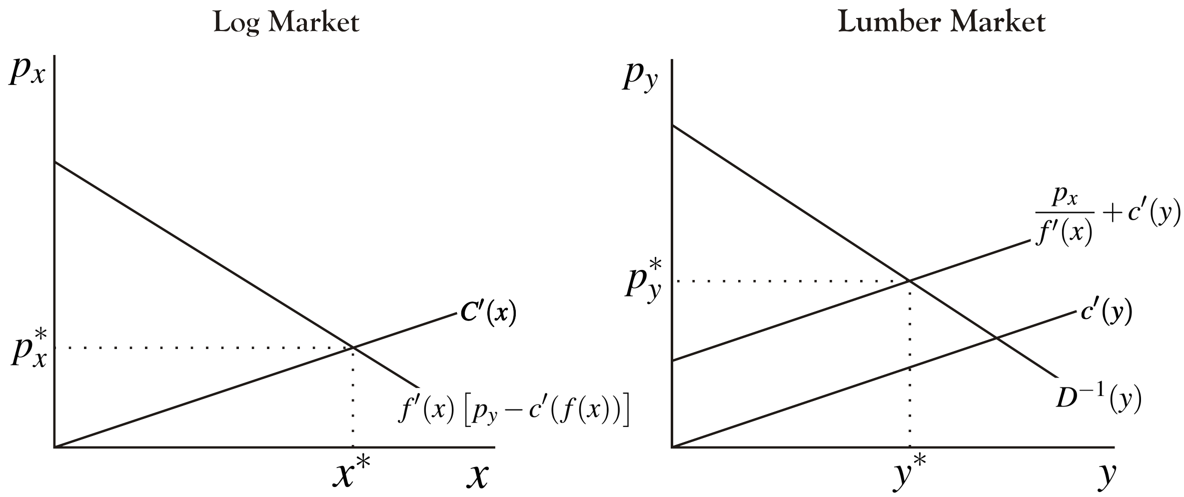
$$p_x^* = f'(x)[D^{-1}(y^*) - c'(y^*)] \tag{4}$$

$$p_y^* = \frac{C'(x^*)}{f'(x)} + c'(y^*). \tag{5}$$

To visualize this, figure 1 plots the markets for logs and lumber side by side. From figure 1, it might appear that lumber producers are earning surplus in both the market for lumber and the market for logs, but this is not the case. The derived demand for logs is a locus of lumber producers' willingness to pay for them (given fixed p_y^*), which is entirely determined by the surplus they earn in the lumber market. In other words, their willingness to pay for a small increase in logs is determined by the increase in producer surplus they would receive from converting it to lumber. The lumber producers' surplus is simply the amount they receive for lumber in excess of what they are willing to sell it for. This quantity can be measured either by the area between p_y^* and the lumber supply curve, or the area between the log demand curve and p_x^*.

We now examine the impact of an exogenous decrease in timber supply. To model this, a maximum harvest of $\overline{x}$ is imposed on the industry. This is illustrated in figure 2 for the post-MPB scenario. From the figure, it is clear that the timber producers' surplus is ambiguously affected, while the lumber producers' surplus unambiguously

Figure 1: Pre-MPB Markets

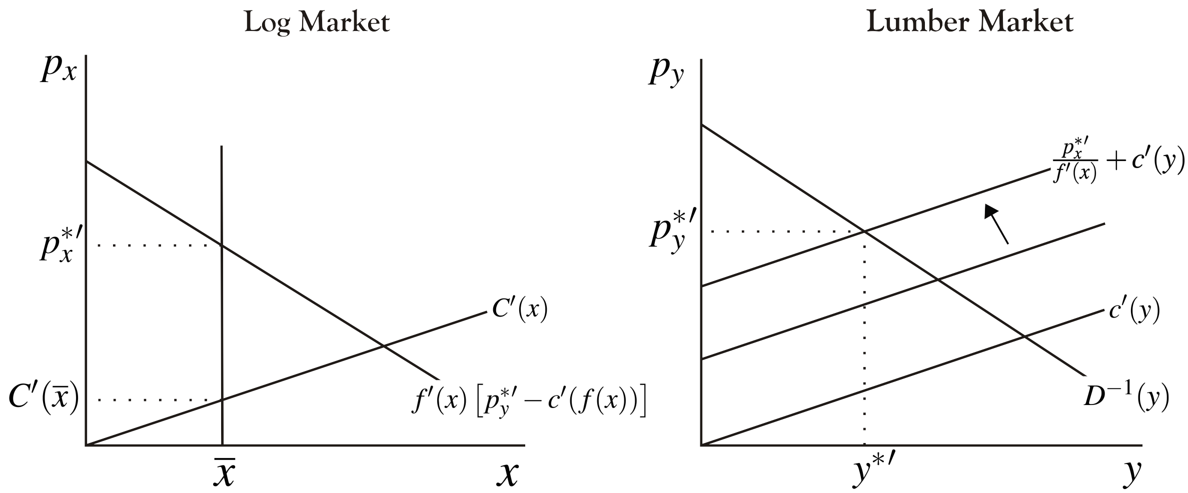


declines. These results are not all that surprising. In the log market the the timber supply reduction acts like a quota restriction. The difference between the new price of logs $p_x^{*\prime}$ and $C'(\overline{x})$ is a rent that is paid to the timber producers. In the lumber market, the increased price of logs shifts the supply curve up. It is noteworthy that cost increase in the lumber market is more than the price increase in the log market, since the lumber supply curve shifts upward by $\Delta p_x/f'(x)$. If the recovery rate is constant at 50%, the lumber supply curve will shift up by double the log price increase.

The actual increase in the price of logs depends on the log supply and demand elasticities. The price elasticity of round wood demand is estimated by Latta and Adams (2000) to be -0.12 in the B.C. interior. Relatively inelastic demand coupled with perfectly inelastic supply (when the capacity constraint binds) implies that the log price increase is likely to be substantial.

The actual impact of MPB-induced timber shortages on B.C.'s forest sector will also depend on the future demand for B.C. lumber, which is affected by the rapidly changing global forest industry. In theory, the Russian export tax should increase the demand for B.C. lumber (at least in the short run), and the increasing outputs from plantation

Figure 2: Post-MPB Markets



forests should decrease it. In the remainder of the paper, we use a multiple-region, global and dynamic trade model to examine the economic impact of the projected B.C. timber shortage.

3 Computational Methods

We construct a spatial price equilibrium model with 21 regions. The model is solved for an equilibrium in each period, with periods connected via a dynamic updating procedure. This approach is similar to that used in the PELPS model (see Zhang et al. 1993, 1996; Zhu et al. 1999), but, unlike PELPS, we employ continuous linear demand and cost functions. This requires the use of quadratic programming rather than recursive linear programming. The quadratic programming solution to spatial price equilibrium problems is discussed in detail by Takayama and Judge (1971) and Boyd and Krutilla (1987), while Mogus et al. (2006) provide a recent application to North American lumber trade. In the dynamic updating procedure, we incorporate uncertainty regarding the values of the demand parameters using Monte Carlo simulation. In particular, we iterate over the dynamic phase many times, which enables us to determine expected outcomes and confidence intervals over the outcomes. The programming was done using an Excel-MATLAB-GAMS interface, where Excel was used for data storage, MATLAB for the dynamic phase and C-PLEX execution in GAMS for the static phase (GAMS Development Corporation 2001). The demand function parameters and associated standard errors are provided in the Appendix; also provided in the Appendix are transportation costs and production parameters and description of data sources.

Static Phase

In the static phase of our model a Pareto efficient outcome is solved by maximizing the total surplus of lumber consumers, lumber producers and timber producers. We assume consumers have convex, continuous and monotonic preferences, so that the outcome is a competitive equilibrium (Varian 1992, p. 326). As a measure of total surplus, we use total consumer benefits minus the cost of production in both the timber and lumber sectors of the industry.

The regions of the model are indexed by r. Each region is assumed to have a linear demand function of the form $D^{-1}(y_r^d) = \alpha_r + \gamma_r I_r - \beta_r y_r^d$, where I is income and y^d is lumber consumption. Marginal cost functions are assumed to be linear such that $c'(y_r^s) = c_r y_r^s$ is the marginal cost of producing lumber, and $C'(x_r^s) = C_r x_r^s$ is the marginal cost of producing timber. The $r \times r$ matrices X and Y contain the quantities of logs and lumber traded between each region pair. For each region there is a row for exports and a column for imports; for example, the $(2, 3)$ element of X is log exports from region 2 to region 3. The domestic supply in each region is given by the (r, r) element on the diagonal of the appropriate matrix. Transport costs (per cubic meter) are given by Z, and export taxes/import tariffs on logs and lumber are given by T^x

and T^y, where all are $r \times r$ matrices. The static or per period objective function is:

$$\max \sum_r \left\{ (\alpha_r + \gamma_r I_r) y_r^d - \frac{1}{2} \left[\beta_r \cdot (y_r^d)^2 + c_r \cdot (y_r^s)^2 + C_r \cdot (x_r^s)^2 \right] \right\} \tag{6}$$

$$- \sum_{i,j} \left\{ Z_{i,j}(X_{i,j} + Y_{i,j}) + T_{i,j}^x X_{i,j} + T_{i,j}^y Y_{i,j} \right\},$$

where i and j refer to the rows and columns of the matrices respectively. Problem (6) is solved subject to the following constraints:

harvest $\leq$ AAC	x_r^s	$\leq$	h_r	(7)
log supply $\leq$ harvest	$\sum_j X_{i,j}$	$\leq$	x_r^s	(8)
lumber production $\leq$ recovery $\times$ log input	y_r^s	$\leq$	$\phi_r \sum_i X_{i,j}$	(9)
lumber production $\leq$ capacity	y_r^s	$\leq$	$\overline{y}_r$	(10)
lumber supply $\leq$ production	$\sum_j Y_{i,j}$	$\leq$	y_r^s	(11)
lumber demand $\leq$ lumber supply	y_r^d	$\leq$	$\sum_i Y_{i,j}$	(12)

The parameters h, ϕ and $\overline{y}$ refer respectively to maximum timber removals (AAC), the recovery rate and lumber production capacity, respectively. The AAC can be regarded as a sustainability constraint that prevents harvesting from exceeding growth.

The static phase output includes the quantities of lumber and logs produced in each region, as well as trade in both commodities between each region pair. The prices of logs and lumber in each region are calculated as the shadow prices of equations (8) and (11). The shadow price of equation (10) gives the marginal value of capacity in each region. The economic surpluses of consumers and timber and lumber producers are computed from the prices and quantities.

Dynamic Phase

The dynamic procedure consists of a series of simple recursive relationships that update the model parameters before the next static phase begins. The model updates regional incomes, demand parameters, AACs, tariff levels and capacity constraints. The uncertainty of estimated model parameters is incorporated at this stage. The initial parameter values are actual data from 2004.

For each period, computation of demand parameters begins by randomly choosing income growth, income elasticity and price elasticity from their respective distributions (see table A1). Income growth and the previous period's income are used to calculate the present income. This is combined with the new elasticities to calculate the demand parameters $\alpha_{r,t}$, $\beta_{r,t}$ and $\gamma_{r,t}$. Tariff levels are calculated in each period based on the market clearing price in the previous period. For example, the 2008 export tax on Russian logs is calculated as 25% of the 2007 Russian log price. In jurisdictions where tarrif levels depend on commodity prices, a series of logical statements precedes calculation of the tariff to ensure the correct level is computed.

Maximum timber removals are computed in each period based on the previous period's maximum harvest and a stochastic growth rate. The distribution of change in AAC from one period to the next is assumed constant for all regions except the B.C. interior (BCI), where the AAC is adjusted to reflect the impact of the MPB with available harvests as projected by the Ministry of Forests (2007). By 2007, BCI's timber supply peaks at an average of 8.7 million cubic meters above the pre-outbreak level. This level is maintained for five years, and then falls by about 20.1 million cubic meters between 2012 and 2016. The harvest slowly recovers at a rate averaging just below 1% for the remaining years of the time horizon.

Increases in lumber production capacity for each period are modeled as a free entry Cournot game. A good discussion of this type of market entry is given by Cheung

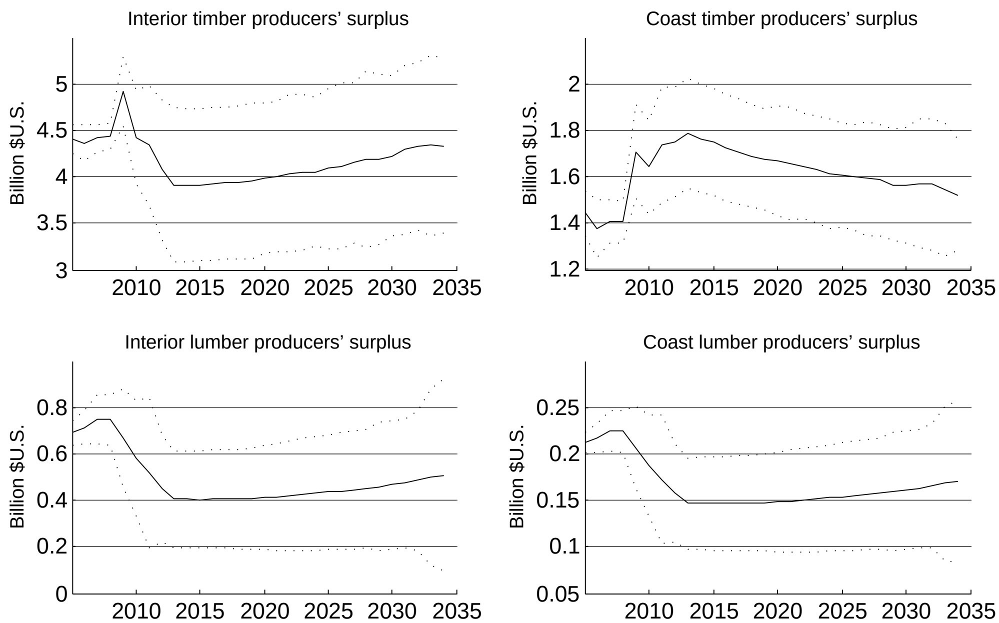
(1970) in the context of fisheries. The logic is that market entry will occur if economic rent exists, and the entering firm will invest so that the rent it extracts is maximized. To determine the rent maximizing investment, the demand curve must be known. In the model, demand curves are added horizontally in the usual fashion, but market share is used to determine the fraction of each demand curve attributed to each region. For example, if BCI has 25% of the Japanese market in 2020, one quarter of the Japanese demand curve is included in the calculation of the 2021 BCI total demand curve.

An annual time step over the period 2005-2035 is employed, and parameters are updated once each year. The way that uncertainty is incorporated into the model implies that the path of a parameter can vary quite widely from one iteration to the next. This is because shocks are stationary, and in a sense permanent. A large positive shock to a parameter in one year will raise the expected value of that parameter in all future years in that iteration. The model is iterated 2000 times to ensure distributional convergence of results.

4 Results

We present full results for British Columbia, and selected ones for other regions. The results provided for other regions are meant to give context to the B.C. results. Results for lumber and timber producers' surpluses for the B.C. coast (BCC) and BCI are provided in figure 3(a). The solid lines represent the expected path of the variable, while dashed lines represent the upper and lower bounds of 95% confidence intervals. It is no surprise that both the BCI timber and lumber sectors are negatively impacted by the timber shortage. By 2015 the surplus of timber producers in BCI is down by about $0.5 billion and the surplus of lumber producers is down by about $0.3 billion. It is curious that in the BCC region timber producers' surplus increases by $0.4 billion,

Figure 3(a): B.C. Regional Surplus



but lumber producers' surplus decreases by $70 million. This is due to the shipment of logs from BCC forests to BCI sawmills in our model. This is a significant departure from the current norm, but the sawmills in the interior are far more efficient than those on the coast, and the utilization of coastal logs by more efficient BCI mills is enough to justify the expense of shipping logs.

In figure 3(a) there is a notable spike in timber producers' surplus in 2009. This positive shock is caused by the implementation of the 80% Russian log export tax. Interestingly, the shock appears to create significant benefits for timber producers, but not lumber producers. The timber industry is able to capture scarcity rents created by the Russian tax, but the lumber industry is not.

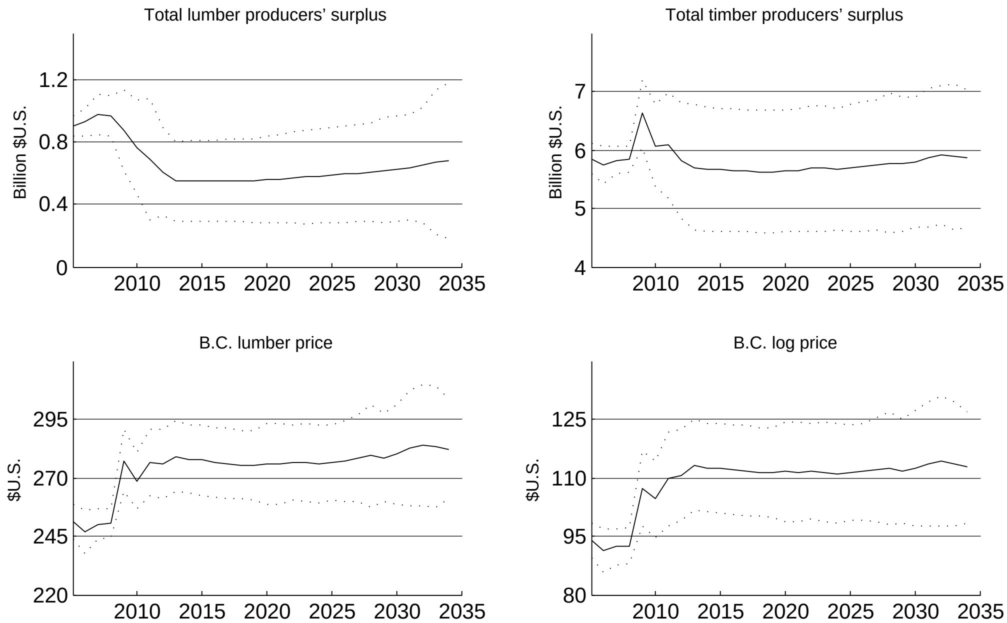
Figure 3(b) presents results for the total surplus earned by the B.C. forest sector, and the prices in B.C. markets. Lumber producers in B.C. experience a total decrease in surplus of about $0.4 billion, while timber producers experience a lesser decrease in surplus of about \$0.1 billion. It is obvious that the lumber manufacturing sector bears a larger proportion of the economic loss resulting from the timber shortages than the timber sector. This is simply a realization of the timber shortage creating quota-like rents in the timber sector, while creating a pure cost increase in the lumber sector. As the timber producer, government could of course transfer the rents back to lumber producers, but this could result in retaliatory action by the United States.

The behaviour of prices in the model is rather interesting. Both lumber and log prices increase as a result of the Russian log export tax in 2009. The price of logs rises by \$15/m^3 and the price of lumber by \$25/m^3. The log to lumber proportional price increase of 60% is identical to the proportions described by Dumont and Wright (2006), the cause of which is recovery rates that are less than unity. Beyond 2009 the price of lumber in B.C. appears to stabilize, while the price of logs exhibits a small additional increase before stabilizing by 2015. The extra growth in log prices is a result of the receding timber supply in those years.

In the introduction we alluded to the notion that increased prices could offset some of the impact of a reduced timber supply. The results here indicate that substantial price increases do occur, but there is still a net decrease in B.C. forest industry producers' surplus. In the timber sector higher prices come close to offsetting quantity reductions, but both sectors of the industry still experience a decrease in producers' surplus.

Selected international timber supply results are provided in figure 4(a). There is a marked decrease in the supply of timber from Russia in 2009, and, once an equilibrium is attained, the Russian supply is lower by about 25 million cubic meters annually. This decrease in Russian timber supply is larger than the expected decrease in BCI timber supply by just under five million m^3. Examination of the solution for Finland's timber supply shows an increase of about three million m^3 over current supply in 2009. In the same year, the timber supply in the U.S. south increases approximately eight million

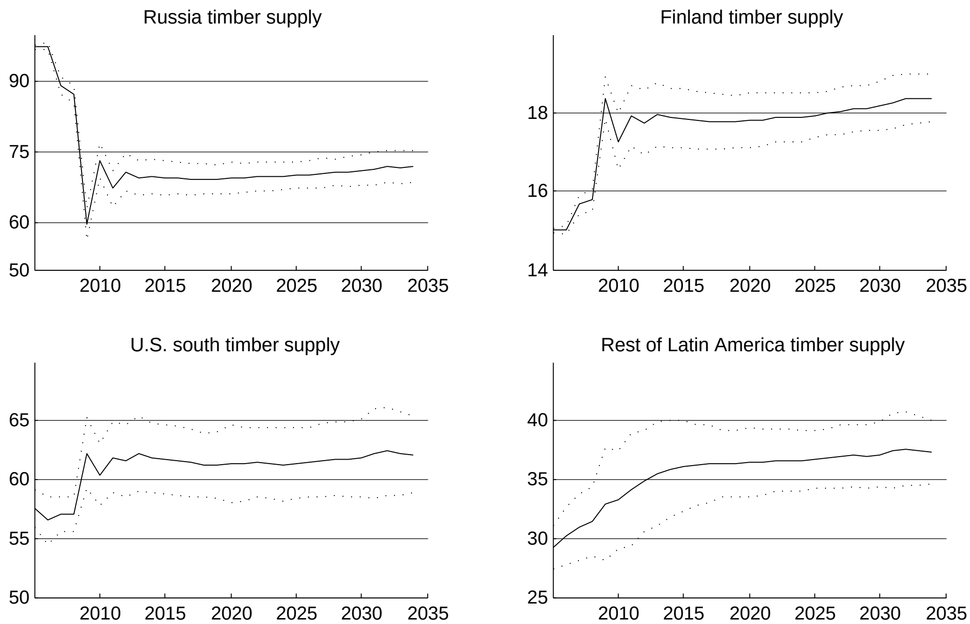
Figure 3(b): B.C. Total Surplus and Prices



m^3 and the rest of Latin America (Latin America except Chile) timber supply increases by two million m^3. These are just examples, but the general result is that many regions increase their timber supplies in 2009 to capture the rents created by the Russian tax.

Figure 4(b) plots a selection of international lumber supplies. There is a marked increase in the growth rate of the Russian lumber supply in 2009. This is not surprising given that lower log prices created by the export tax will increase the potential rents that Russian lumber manufacturers can earn. The results for the Swedish lumber supply are very similar to those for Finland (not shown). Both countries initially maintain their outputs, but in the long run decrease lumber supply as expected. The effect of the Russian tax on these countries is to make logs more expensive and marginalize lumber outputs. The great deal of uncertainty around the path of Sweden's lumber supply is indicative of this, as output is very sensitive to changes in market conditions. Eastern Europe's lumber supply decreases in the years preceding 2009, then jumps and begins

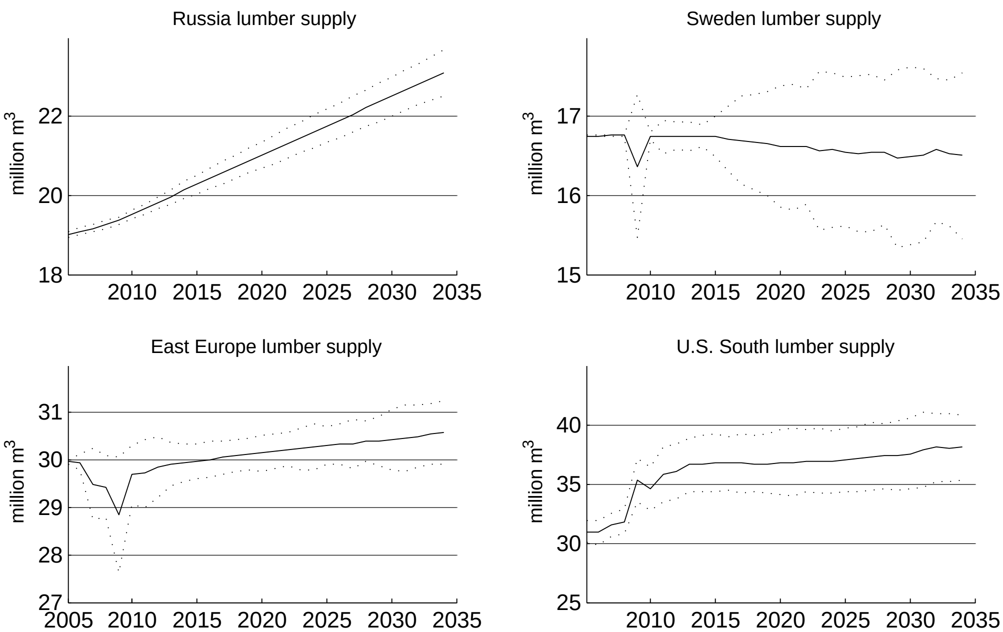
Figure 4(a): International Timber Supply



to grow when the Russian tax is implemented. The pattern is caused by the rise in world lumber prices following the tax, which causes sawmilling in Eastern Europe to become more viable. The U.S. south is indicative of many world regions. There is an increase in supply to capture some of the available rents when prices jump in 2009.

The last set of results, presented in figure 5, are for the Asian markets. The two Asian regions in our model are the destination of the largest proportion of pre-2009 Russian log exports. The sawmilling industry in both these regions is heavily reliant on those log imports, but their reactions to the export tax are quite different. The path of expected Japanese lumber production appears not to be affected by the 2009 tax. The Japanese continue to import as much raw material as their growing lumber sector requires, some from alternative regions. In contrast, log imports in the rest of Asia drop between 2005 and 2009, and lumber production correspondingly drops by nearly four million cubic meters. These differences are a result of Japan's superior mill

Figure 4(b): International Lumber Supply

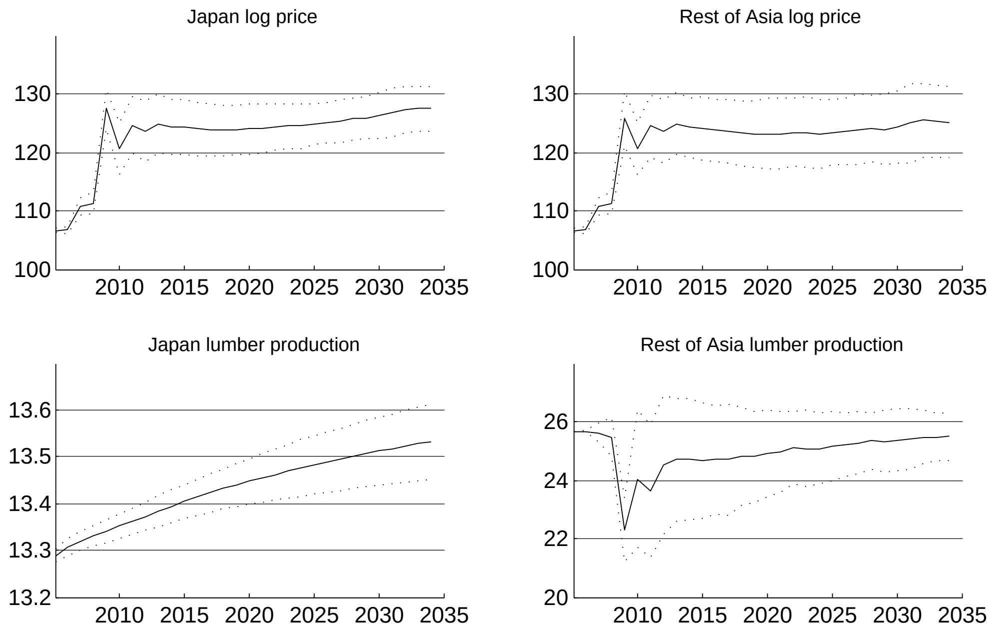


efficiency, and much higher consumer willingness to pay. Japan is in a sense able to 'buy the market' when timber shortages arrive. As indicated in figure 5, the price of saw logs in Japan rises about $\$18/m^3$ in 2009, whereas in the rest of Asia it rises only about $\$17/m^3$. This disparity is simply the result of Japan out competing other Asian countries for scarce log imports.

5 Discussion and Conclusion

As shown in figure 3(a), the coming timber supply reduction in B.C. will lead to a substantial decrease in lumber producers' surplus. This does not necessarily imply a corresponding decrease in the profitability of the B.C. forest industry, but rather a decrease in its size. It can actually be inferred from the results that the smaller industry that exists following the onset of timber shortages might be more profitable than at

Figure 5: Asian Market Result



present. The average price of lumber in B.C. is expected to rise by approximately $\$25/m^3$, and even the lower bound on our 95% confidence interval indicates a price rise. The price of sawlogs in B.C. will rise by about $\$15/m^3$, which should essentially offset the lumber price increase. The increased profitability of sawmilling will arise from decreased production costs. Cost savings should result from the allocation of remaining timber resources to the most efficient mills. As the industry shrinks, the least efficient firms will exit first, leaving only lower cost efficient capital to do the remaining work. This supports conjectures that those who have access to timber will do well in the forest industry over the next thirty years.

This does not mean, of course, that the outlook is positive for all interested parties. For those who remain there will be profit, but for those who are pushed out of the market there will naturally be losses. It is inevitable that the mills that close will be those with the highest dependence on labor. In our model, labor constitutes a production cost, while in reality it earns rents that should be considered a benefit to the Province. Jobs will be lost at inefficient mills that close due to timber shortages, and those mills that remain will be efficient with lower labor to output ratios.

Earlier we suggested that a 25% decrease in B.C. timber supply would imply a $250 million decrease in government revenue if prices do not change. Our analysis indicates, on the contrary, that prices will change such that the timber sector will be the least effected in terms of economic surplus. If the provincial government can effectively capture surplus created by higher world prices, they may not experience dramatic revenue losses. Whether this happens will depend on whether the B.C. log market is competitive, and how willing the government will be to raise stumpage fees and capture the rent. If the market were perfectly competitive, the rent created by the capacity constraint should go to the government. The government may not, however, be willing to capture all of the rent. By raising stumpage fees, they may inadvertently be decreasing the supply of timber needlessly by making some timber uneconomical to cut, although this might be offset by utilization standards.

Timber supply in many parts of B.C. will be unaffected by the mountain pine beetle crisis, particularly on the Coast. The coastal region is in the midst of re-building and an end to softwood lumber tariffs may be integral to its future success. If the government chooses to keep stumpage fees artificially low for the benefit of MPB affected regions, there will be little hope of an end to the trade dispute with the United States. Free-trade may be one of the most important factors in the future of the Coastal industry and, by implementing a competitive timber allocation mechanism, B.C. may be able to achieve it.

The model employed in this study can be expanded in several possible directions. The model does not incorporate detail with respect to differentiated forest products and substitutes. A model that differentiates between spruce-pine-fir (SPF) and other products (e.g. cedar) would give a better indication of how markets behave. It is not clear from our model whether the price of other products will be affected by SPF shortages. The inclusion of building material substitutes would also be a good addition, as their presence should reduce some of the price increases seen in our model (e.g., see Mogus et al. 2006). At present the data required to calibrate such a model are not readily available at the global level.

Another extension, and one that will not be trivial, would be to make this model a true dynamic programming model. Such a model would allow regions to choose to harvest larger amounts of their timber base at early dates at the expense of decreased harvests later, or vice versa. Such a model would provide a better indication of the world timber supply response to anticipated disturbances like the Russian export tax. Even better would be a dynamic programming model with both capital investment and harvesting decisions made endogenously. In combination these would give much more realistic approximations to the real world than the present model. The only drawback to doing so is that the model will almost certainly be non-linear and much more difficult to solve numerically.

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Appendix - Data and Sources

The data used to calibrate the model come from a variety of sources. For the Monte Carlo simulation, parameters of the demand functions are random variables with means and standard deviations given in Table A1. Transportation cost data are provided in Table A2, while production (cost) parameters are provided in Table A3. A discussion of methods and sources follows each table.

Table A1: Demand Data

	ΔI		ϵ_I		ϵ_p		2004	
Region	avg.	s.d.	avg.	s.d.	avg.	s.d.	p_y	y^d
Japan (JAP)	0.045	0.038	0.14	0.03	-0.1	0.03	297.55	21805
U.S. North (USN)	0.034	0.020	0.14	0.03	-0.1	0.03	250.00	47644
U.S. South (USS)	0.034	0.020	0.14	0.03	-0.1	0.03	250.00	52976
U.S. Pacific N.W. (PNW)	0.034	0.020	0.14	0.03	-0.1	0.03	250.00	4922
Rest of U.S. (ROUS)	0.034	0.020	0.14	0.03	-0.1	0.03	250.00	27455
B.C. Interior (BCI)	0.034	0.021	0.14	0.03	-0.1	0.03	213.05	997
B.C. Coast (BCC)	0.034	0.021	0.14	0.03	-0.1	0.03	213.05	3093
Alberta (ALTA)	0.034	0.021	0.14	0.03	-0.1	0.03	213.05	3726
Atlantic Canada (AC)	0.034	0.021	0.14	0.03	-0.1	0.03	241.62	1498
Rest of Canada (ROC)	0.034	0.021	0.14	0.03	-0.1	0.03	241.62	14868
New Zealand (NZ)	0.026	0.032	0.14	0.03	-0.1	0.03	247.48	2581
Australia (AUS)	0.037	0.020	0.14	0.03	-0.1	0.03	260.00	3549
Chile (CHL)	0.044	0.049	0.09	0.03	-0.08	0.03	143.06	5496
Sweden (SWE)	0.026	0.020	0.14	0.03	-0.1	0.03	214.00	5697
Finland (FIN)	0.032	0.028	0.14	0.03	-0.1	0.03	174.00	5593
Russia (RUS)	0.029	0.055	0.09	0.03	-0.08	0.03	201.00	6567
Western Europe (WEUR)	0.023	0.013	0.14	0.03	-0.1	0.03	212.15	48540
Eastern Europe (EEUR)	0.036	0.044	0.09	0.03	-0.08	0.03	205.61	33557
Rest of Latin Am. (RLAT)	0.031	0.028	0.09	0.03	-0.08	0.03	162.01	15156
Rest of Asia (ROA)	0.070	0.039	0.09	0.03	-0.08	0.03	284.14	33329
Rest of World (ROW)	0.045	0.030	0.09	0.03	-0.08	0.03	179.49	7776

The average GDP growth rate, ΔI, and its standard deviation were calculated using annual 1965-2005 real GDP (2000 USD) data from the United Nations statistical database table 29918. Income elasticity, ϵ_I, price elasticity ϵ_p and associated standard deviations were those estimated by Zhu et al. (1999). The 2004 price and consumption data used to anchor the demand curves was calculated from the FAO database. Prices were calculated as a weighted average of real (2000 USD) import and export prices, and consumption was calculated as production plus net imports.

Table A2: Transport Costs per m^3

r/r	JAP	USN	USS	PNW	ROUS	BCI	BCC	ALTA	AC	ROC
JAP	0.00	94.65	86.60	56.45	72.07	60.03	56.45	63.61	100.15	89.71
USN	63.02	0.00	22.83	38.20	38.94	35.46	38.59	32.32	9.84	5.96
USS	46.89	22.83	0.00	30.15	22.07	29.86	31.58	28.15	32.08	20.96
PNW	24.82	38.20	30.15	0.00	15.62	6.98	6.45	7.50	43.69	32.92
ROUS	24.82	38.94	22.07	15.62	0.00	18.40	17.49	19.32	46.87	34.61
BCI	28.32	35.46	29.86	6.98	18.40	0.00	5.27	5.27	40.42	30.11
BCC	24.82	38.59	31.58	6.45	17.49	9.64	0.00	12.84	43.70	33.26
ALTA	31.98	32.32	28.15	7.50	19.32	6.64	9.84	0.00	37.14	26.95
AC	68.52	9.84	32.08	43.69	46.87	40.42	43.70	37.14	0.00	12.88
ROC	58.08	5.96	20.96	32.92	34.61	30.11	33.26	26.95	12.88	0.00
NZ	42.88	68.86	57.83	54.68	50.90	56.59	55.08	58.10	73.39	67.36
AUS	37.97	77.56	67.02	60.49	58.54	62.26	60.63	63.89	81.57	75.50
CHL	83.56	40.05	36.35	50.34	43.65	50.61	51.19	50.03	42.26	41.82
SWE	22.15	43.18	43.18	81.38	65.25	78.64	81.77	75.50	43.18	49.14
FIN	22.15	43.18	43.18	81.38	65.25	78.64	81.77	75.50	43.18	49.14
RUS	22.15	43.18	43.18	81.38	65.25	78.64	81.77	75.50	43.18	49.14
WEUR	22.15	43.18	43.18	81.38	65.25	78.64	81.77	75.50	43.18	49.14
EEUR	22.15	43.18	43.18	81.38	65.25	78.64	81.77	75.50	43.18	49.14
RLAT	89.87	37.29	38.27	52.95	48.06	52.46	53.60	51.32	37.71	39.71
ROA	10.17	94.65	78.52	56.45	56.45	60.03	56.45	63.61	100.15	89.71
ROW	71.49	60.94	67.20	72.09	77.87	78.13	79.76	76.50	58.28	63.56

Table A2(cont): Transport Costs per m^3

r/r	NZ	AUS	CHL	SWE	FIN	RUS	WEUR	EEUR	RLAT	ROA	ROW
JAP	42.88	37.97	83.56	52.67	52.67	52.67	52.67	52.67	89.87	10.17	71.49
USN	68.86	77.56	40.05	23.88	23.88	23.88	23.88	23.88	37.29	63.02	60.94
USS	57.83	67.02	36.35	23.88	23.88	23.88	23.88	23.88	38.27	46.89	67.20
PNW	54.68	60.49	50.34	62.08	62.08	62.08	62.08	62.08	52.95	24.82	72.09
ROUS	50.90	58.54	43.65	45.95	45.95	45.95	45.95	45.95	48.06	24.82	77.87
BCI	56.59	62.26	50.61	59.34	59.34	59.34	59.34	59.34	53.60	28.68	78.13
BCC	55.08	60.63	51.19	62.47	62.47	62.47	62.47	62.47	50.60	24.82	79.76
ALTA	58.10	63.89	50.03	56.20	56.20	56.20	56.20	56.20	51.32	32.53	76.50
AC	73.39	81.57	42.26	33.72	33.72	33.72	33.72	33.72	37.71	64.37	58.28
ROC	67.36	75.50	41.82	29.84	29.84	29.84	29.84	29.84	39.71	54.92	63.56
NZ	0.00	10.45	46.89	82.51	80.81	78.59	88.94	86.64	58.31	50.48	57.10
AUS	10.45	0.00	55.03	75.66	73.74	70.33	82.43	78.02	64.79	43.41	53.41
CHL	46.89	55.03	0.00	63.47	65.39	68.53	56.63	60.50	92.45	12.55	38.52
SWE	82.51	75.66	63.47	0.00	4.02	11.33	13.13	9.81	52.99	22.15	50.29
FIN	80.81	73.74	65.39	4.02	0.00	8.38	16.55	11.99	54.83	22.15	50.83
RUS	78.59	70.33	68.53	11.33	8.38	0.00	22.52	15.18	54.83	22.15	49.16
WEUR	88.94	82.43	56.63	13.13	16.55	22.52	0.00	9.64	57.24	22.15	46.90
EEUR	86.64	78.02	60.50	9.81	11.99	15.18	9.64	0.00	46.06	22.15	36.16
RLAT	58.31	64.79	92.45	52.99	54.83	57.24	46.06	49.21	49.21	85.35	30.77
ROA	50.48	43.41	92.45	52.67	52.67	52.67	52.67	52.67	85.35	0.00	62.84
ROW	57.10	53.41	38.52	50.29	50.83	49.16	46.90	36.16	30.77	62.84	0.00

Transport costs come from two sources, one for shipping by land and the other by sea. Calculation was required. For some regions calculations involved only land or sea shipping, but often a combination of the two was used. For example, shipping from Alberta to Japan includes shipping first by land to B.C., then by sea to Japan. Ground shipping costs were calculated based on the method of Mogus et al. (2006), in which a loading cost and a per kilometer cost are calculated for each cubic meter shipped. For sea shipping, container shipping costs compiled by Rodrigue (2005) between the major continents are used. Per cubic meter costs of shipping between continents are based on the cost of shipping a container and the volume of a container. This data set is especially useful as the transport costs reflect direction based cost differences caused by trade imbalances.

Table A3: Production Parameters

region	ϕ	η	AAC_0	C_r	c_r
JAP	0.55	0.89	13167	70	44
USN	0.45	0.52	19255	67	62
USS	0.53	0.41	184229	67	62
PNW	0.57	0.92	45902	67	62
ROUS	0.51	0.92	31725	67	62
BCI	0.5	0.86	58063	41	52
BCC	0.5	0.86	25911	65	60
ALTA	0.55	0.86	14252	41	41
AC	0.45	0.86	15990	47	60
ROC	0.52	0.86	54417	47	60
NZ	0.50	0.60	19604	53	57
AUS	0.35	0.64	14812	53	57
CHL	0.45	0.60	26103	38	42
SWE	0.51	0.60	89542	78	44
FIN	0.51	0.54	43226	78	44
RUS	0.49	0.54	101000	24	49
WEUR	0.65	0.72	87087	78	44
EEUR	0.49	0.60	97475	60	43
RLAT	0.49	0.52	54606	38	42
ROA	0.46	0.56	74946	70	24
ROW	0.48	0.61	12276	38	42

The parameters ϕ and η are the recovery rate and saw log share of harvest, respectively. The recovery rate is lumber production divided by saw log inputs, and the saw log share of harvest is the proportion of industrial harvest that is used as saw logs.

Both parameters are calculated from FAO data as an average over the years 1994 to 2004. The parameters C_r and c_r are the respective marginal costs of producing saw logs and lumber, when operating at capacity. The slopes of the marginal cost curves are obtained by dividing these parameters by production capacity. The numbers for C_r and c_r in table 3 are taken from PriceWaterhouseCoopers (2004).