J. For. Res. 7: 41–48 (2002)

Japanese Forest Sector Modeling through a Partial Equilibrium Market Model

Atsushi Yoshimoto*,[1] and Kiyoshi Yukutake**

*Department of Statistical Methodology, The Institute of Statistical Mathematics, Minato-ku,Tokyo 106–8569, Japan.
**Department of Agriculture and Forest Sciences, Miyazaki University, Miyazaki 889–2192, Japan.

The structure of Japanese timber markets has changed drastically during recent decades. After the introduction of a large amount of imported softwood products, Japanese timber producers have faced global competition with foreign timber suppliers such as Canada, the US, and recently Nordic countries. In this paper, we present a forest sector model for lumber markets with a focus on eight aggregate regions (Tohoku, Kanto, Hokuriku, Chubu, Kinki, Chugoku, Shikoku, and Kyushu) in Japan. The proposed model is based on the Samuelson-partial equilibrium formulation, which searches for an optimal solution by maximizing the net social payoff subject to demand and supply constraints. A nonlinear programming solution technique is incorporated into the proposed model. Three types of lumber are considered, *i.e.*, domestic lumber, the lumber processed in Japan from imported logs, and imported lumber from the US and Canada. Using data for 1998, our analysis indicates that the derived equilibrium solution has a higher price for the imported lumber supply in all regions, and a lower price for the other two products in most regions than the actual current price in 1998. The derived net social payoff gains 1.6% compared with the one derived with the current set of prices and quantities.

Key words: forest economics, forest sector analysis, market modeling, timber trade

After the opening of Japanese timber markets to foreign suppliers in 1964, the structure of the markets has changed drastically. Imported timber products were initially introduced as a substitute for domestic timber products in order to fill a shortage of domestic timber supply. Asian nations, the US and Canada have been the main timber suppliers to Japan. Due to the price superiority of imported timber products, they dominated markets and now take approximately an 80% share.

As for lumber markets, the price superiority of imported lumber remained until recently. Since 1989, however the price of one of the major Japanese species, sugi (*Cryptomeria japonica*), has decreased, resulting in a small price difference between sugi and such imported species as Hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*) from North America. This seems to suggest that domestic timber suppliers have become price-competitive in markets (Yukutake, 1992) with a small increase in supply.

The structure of Japanese timber markets was analyzed by various researchers through an econometric modeling approach. Examples include McKillop (1973), Gallagher (1980), Yukutake (1984, 1985), Mori (1991), Vincent *et al.* (1991), Furuido *et al.* (1991), Nagata *et al.* (1992) and Flora and Lane (1994). McKillop (1973) constructed an econometric model with three supply functions (US log and lumber supply, and Canadian lumber supply to Japan), and three demand functions (Japanese demand for US logs, US lumber and Canadian lumber). Using quarterly data from 1950 to 1970, he concluded that the Japanese demand for lumber from North America was very inelastic. Using a softwood log trade model between the US and Japan, Gallagher (1980) pointed out that Japanese excess demand for logs and US excess supply of logs were price responsive in markets, and that changes in housing starts and log production in Japan were important factors in forecasting the level of the US log exports to Japan. Using a Japanese log trade model, Mori (1991) showed that both demand and supply of domestic logs, and supply of imported logs were inelastic to their own price, while the demand of imported logs was elastic. Vincent *et al.* (1991) examined the Japanese timber trade structure using sawlog data. They concluded that sawlogs from North America, the Russia (the former Soviet Union), and the South Seas were substitutable for each other from 1970 to 1987, and that log imports from each country were affected by their relative net price, *i.e.*, lumber price minus log input cost per unit of lumber. Using data from 1965 to 1989, Furuido *et al.* (1991) revealed a significant relationship between the softwood lumber supply from the US to Japan and the real lumber price in the US, the export lumber price to Japan, and housing starts in the US. As for other products, Tachibana (2000) recently examined the effect of log export restrictions in Southeast Asia on the Japanese plywood market with the use of an econometric model. Note that these researchers focused on the market structure at the national level.

Regarding the current situation of Japanese forest stocking, a large amount of artificial forest planted in the 1960's is becoming ready for harvesting. However, as mentioned by Yukutake and Yoshimoto (2001), the operational costs for forest management remain high, so that the so-called sustainable forest resource management may become doubtful to achieve. That is, we may have a large surplus of forest stock without having an opportunity to utilize or even manage it, but remain dependent on foreign suppliers. In the recent report from the Forestry Agency on their stance toward the WTO negotiations, it was pointed out that forest resources, as one of the renewable resources, should be under "appropriate" management through activities for timber production. In such a case, the Forestry Agency would recognize a wide variety of functions as public goods provided by forest resources.

Regional forest resources are usually managed with a local perspective on market environments. This is because, depending upon location, product species, forest productivity, pro-

[1] Corresponding author (E-mail:yoshimoa@ism.ac.jp).

duction costs, transportation costs, and even prices vary. In this sense, in order to seek sustainable forest resource management, we need to consider the situation of local forest resources and markets in forest sector modeling. Without knowing this, foreseeing that products from these forest resources will become available in the markets would be difficult.

In this paper, we propose a forest sector model through a partial equilibrium market modeling approach with a view to regional level analysis. The proposed market model proceeds from the former model called JAFSEM (*JA*panese *F*orest *SE*ctor *M*odel) by Yukutake *et al.* (1996). The main difference in the modeling effort is that the former model was based on the Koopmans-Hitchcock minimum-transportation-cost problem (see Labys, 1989), while the proposed model is derived with use of the Samuelson-partial equilibrium formulation (Samuelson, 1952). Assuming all prices in different markets equal, local production and use given, the Koopmans-Hitchcock problem is to search for an equilibrium quantity in markets by minimizing the transportation costs for delivering products among markets. Since prices at markets vary, the Samuelson-partial equilibrium formulation, on the other hand, seeks a solution by maximizing the social net profit consisting of consumer surplus and producer surplus minus transportation costs given competitive market conditions. The solution of the model is used to evaluate deviations from competitive efficiency by comparing the efficient model solution with the actual or existing one. The supply and demand potential of products is also discussed along with supply flows within eight aggregate regional markets (Tohoku, Kanto, Hokuriku, Chubu, Kinki, Chugoku, Shikoku, and Kyushu) in Japan.

The Samuelson-Partial Equilibrium Formulation

Our forest sector model is based on the Samuelson-partial equilibrium formulation. A solution is equilibrium both spatially and temporally. To search for an equilibrium solution for price and quantity of each product at each market under competitive market conditions, we solve a net social payoff maximization problem on a static and single period basis. The net social payoff (NSP) is defined by the sum of all consumer surpluses and producer surpluses minus the total transportation costs of delivering products among markets.

An optimal solution of demand, supply and delivered quantities, $(\{D_i^*\},\{S_j^*\},\{Q_{i,j}\})$ is the one that satisfies the following.

$$\underset{[\{D_i^*\},\{S_j^*\},\{Q_{i,j}\}]}{\text{maximize}}\ NSP=\sum_{i=1}^{m}\int_0^{D_i^*}P_i^d(q_i)dq_i-\sum_{j=1}^{n}\int_0^{S_j^*}P_j^s(q_j)dq_j-\sum_{i=1}^{m}\sum_{j=1}^{n}Q_{i,j}\cdot T_{i,t} \tag{1}$$

subject to

$$D_i^*\le\sum_{j=1}^{n}Q_{i,j}\quad\forall i \tag{2}$$

$$S_j^*\ge\sum_{i=1}^{m}Q_{i,j}\quad\forall j \tag{3}$$

$$\{D_i^*\},\{S_j^*\},\{Q_{i,j}\}\ge 0 \tag{4}$$

where D_i^* is an optimal demand quantity at the i-th regional market, S_j^* is an optimal supply quantity at the j-th regional market, $Q_{i,j}$ and $T_{i,j}$ are the amount of lumber delivered from the i-th regional market to the j-th regional market and its corresponding unit transportation cost. m is the number of consumption markets, and n is the number of production markets. $P_i^d(q_i)$ and $P_j^s(q_j)$ are indirect demand and supply functions of quantity. Equation (2) limits inflow to the i-th consumption market to an amount greater than or equal to the corresponding demand, while Eq. (3) constrains outflows from the j-th production market to a quantity less than or equal to the corresponding supply capacity. Note that the problem does not take into account dynamics of market changes.

For simplicity and ease of deriving demand and supply functions, we apply a linear functional form to both. This allows the problem to be reduced to a quadratic programming problem. Application of the Samuelson-partial equilibrium formulation such as in Adams and Haynes (1980) and recently Trømborg *et al.* (2000), has often utilized a recursive linear programming technique to overcome nonlinearity of the objective function. This was mainly due to the availability of commercial software to solve linear programming problems. In our model, however we directly use a quadratic objective function in the nonlinear programming framework. Buongiorno *et al.* (1999) applied a similar objective function as Eq. (1) for the global trade model called GFPM (Global Forest Products Model) (Zhu *et al.*, 1998) with some modification to reflect differences in manufacturing environments by nations as to the cost situation. They utilized manufacturing costs instead. Unlike the above, the dynamic nature of yearly changes in the market equilibrium conditions is also taken into consideration in GFPM for the projection purpose under a hierarchical structure, consisting of one main phase to allocate products within four demand and supply regions (Africa, America, Asia, and Europe), and four sub-models corresponding to each region to solve trade flows within each region.

In order to derive the above indirect demand and supply functions, we need to estimate the price elasticity of demand and supply for products. The elasticity is used to derive the linear indirect demand and supply functions used in Eq. (1). Derivation of demand and supply functions follows. Let ε_i^d be the price elasticity of lumber demand in the i-th market, and ε_j^s be the price elasticity of lumber supply in the j-th market. Given one set of price and quantity, (p_i^d, q_i^d) for lumber demand, we have a linear indirect demand function as follows,

$$P_i^d(q_i)=\left(1+\frac{1}{\varepsilon_i^d}\right)\cdot p_i^d-\frac{1}{\varepsilon_i^d}\cdot\frac{p_i^d}{q_i^d}\cdot q_i \tag{5}$$

As for the indirect supply function with a given point (p_j^s, q_j^s), the following is obtained.

$$P_j^s(q_j)=\left(1-\frac{1}{\varepsilon_j^s}\right)\cdot p_j^s+\frac{1}{\varepsilon_j^s}\cdot\frac{p_j^s}{q_j^s}\cdot q_j \tag{6}$$

Since a linear function is used for demand and supply, estimation of price elasticity with one set of prices and quantities is sufficient for functional derivation. As is often the case for econometric modeling of the demand and supply function, many exogenous variables, *e.g.*, GDP (gross domestic product), exchange rates and carryover products, are introduced to estimate coefficients of the functions. In the proposed model, however, these variables are regarded as a part of a constant coefficient of the functions (5) and (6), so that considering them for modeling becomes unnecessary. This is one benefit for using the linear demand and supply function. Once demand and supply functions are obtained, the optimization phase starts with the given transportation costs among markets on a static and single period basis. That is, unlike GFPM (Global Forest Products Model) developed by Zhu *et al.* (1998), no dynamic change over time is incorporated into the proposed model.

JAFSEM II (Japanese Forest Sector Model)

In our model, lumber markets are of concern. Lumber flows between eight regional aggregated markets (Tohoku, Hokuriku, Kanto, Chubu, Kinki, Chugoku, Shikoku, and Kyushu) in Japan are considered. Table 1 shows prefectures classified into each regional market. Historical data from 1974 to 1998 in Fig. 1 show that Tohoku and Kyushu have extensively produced domestic lumber, while Chugoku mainly imports US logs for lumber production. Kanto is the largest lumber consumption area, followed recently by Kyushu, Chubu, and Kinki. We consider three kinds of lumber, namely, domestic lumber, imported lumber from the US and Canada, and lumber processed from imported logs. They are assumed to be homogeneous. In other words, no differentiation exists in quality of the products. Since the imported logs are mainly from the US, we call the lumber processed from imported logs the US-JP lumber hereafter. Once lumber is produced or imported at each regional market, it is delivered to other markets or consumed there.

In the proposed model, we applied price elasticity to derive the indirect demand and supply functions at each aggregated market. The translog function was used for both demand and supply. The basic form of a demand function at the i-th regional market was

$$\log(q_i^D)=c_i^D-\varepsilon_i^D\cdot\log(P_i^D)+\sum_k a_{i,k}\cdot\log(ED_{i,k}) \tag{7}$$

while for a supply function at the j-th regional market it was

$$\log(q_j^s)=c_j^s+\varepsilon_j^s\cdot\log(P_j^s)+\sum_k b_{j,k}\cdot\log(ES_{j,k}) \tag{8}$$

where c_i^D, c_j^s are constant coefficients and $\{a_{i,k}\},\{b_{j,k}\}$ are coefficients of exogenous variables, $\{ED_{i,k}\},\{ES_{j,k}\}$ for demand and supply, respectively. Price elasticity for demand is expressed by $\{\varepsilon_i^D\}$, while for supply by $\{\varepsilon_j^s\}$. Superscript, s, of the supply function becomes either *JS*, *US*, or *IS*, indicating domestic, JS-JP or imported lumber.

Note that due to limitations of data availability with regard to imported lumber supply and lumber demand, one estimate was used for the imported lumber supply as a whole, while one estimate was applied to each regional market for the total lumber demand. That is, price data for imported lumber at each regional market were not available, only quantity data. Also, data for demand for the three kinds of lumber were not available, only lumber demand as a whole at each market. In order to overcome this lack of data, we applied the following adjustment.

At each regional market, a supply function of imported lumber was estimated in the following way. Let $Q_j^{IS}(\cdot)$ be the direct supply function for imported lumber at the j-th regional market, and $Q^{IS}(\cdot)$ be the supply function for the nation derived from the estimated elasticity. Since imported lumber supply to the nation is an aggregation of regional supplies, we have

$$Q^{IS}(\cdot)=\sum_{j=1}^{8}Q_j^{IS}(\cdot) \tag{9}$$

Assuming a proportion, r_j, of imported lumber in the j-th region relative to one for the nation, the following can be set

$$Q_j^{IS}(\cdot)=r_j\cdot Q^{IS}(\cdot) \tag{10}$$

where

$$\sum_{j=1}^{8}r_j=1 \tag{11}$$

Based on the above, we disaggregated the national level supply function for imported lumber into each regional market by an estimated proportion of imported lumber sales. Given the proportion for each regional market, the indirect supply

Table 1 Aggregation of regional markets.

	Regional markets							
	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu
Prefecture	Aomori	Ibaraki	Niigata	Gifu	Shiga	Tottori	Tokushima	Fukuoka
	Iwate	Tochigi	Toyama	Shizuoka	Kyoto	Shimane	Kagawa	Saga
	Miyagi	Gunma	Ishikawa	Aichi	Osaka	Okayama	Ehime	Nagasaki
	Akita	Saitama	Fukui	Mie	Hyogo	Hiroshima	Kochi	Kumamoto
	Yamagata	Chiba	Nagano		Nara	Yamaguchi		Oita
	Fukushima	Tokyo			Wakayama			Miyazaki
		Kanagawa						Kagoshima
		Yamanashi						Okinawa

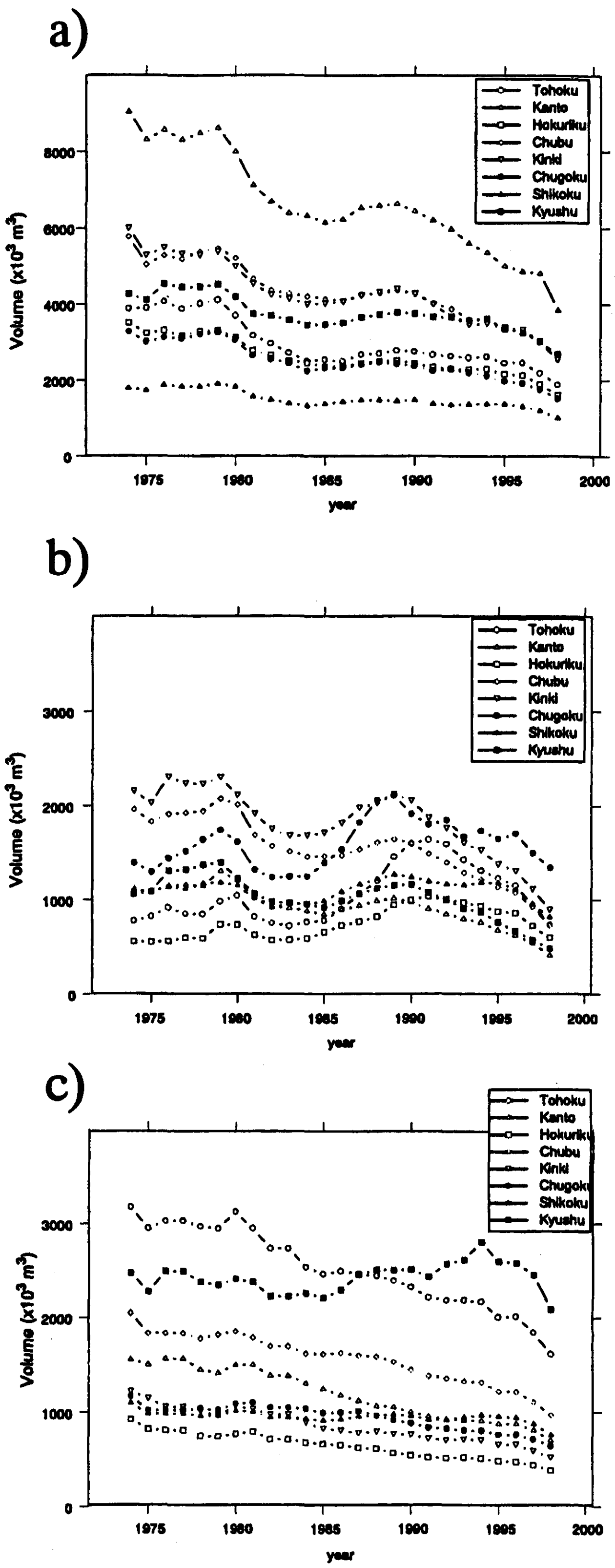

Fig. 1 Lumber demand and supply in Japanese markets. a) Lumber demand, b) Domestic lumber supply, c) US-JP lumber supply. Data source: "Forest Product Demand & Supply Annual Report".

function for imported lumber was specified by

$$P_j^{IS}(q_j) = \left(1-\frac{1}{\varepsilon^{IS}}\right)\cdot p^{IS} + \frac{1}{r_j}\cdot\frac{1}{\varepsilon^{IS}}\cdot\frac{p^{IS}}{q^{IS}}\cdot q_j \qquad (12)$$

where $P_j^{IS}(\cdot)$ is the indirect supply function of the j-th regional market, ε^{IS} is the price elasticity of the imported lumber supply to the nation, and (p^{IS},q^{IS}) is one set of a price-quantity combination for imported lumber. The j-th proportion is calculated by

$$r_j = \frac{q_j^{IS}}{q^{IS}} \qquad (13)$$

where q_j^{IS} is the supply quantity of imported lumber at the j-th market.

As is often the case for market modeling, the total demand and supply do not always match. This is partly due to methodological differences in data collection, *e.g.*, an interview-based and report-based data collection. In the data we used, discrepancies also existed between the amount of total lumber demanded and the sum of the supply of domestic lumber, US-JP lumber and imported lumber. In this paper, we do not go into further discussion on this matter, but adjust the given data for modeling. Adjustment was only applied to a given set of price-quantity combinations. Total lumber demand was set to be equal to the sum of lumber supplies with the corresponding multiplier.

$$m\cdot\sum_i q_i^D = \sum_j (q_j^{JS} + q_j^{US} + q_j^{IS}) \qquad (14)$$

where m is the multiplier. In the proposed model, the lumber demand in each market was assumed to be the product of a given quantity and the derived multiplier, so that a set of constraints used in the optimization framework become always feasible.

Besides the above data adjustment, we modified the objective function as follows. The model specified by Eq. (1) assumes positive values for all intersections of demand and supply function if they are linear. Based on the values provided by Yukutake (personal communication), all derived indirect supply functions indicated negative intersections. While Yoshimoto *et al.* (1999) used the direct supply function of quantity to incorporate producer surplus directly into the objective function, we kept to the indirect demand and supply functions and made the following modification to the objective function in order to avoid irrelevancy of negative prices

$$\underset{[\{D_i^*\},\{P_j^*\},\{Q_{i,j}\}]}{\text{maximize}}\; NSP = \sum_{i=1}^{8}\int_0^{D_i^*} P_i^d(q_i)dq_i - \sum_{j=1}^{8}\int_{S_j^0}^{S_j^*} P_j^s(q_j)dq_j - \sum_{i=1}^{8}\sum_{j=1}^{8} Q_{i,j}\cdot T_{i,t} \qquad (15)$$

where S_j^0 is a minimum supply quantity at the j-th market satisfying

$$0=\left(1-\frac{1}{\varepsilon_j^s}\right)\cdot p_j^s+\frac{1}{\varepsilon_j^s}\cdot\frac{p_j^s}{q_j^s}\cdot S_j^0 \qquad (16)$$

Thus, an additional constraint is imposed.

$$S_j^* \geq S_j^0 \quad \forall j \qquad (17)$$

We constructed the second version of *JA*panese *F*orest *SE*ctore *M*odel (JAFSEM II) to implement analysis using the framework described above. The model was written in the FORTRAN programming language with the FORTRAN library for a nonlinear programming called MINOS (Murtagh and Saunders, 1993). It is executable on a personal computer.

Table 2 An input data for JAFSEM II based on the current price and quantity data.

Product	Region	Price elasticity	Input price (yen/m^3)	Input quantity (m^3)
Lumber demand	Tohoku	0.52739	48632	2184584*
	Kanto	0.98239	52446	4437257
	Hokuriku	0.58264	49935	1863763
	Chubu	1.03356	53292	2939322
	Kinki	1.30152	50037	2958941
	Chugoku	0.71129	53326	1749514
	Shikoku	0.42563	52059	1169035
	Kyushu	0.13899	43587	3098579
Imported lumber supply	Tohoku	0.48642	40670	649399
	Kanto	0.48642	40670	2591731
	Hokuriku	0.48642	40670	180023
	Chubu	0.48642	40670	1153146
	Kinki	0.48642	40670	1513687
	Chugoku	0.48642	40670	56684
	Shikoku	0.48642	40670	167196
	Kyushu	0.48642	40670	393121
US-JP lumber supply	Tohoku	0.46154	44481	737000
	Kanto	0.47210	52351	410000
	Hokuriku	0.18320	48606	600000
	Chubu	0.23928	52599	730000
	Kinki	0.46979	52347	893000
	Chugoku	0.08309	51688	1339000
	Shikoku	0.42995	55116	815000
	Kyushu	0.36819	46296	483000
Domestic lumber supply	Tohoku	0.21322	50526	1615000
	Kanto	0.12505	52502	705000
	Hokuriku	0.16656	52000	386000
	Chubu	0.18339	53812	972000
	Kinki	0.31612	46080	521000
	Chugoku	0.31169	56754	640000
	Shikoku	0.19919	48798	764000
	Kyushu	0.20373	42960	2086000

* Adjusted value to fill the gap between the total demand and the sum of all supplies. Data source: "Forest Product Demand & Supply Annual Report," "Annual Report of Imported Logs and Lumber," "FAOSTAT database."

Comparison of an Equilibrium Solution to the Current Set of Price and Quantity

In this section, we seek a market equilibrium solution using JAFSEM II in order to investigate how different the current set of lumber price and quantity is from the derived one. In other words, the solution of the model is used to evaluate deviations from competitive efficiency by comparing the efficient model solution with the current one. The price elasticities, the current set of prices and quantities used for each market are given in Table 2. Those data were in the 1998 base. The data source was "Forest Product Demand & Supply Annual Report" from the Japanese Forestry Agency for the regional information, *i.e.*, the domestic and US-JP lumber supply and domestic lumber demand, while the FAOSTAT database was used for the imported lumber supply. Disaggregation of the imported lumber supply into each regional market supply specified by Eq. (13) was based on "Annual Report of Imported Logs and Lumber" from Japan Lumber Importers' Association. As for the multiplier in Eq. (14) to equate the total lumber demand and supply quantity, we estimated at 1.154. Intuitively the total demand quantity should be greater than the sum of the domestic, US-JP and imported lumber supply because figures for lumber demand used here are supposed to include lumber imported from other nations besides the US and Canada. Thus we expected values less than 1.0, *i.e.*, the total demand is to be greater than the sum of the domestic, US-JP and imported. According to the authority, the reason for this discrepancy was mainly due to different survey timing and methods, and interviewees for demand and supply data collection. In our analysis, we adjusted data in the way explained before for feasibility of the problem. Table 3 shows the transportation cost per unit volume of lumber assumed among eight markets. It varies from 2,000 to 10,000 yen/m^3, depending upon delivery distance.

Given the input data in Tables 2 and 3 the equilibrium solution was found under competitive market conditions. Table 4 shows the derived price and quantity as compared with the current set of price and quantity in each market. The derived net social payoff became 1,887.3 billion yen with

Table 3 Transportation costs between regional markets (yen/m^3).

		Destination							
	Region	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu
Origin	Tohoku	2000	3500	4000	4500	7000	8000	8000	10000
	Kanto	3500	2000	3500	3000	3500	3500	4000	7000
	Hokuriku	4000	3500	2000	3000	2800	4000	4000	7000
	Chubu	4500	3000	3000	2000	3000	4000	4000	7000
	Kinki	7000	3500	2800	3000	2000	3000	3000	4000
	Chugoku	8000	3500	4000	4000	3000	2000	2500	4000
	Shikoku	8000	4000	4000	4000	3000	2500	2000	4000
	Kyushu	10000	7000	7000	7000	4000	4000	4000	2000

Table 4 A derived equilibrium solution and the current set of price and quantity.

	Region	Quantity Current (m³)	Quantity Estimated (m³)	Quantity Difference (%)	Price Current (yen/m³)	Price Estimated (yen/m³)	Price Difference (%)
Lumber demand	Tohoku	2184584	2185670	0.05	48632	48586	−0.09
	Kanto	4437257	4633770	4.43	52446	50082	−4.51
	Hokuriku	1863763	1849760	−0.75	49935	50579	1.29
	Chubu	2939322	3082450	4.87	53292	50781	−4.71
	Kinki	2958941	2978770	0.67	50037	49779	−0.52
	Chugoku	1749514	1855520	6.06	53326	48783	−8.52
	Shikoku	1169035	1200240	2.67	52059	48794	−6.27
	Kyushu	3098579	3041340	−1.85	43587	49380	13.29
Imported lumber supply	Tohoku	649399	695369	7.08	40670	46589	14.55
	Kanto	2591731	2821720	8.87	40670	48090	18.24
	Hokuriku	180023	197069	9.47	40670	48587	19.47
	Chubu	1153146	1265050	9.70	40670	48784	19.95
	Kinki	1513687	1642450	8.51	40670	47782	17.49
	Chugoku	56684	60832	7.32	40670	46788	15.04
	Shikoku	167196	179429	7.32	40670	46788	15.04
	Kyushu	393121	424639	8.02	40670	47373	16.48
US-JP lumber supply	Tohoku	737000	753092	2.18	44481	46585	4.73
	Kanto	410000	394242	−3.84	52351	48089	−8.14
	Hokuriku	600000	599965	−0.01	48606	48591	−0.03
	Chubu	730000	717334	−1.74	52599	48785	−7.25
	Kinki	893000	856442	−4.09	52347	47785	−8.71
	Chugoku	1339000	1328450	−0.79	51688	46787	−9.48
	Shikoku	815000	762056	−6.50	55116	46788	−15.11
	Kyushu	483000	487129	0.85	46296	47371	2.32
Domestic lumber supply	Tohoku	1615000	1588150	−1.66	50526	46586	−7.80
	Kanto	705000	697587	−1.05	52502	48087	−8.41
	Hokuriku	386000	381780	−1.09	52000	48587	−6.56
	Chubu	972000	955363	−1.71	53812	48790	−9.33
	Kinki	521000	527110	1.17	46080	47790	3.71
	Chugoku	640000	604966	−5.47	56754	46787	−17.56
	Shikoku	764000	757724	−0.82	48798	46786	−4.12
	Kyushu	2086000	2129570	2.09	42960	47364	10.25

$$Difference = \frac{Estimated - Current}{Current} \cdot 100\ (\%).$$

44.2 billion yen as the total transportation costs. Based on the current set of price and quantity, the calculated net social payoff was 1,856.9 billion yen, 1.6% less than the above. Although no information was available regarding delivering products, the total transportation costs could be estimated by subtracting the integral part of the indirect demand and supply function in the objective function from the calculated net social payoff. The integral part was estimated at 1,926.9 billion yen, resulting in 70.0 billion yen total transportation costs, 58.4 % higher than the derived costs. These results imply that under the competitive market conditions with the given input data, the current situation of lumber demand and supply, and flows among the regions could be improved with the higher net social payoff. A large reduction in the total transportation costs can be expected by changing the source and destination of lumber delivery.

As for demand and supply quantities, the derived lumber demand slightly increased to 20.8 million m^3, as opposed to 20.4 million m^3 in the input data. The total imported lumber supply increased to 7.29 million m^3 compared with the actual 6.70 million, while the US-JP and domestic lumber supplies decreased to 5.90 million m^3 and 7.64 million m^3 compared with the actual figures of 6 million and 7.69 million, respectively. It could be revealed that efficient location of lumber demand and supply flows results in more shares of the imported lumber, and a lesser share of the other two in the markets than those of the current situation.

Across different regions, the efficient solution of the model indicates the supply and demand potential in each market as follows. The lumber demand in Kanto showed the largest increase of 196 thousand m^3 followed by Chubu with a 143 thousand m^3 increase and Chugoku with a 106 thousand m^3 increase compared with the current set of prices and quantities in the input data. A reduction in lumber demand was found in Kyushu, by 57 thousand m^3 and in Hokuriku, by 14 thousand m^3. As for demand, an increase in quantity implies a decrease in price and vice versa. In the input data, demand prices ranged from 43,587 yen/m^3 in Kyushu to 53,326 yen/m^3 in Chugoku. By contrast, the derived demand price in the equilibrium solution varied from 48,586 yen/m^3 in Tohoku to 50,781 yen/m^3 in Chubu. The price in Chugoku decreased the most, by 4,543 yen/m^3, and Shikoku, Chubu and Kanto fol-

Table 5 Delivery destination in an equilibrium solution among lumber markets.

		Lumber demand (m^3)							
	Region	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu
Imported lumber supply (m^3)	Tohoku	695369	0	0	0	0	0	0	0
	Kanto	0	2821720	0	0	0	0	0	0
	Hokuriku	0	0	197069	0	0	0	0	0
	Chubu	0	0	0	1265050	0	0	0	0
	Kinki	0	0	13113	0	1629340	0	0	0
	Chugoku	0	0	0	0	60832	0	0	0
	Shikoku	0	0	0	0	179429	0	0	0
	Kyushu	0	0	0	0	0	0	0	424639
US-JP lumber supply (m^3)	Tohoku	753092	0	0	0	0	0	0	0
	Kanto	0	394242	0	0	0	0	0	0
	Hokuriku	0	0	599965	0	0	0	0	0
	Chubu	0	0	0	717334	0	0	0	0
	Kinki	0	0	0	0	856442	0	0	0
	Chugoku	0	0	0	0	0	1328450	0	0
	Shikoku	0	0	0	144701	0	0	617355	0
	Kyushu	0	0	0	0	0	0	0	487129
Domestic lumber supply (m^3)	Tohoku	737211	720214	130722	0	0	0	0	0
	Kanto	0	697587	0	0	0	0	0	0
	Hokuriku	0	0	381780	0	0	0	0	0
	Chubu	0	0	0	955363	0	0	0	0
	Kinki	0	0	527110	0	0	0	0	0
	Chugoku	0	0	0	0	77894	527072	0	0
	Shikoku	0	0	0	0	174839	0	582886	0
	Kyushu	0	0	0	0	0	0	0	21290570

lowed.

The imported lumber supply increased in all regions. Increase in Kanto was the largest by 230 thousand m^3, followed by Kinki by 129 thousand m^3. The smallest was in Chugoku by 4 thousand m^3. This resulted in price increase in each region. Tohoku showed the minimum increase by 5,919 yen/m^3, and Chubu did the maximum increase by 8,114 yen/m^3. The US-JP and domestic lumber supply showed decreases in most regional markets. Exceptions were the US-JP lumber supply in Tohoku and Kyushu, and the domestic lumber supply in Kinki and Kyushu. The decrease in the US-JP lumber supply was largest in Shikoku at 53 thousand m^3, followed by Kinki (37 thousand m^3) and Kanto (16 thousand m^3), while the domestic lumber supply showed the largest decrease in Chugoku dropping by 35 thousand m^3. In other regions, the decrease was approximately 1 to 2%. The corresponding lumber price changed likewise. It ranged from 46,585 to 48,785 yen/m^3 for US-JP lumber, and from 46,586 to 48,790 yen/m^3 for domestic lumber.

Table 5 shows delivery destinations of lumber among all regional markets. Lumber demand in Tohoku, Chugoku, Shikoku and Kyushu was satisfied by their own supply. In Kanto, excess domestic lumber supply from Tohoku was delivered to fill a local shortage of supply. Shortage of lumber in Hokuriku was covered by the imported and domestic lumber supply from Kinki as well as the domestic lumber supply from Tohoku. Excess imported and domestic lumber supply from Chugoku and Shikoku was, instead, delivered to Kinki. These supply flows from Kinki to Hokuriku and from Chugoku and Shikoku to Kinki, seemed to contradict efficient supply flows. Observing the derived market prices in Hokuriku, Kinki, Chugoku, and Shikoku, however, it becomes apparent that they sell the products at a higher price in Hokuriku, and buy at a cheaper price from Chugoku and Shikoku, which is consistent with a rational market behavior under competitive market conditions.

As stated earlier, the total transportation costs for this equilibrium solution were 44.2 billion yen. Dividing this by the total lumber supply, the average delivery cost per unit volume of 2,125 yen/m^3 is arrived at. On the other hand, the solution from the current set of prices and quantities in the input data gave transportation cost of 70.0 billion yen, resulting in 3,431 yen/m^3 as the average delivery cost. This difference in average cost could imply how costly the current flows of the products among the regional markets in the input data are, on the basis of transportation costs, from the social benefit point of view.

Conclusions

The objective of this study was to propose a Japanese forest sector model using the Samuelson-partial equilibrium formulation. We constructed a second version of the JAFSEM (*JA*panese *F*orest *SE*ctor *M*odel) within a nonlinear programming framework. The model searches for a spatial and temporal equilibrium on a static and single period basis, where an equilibrium quantity of lumber traded in markets is determined by maximizing the net social payoff defined by the sum of consumer and producer surpluses minus all transportation costs incurred in delivering lumber from one market to another under demand and supply constraints. This stems from competitive market conditions. Since we assumed a linear functional form for the indirect demand and supply functions, estimating price elasticity of demand and supply as well as one set of prices and quantities were enough to implement the proposed model. This is one advantage for the proposed forest sector modeling approach.

As is often the case in market modeling, limitations or lack of data remained in our analysis. We adjusted the input data set in order to overcome the problem of an imbalance of demand and supply quantities. Based on the adjusted data set, our analysis on the supply and demand potential under competitive market conditions showed the following. Compared with the input data set of the current situation, the derived equilibrium solution indicated increases in the imported lumber supply of 7.08 to 9.70% along with increases in supply price. That is, the current price set of imported lumber was relatively cheaper than one derived under competitive market conditions, implying that more imported lumber could be delivered to Japan. In other words, if the market were competitive, cheaper products, *i.e.*, imported lumber, would be in greater quantity in the market, shifting its price up to an equilibrium level. In contrast, a reduction in supply was observed for domestic and US-JP lumber in most regional markets. Exceptions were the US-JP lumber supply from Tohoku and Kyushu, and the domestic lumber supply from Kinki and Kyushu. In the domestic lumber supply, potential increases of 1.17 and 2.09% may be expected in the Kinki and Kyushu regions, respectively. Lumber demand also changed. Except Hokuriku and Kyushu, all regions showed an increase in demand, resulting in price reductions. These results indicated that the current level of price for imported lumber supply is too low, and for the other two too high. Our analysis showed that Tohoku would play an important role in supplying lumber to Kanto and Hokuriku, while Chugoku and Shikoku would for Kinki. Given competitive or efficient market conditions, lumber supply from Kinki would aim at Hokuriku with a higher lumber price, and the resultant shortage of lumber supply in Kinki would be satisfied by supply from Chugoku and Shikoku with a lower price. These results imply potential improvement of the social welfare defined by the net social payoff by shifting location and flows of lumber demand and supply in the markets.

The analysis conducted here was based on the best knowledge of the published data set and delivery information. We believe that a forest sector modeling approach applied in this paper is useful in order to investigate potential changes in the market structure under competitive market conditions. Further analysis has to be conducted as to effects of change in factors, *e.g.*, the unit transportation cost, incorporated into the proposed model on the equilibrium solution for forest policy analysis.

This is research was supported by the Grant-in-Aid for Scientific Research (No.11691090) from the Ministry of Education, Culture, Science, Sports, and Technology of Japan.

Literature cited

Adams, D.M. and Haynes, R.W. (1980) The 1980 softwood timber assessment market model: Structure, projections, and policy simulations. For. Sci. Mono. 22: 62.

Buongiorno, J., Zhu, S., and Tomberlin, D. (1999) Modeling the global and Asia-Pacific forest sectors: Experiences and prospects. *In* Global concerns for forest resource utilization. Yoshimoto, A. and Yukutake, K. (eds.), 361pp, Kluwer Academic Publishers, Dordrecht, 169–182.

Flora, D. and Lane, C. (1994) Equilibrium modeling of Pacific rim trade in logs and lumber. J. For. Econ. 126: 9–11.

Furuido, H., Kato, T., Inoue, M., Nagata, S., and Oka, H. (1991) Econometric analysis of forest products trade in the Pacific region (1) Softwood lumber exports from USA to Japan. Trans. 102nd Annu. Meet. Jpn. For. Soc.: 33–35. (in Japanese)

Gallagher, P. (1980) An analysis of the softwood log trade between the United States and Japan. Technical Bulletin, 330. Agricultural Experiment Station, University of Minnesota, Forestry Series No. 34, 2–19.

Labys, W.C. (1989) Spatial and temporal price and allocation models of mineral and energy markets. *In* Quantitative methods for market-oriented economic analysis over space and time. Labys, W.C., Takayama, T., and Uri, N.D. (eds.), 329pp, Avebury, Vermont, 14–47.

McKillop, W.L.M. (1973) Structural analysis of Japanese-North America trade in forest products. Forest Sci. 19: 63–74.

Mori, Y. (1991) Timber market in Japan: An econometric analysis. Mem. Coll. Agric., Kyoto Univ.: 179–191.

Murtagh, B.A. and Saunders, M.A. (1993) MINOS 5.4 user's guide (preliminary). 135pp, Department of Operations Research, Stanford University, Stanford, CA.

Nagata, S., Furuido, H., Kato, T., and Oka, H. (1992) Econometric analysis of forest products trade in the Pacific region (2) Making of an econometric model for coniferous wood trade between Japan and North America. Trans. 103rd Annu. Meet. Jpn. For. Soc.: 29–31. (in Japanese)

Samuelson, P.A. (1952) Spatial price equilibrium and linear programming. Am. Econ. Rev. 42: 283–303.

Tachibana, S. (2000) Impacts of log export restrictions in Southeast Asia on the Japanese plywood market: An econometric analysis. J. For. Res. 5: 51–57.

Trømborg, E., Buongiorno, J., and Solberg, B. (2000) The global timber market: Implications of changes in economic growth, timber supply, and technological trends. Forest Policy Econ. 1: 53–69.

Vincent, J.R., Brooks, D.J., and Gandapur, A.K. (1991) Substitution between tropical and temperate sawlogs. Forest Sci. 37: 1484–1491.

Yoshimoto, A., Kajita, J., and Yukutake, K. (1999) Japanese forest sector modeling : Possibility of increasing domestic timber production. *In* Global concerns for forest resource utilization. Yoshimoto, A. and Yukutake, K. (eds.), 361pp, Kluwer Academic Publishers, Dordrecht, 183–200.

Yukutake, K. (1984) Econometric analysis of South Sea and USSR log Market in Japan. Jpn. Agric. Res. Quart. 17: 269–279.

Yukutake, K. (1985) Simulation analysis of log and lumber: Econometric model for Japan. Curr. State Jpn. For. 4: 1–14.

Yukutake, K. (1992) US-Japan trade friction and the change in the supply-demand structure for forest products. Curr. State Jpn. For. 8: 76–86.

Yukutake, K. and Yoshimoto, A. (2001) Cost analysis of timber production from domestic resources. Jpn. J. For. Plann. 35: 75–80. (in Japanese)

Yukutake, K., Yoshimoto, A., Nagata, S., and Tachibana, S. (1996) Forest sector modeling in Japan. *In* Proceeding of Project Group P.6.11 FORESEA Meeting at the 20th IUFRO World Congress, University of Washington, SP22, 111–134.

Zhu, S., Tomberlin, D., and Buongiorno, J. (1998) Global forest products consumption, production, trade, and prices: GFPM model projections to 2010. 333pp, Forestry Policy and Planning Division, Forestry Department, FAO, Rome.

(Accepted December 25, 2001)