Theoretical and Empirical Analysis of China's Round Wood Supply

Abstract: China is one of the few countries in the world to restrict tree harvest by strict logging quota system. Optimal control models are introduced here to examine timber output with and without logging quota restriction. In second part of this paper, an empirical study based on a panel data of 28 provinces from 1989—2003 of China's round wood supply confirms that round wood output in China was highly correlated with logging quota. Another forestry policy, Natural Forest Conservation Program, was also significantly reduced the output of round wood.

Introduction

As China quickly becomes the world largest market and supplier of forest products over the past decade, her domestic policy change and ensuing supply trends becomes interesting to many. As being increasingly recognized, changes of China's domestic policy and wood supply have had drastic impacts on world market and global forest resources. Despite the significance of the issue, understanding of China's unique policy framework, institutional foundation and future supply trends in forest products remains limited.

This paper is part of a project developed to understand the structure of forest product market and its driving force in China. The focus is set on round wood supply here for the reason that round wood production is the segment directly affected by domestic forest policy change. The increased supply of round wood in the future, as being expected by Chinese government, will be results of forest policy change, institutional improvement, market development and international process. Yet the mechanism is still to be unveiled.

The remainder of the paper organized in three sections. The first section develops an optimal control model to analyze the timber supply behaviors of a representative producer given different goals and constraints. The second section elaborates an econometric model of China's round wood supply using a province level panel data from 1989 to 2003. Some concluding remarks are provided at the third section.

I. Optimal Control Model of China's Timber Production

Traditional timber supply model, in which the rotation age is the only decision variable considered, can be dated back to Faustmann's seminal work and is further developed by many following efforts (to name a few, see Hartman [1976] and Hyde [1980]). Following such models, the amount of timber produced depends on the rotation age, and therefore on price. But the reality is not so simple for forest managers as to decide when to harvest only. They may have to decide how much timber to harvest this year and how much next year. In other words, the production decision is continuous, therefore a forest level model makes more intuitive sense. Here attempt to approach the timber supply problem of this nature by a general optimal control model.

①Only timber values and no logging quota restricts

Assume there is no any policy limit on harvest amount and forest managers care about the revenue from timber harvest only. Then within the decision period 0~t, the forest manager solves

$$\max \int_0^t p(t)Q(t)e^{-r(t)t}dt \tag{1}$$

$$s.t. \quad \dot{I}(t) = g(I, t) - Q(t) \tag{2}$$

$$I(t_0) = I_0 \tag{3}$$

The control variable in this optimal control model is the amount of timber harvested *Q(t)*, state variable is the timber inventory *I(t)*. Forest manager chooses the amount of timber harvested at each time t, or the path of harvest *Q(t)*, as the solution to this optimal control problem. *r(t)* denotes discount rate, *p(t)* denotes exogenous price of timber, *g(I, t)* is the natural growth function of timber, and I_0 is the given initial inventory. Then the Hamiltonian is:

$$H = p(t)Q(t)e^{-r(t)t} + \lambda\left[g(I, t) - Q(t)\right] \tag{4}$$

According to optimal control theory, the optimal state trajectory $I(t)^*$, optimal control $Q(t)^*$, and corresponding Hamilton multiplier λ^* must satisfy following equations:

$$\frac{\partial H}{\partial Q} = p(t)e^{-r(t)t} - \lambda^* = 0 \tag{5}$$

$$\frac{d\lambda^*}{dt} = -\frac{\partial H}{\partial I} = -\lambda^* \frac{\partial g}{\partial I} \tag{6}$$

$$\frac{dI}{dt} = \frac{\partial H}{\partial \lambda} = g(I,t) - Q(t) \tag{7}$$

$$\frac{\partial^2 H}{\partial Q^2} \le 0 \tag{8}$$

②Timber harvest decision under logging quota restriction

We consider a case specific to Chinese context. Here producer maximizes timber revenue, but in the context of logging restriction. Forest manager solves:

$$\max \int_{t_0}^{t_1} p(t)Q(t)e^{-r(t)t}dt \tag{9}$$

$$s.t. \quad \dot{I}(t) = g(I, t) - Q(t) \tag{10}$$

$$I(t_0) = I_0 \tag{11}$$

$$Q(t) \le Q_0 \tag{12}$$

Q_0 denotes the upper limit of logging set by forest authority. The only difference between model (1)~(3) and model (9)~(12) is the constraint (12) in the latter. Corresponding Hamiltonian is defined as:

$$H = p(t)Q(t)e^{-r(t)t} + \lambda\left[g(I, t) - Q(t)\right] + \mu\left[Q_0 - Q(t)\right] \tag{13}$$

μ denotes Lagrange multiplier vector, the equations that $I(t)^*$, $Q(t)^*$, and λ^* must satisfy are:

$$\frac{\partial H}{\partial Q} = p(t)e^{-r(t)t} - \lambda^* - \mu^* = 0 \quad (14)$$

which is a little different to equation (4). μ^* , optimal Lagrange multiplier vector,should satisfy：

$$\mu^* \geq 0,\ Q_0 - Q(t) \geq 0,\ \mu^*\left[Q_0 - Q(t)\right] = 0 \quad (15)$$

Obviously, the solution to model (1)~(3) （$Q_1^*(t),I_1^*(t)$） also solves model (9)~(12), and optimal costate trajectories λ^*(t) in both models are the same. In this case,μ^*=0 in the latter.

Ifμ^*>0, it is obvious that $Q_0 - Q(t)=0$ according to equations (15).That means forest managers tend to harvest as much as policy allows.

In fact,μ^* indicates marginal value of logging quota, that is, the change of optimal revenue from timbre harvest when logging quota changes by one unit. It depends on Q_0 whether the solution to this optimal control problem (9)~(12) would be a corner solution (μ^*=0) or not. If $Q_0>Q_1^*(t)$, solutions to model (1)~(3) and model (9)~(12) are the same: ($Q_2^*(t),I_2^*(t)$) = （$Q_1^*(t),I_1^*(t)$） , which means that logging quota dose not matter; if $Q_0<Q_1^*(t)$, the solution to model (9)~(12) is corner solution, which means that the amount of harvest timber at each time is equal to logging quota Q_0.

For each time t, the impact logging quota on social welfare can be demonstrated by figure 1.[1] Without logging quota, given $p(t)$ as exogenous timber price in a competitive market, the solution to model (1)~(3) would be the equilibrium point, where demand is equal to supply (A in Figure 1). The consumer surplus is depicted in Figure 1, the area covered by horizontal lines. Producer surplus is the profit gained by timber producers p^*Q^*, which is also depicted in Figure 1, the area covered by vertical lines. Aggregated social surplus is equal to the area AQ^*DO. On the other hand, when logging quota exists, the amount of harvest timber reduces to Q_0， and consumers are willing to pay price p_0 for the limited timber (B in Figure 1). In this case, producer surplus is area p_0BQ_0O covered by points, and consumer surplus reduces to area Dp_0B. The loss in social welfare from the case with logging quota restriction is equal to the area BAQ_0Q^*.We can also learn from the domestic supply curve S_d [2] that timber producer would like to producer more timber than Q_0 at price p_0, and they have incentive to gain more profit by increasing production. Thus, restricting timber production at Q_0 would not be able to achieve equilibrium like a free competitive market, and extra cost is necessary to monitor timber producers from over logging.

Certainly, it is possible to import timber in order to satisfy domestic timber demand, just like what China currently does, but the welfare of domestic timber suppliers would be interfered as well. Figure 1 provides an illustration. S_i denotes a supply curve including both international and domestic timber supply[3]. The equilibrium point now turns to C in Figure 1. While consumer

[1]Because the present logging quota is too low rather than too high, the discussion about welfare here only focuses on normal solution ($\mu^* \neq 0$).

2Strictly speaking, the curve of timber supply (Q*(t)) is exactly the solution to optimal control model. For simplicity, supply curve, the conception in Economics Principle, is used here. That is to say, supply curve here is a static linear function of price with positive slope instead of the real dynamic solution.

[3]This supply curve takes both domestic and international timber supply into consideration. Normally, total supply

surplus increases by area p^*p_iCA, the revenue of domestic timber suppliers reduces to p_iQ_0, not only less than the producer surplus without logging quota, but also less than p_0Q_0 when logging restriction exists.

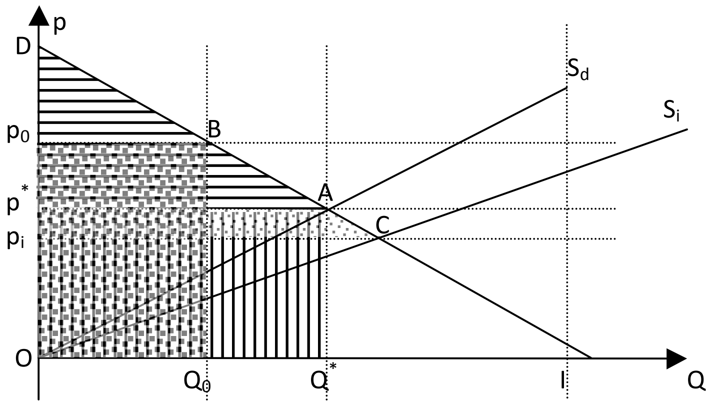

Figure 1 Social welfare with and without logging quota

③Standing forest has value

If the forest manager cares about the value of environmental services of the forests at the same time, his objective function will consist of both the value of harvested timber and standing forests, the optimal control problem becomes:

$$\max \int_{t_0}^{t_1} [p(t)Q(t) + V(I,t)]e^{-r(t)t}dt \tag{16}$$

Constraints (2), (3) apply here.

The value of standing forest (also denoted as non-timber products hereafter) is denoted $V(I, t)$. The new Hamiltonian is:

$$H = [p(t)Q(t) + V(I,\ t)]e^{-r(t)t} + \lambda\big[g(I) - Q(t)\big] \tag{17}$$

The optimal state trajectory $I(t)^*$, optimal control $Q(t)^*$, and corresponding Hamilton multiplier λ^* will satisfy the following equations:

$$\frac{\partial H}{\partial Q} = p(t)e^{-r(t)t} - \lambda^* = 0 \tag{18}$$

$$\frac{d\lambda^*}{dt} = -\frac{\partial H}{\partial I} = -\lambda^* \frac{\partial g}{\partial I} + \frac{\partial V}{\partial I} e^{-r(t)t} \tag{19}$$

$$\frac{dI}{dt} = \frac{\partial H}{\partial \lambda} = g(I,t) - Q(t) \tag{20}$$

$$\frac{\partial^2 H}{\partial Q^2} \le 0 \tag{21}$$

The solution to optimal control problem $Q(t)^*$ is exactly the time path of timber supply.

including international supply is more than domestic supply only at price *p*. Correspondingly, the slope of new supply curve is less than that of domestic supply only (S_d).

Unfortunately, it is very rare for an optimal control problem to have analytical solution, which can be identified by a usual function, and numerical analysis is often used to obtain approximate solution to an optimal control problem. In order to simplify the problem without losing generality, consider a one-period decision model to illustrate influence the environmental value of forest would have on timber production.

Take timber and environmental service as two mutually exclusive commodities from forests generated by corresponding forest volumes（Q_1, Q_2）. Revenue from timber is obtained when trees are harvest (Q_1) and value of environmental service exists only when trees are not harvest (remaining forest volume of Q_2). There is a constraint on the total amount of two commodities: $Q_1+Q_2=I$. It is convenient to consider I as the total inventory of forests. p_1 is the timber price on market, $V(Q_2)$ is the monetary environmental value of forests, which satisfies $V'(Q_2)>0$, $V''(Q_2)<0$[4]. Then the decision problem facing the forest manager is:

$$\max_{Q_1, Q_2} \quad p_1 Q_1 + V(Q_2) \tag{22}$$

$$s.t. \quad Q_1 + Q_2 = I \tag{23}$$

The solution is obtained when the marginal rates of substitution of the two commodities are equal: $V'(Q_2)=p_1$. Let R denote the total value of forests: $R=p_1Q_1+V(Q_2)$. The isoquants associated with revenue level R_1 and R_2 are depicted in Figure 2. The upper contour set $\{R' : R' \geq R\}$ is convex, so model (22)~(23) has one and only one solution （Q_1^*, Q_2^*）; that is, timber producers would choose timber output level according to the marginal rates of substitution of timber and standing trees, and would not harvest all the available timber (Figure 2). While if $V(Q_2) \equiv 0$, or there is no extra environmental value of forests besides timber, the solution to model would turn to $(I,0)$; that is, all the available timber would be harvested.

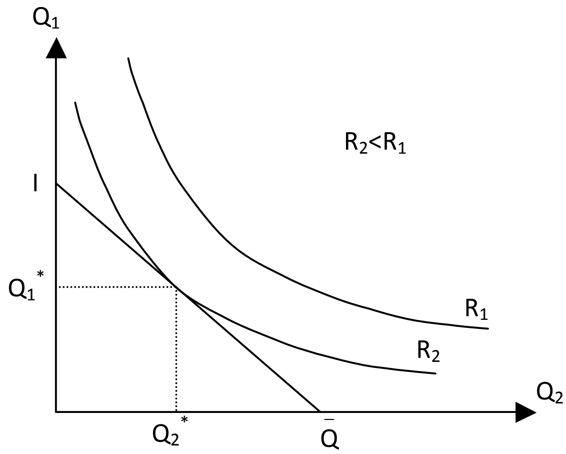

Figure 2 Two commodities supplied by a forest: timber and environmental services

(The analysis here is suitable for the case when user cost of timber production is zero, a special case of problem (1) and (2).)

[4] V(Q2) is strictly convex. See Hartman(1976).

II. Empirical Analysis of China's Round Wood Supply

The theoretical analyses above showed that a stringent logging quota system would limit timber production below socially optimal level. In this case, forests managers tend to harvest tree exactly according to the quota. We will use a provincial level panel dataset to test this hypothesis. The data covers a period between 1989 and 2003 for 28 provinces in China. To better understand the variety of timber production in different parts of China and for the purpose of future research in the perspective of spatial price equilibrium, the 28 sample provinces are divided into three regions: northeastern China, southwestern China and the rest of China.[5]

Part I focuses on the influences of logging quota restriction and non-timber products of forests on timber production with a stylized model. In fact, the key factors that influence timber supply are ranging from the biophysical productivity of forests, the economic environment to prevailing social values.[6] To examine timber supply in the scale of a country also requires full consideration of these possible determinant variables. Thus, the econometric specification is set up as following:

$$\ln Y_{it} = \alpha + \beta_1 \ln P_{it} + \beta_2 \mathrm{NFC}_{it} + \beta_3 \ln L_{it} + \beta_4 SC_{it} + \beta_5 \ln I_{it-1} + \beta_6 \ln W_{it} + \beta_7 R_{it} + \mu_i + \varepsilon_{it} \quad (24)$$

Where *i* is the province; *t* is year. Table 1 presents the descriptions of variables used in (24).

Table 1 Descriptions of variables used in equation (24)

	Description
P	trade price of round wood in local markets
NFCP	policy dummy which is 1 when logging of the province was restricted by Natural Forest Conservation Program (NFCP) (first introduced in 1998)
L	logging quota allocated to a province
SC	ratio of the area of state owned forests to that of collectively owned forests
I	forest inventory
W	average wage of forest workers
R	ratio of average wage of forest workers to local average wage

The data of round wood output and forest inventory both come from the official statistical yearbooks of Chinese forestry. The prices of round wood come from the Price Monitor Center under National Development and Reform Commission. The wage data is given by China Statistical Yearbook.

In estimating unobserved effects of panel data, either the Fixed-effect model or the Random-effect model can be used based on different assumptions about the unobserved effects. If the unobserved effects μ are assumed to have some correlation with the regressors, the random effects model would be inconsistent while the Fixed-effects model is consistent. If the unobserved effects are assumed to have no correlation with the regressors, both models would be consistent though the

[5] Northeastern China Region includes Heilongjiang, Jilin, Liaoning and Inner Mongolia, a net supply region where timber production is more than timber consumption; Southern China Region includes: Jiangxi, Fujian, Hunan, Guangdong, Sichuan, Chongqing, Yunan and Guangxi, a net supply region as well. Rest of China includes all the provinces in China besides listed above and Tibet, Hainan, Hong Kong, Macau and Taiwan, a net consumption region where timber production is less than consumption.

[6] See Williams (1994).

Random-effects estimation would be more efficient since both the within-group (time series) information and the between-group (cross-sectional) information will be utilized, while the Fixed-effects estimation only incorporates the within-group information. In this analysis, Hausman tests suggest that there are systematic differences between the Fixed-effects estimators and the Random-effects estimators, thus the latter would yield inconsistent coefficients.

Table 2 presents the estimation results with a balanced panel of 28 provinces for 15 years. Table 3 presents the estimation results using the same econometric model with three panels of different regions. Generally speaking, the estimation results are consistent in both settings. NFCP has significant negative impact on round wood output, while logging quota is positively correlated with the ultimate output of round wood. In other words, if logging quota increases 1%, output of round wood would increases about 30%. The result verify the fact that present logging quota in China is too low that forests owners tend to produce timber according to how much they are allowed to[7]. Wage of forest workers, as one part of the costs to produce round wood, influences the output negatively. In contrast, the relative wage of forestry workers comparing to other industries has positive correlation with round wood production. That is to say, the higher relative wage of forestry is, the more willing people are involved with timber production, thus higher timber supply. Another interesting variable is *SC*, the ratio of the area of state owned forests to that of collectively owned forests.

Table 2 Estimation results with balanced panel data of 28 provinces

	Output of Round Wood		
	POOL	FE	RE
Log Price of round wood	-0.213	0.186	0.106
	(1.83)*	(1.70)*	(0.98)
NFCP	-1.276	-1.106	-1.077
	(6.69)***	(10.44)***	(10.57)***
Log Logging quota	0.795	0.288	0.416
	(17.10)***	(4.03)***	(7.18)***
State-owned forests	0.033	0.020	0.020
/collectively owned	(5.05)***	(1.22)	(1.65)*
Log Forests Inventory	-0.147	0.172	0.217
(one-year lagged)	(2.72)***	(1.70)*	(3.09)***
Log Forest wage	-0.029	-0.218	-0.219
	(0.27)	(2.11)**	(2.16)**
Forest wage/	0.004	0.008	0.008
average wage	(1.37)	(3.32)***	(3.42)***
observations	392	392	392
R^2	0.79	0.43	
Number of provinces		28	28
Chi value of Hausman test		22.97	

[7] This is the case that the solution to the optimal control model is not corner solution: $\mu^* \neq 0$.

Note: *significant at 10%; **significant at 5%; ***significant at 1%.

The estimation results in Table 2 show that whether forests are state owned or not is not significantly related to the output. While in Table 3, the results indicate that the ratio and round wood output are negatively correlated, particularly in Southern China, where more forests are collectively owned. Heteroskedasticity may be the reason for the insignificance of the parameter in the estimation using whole panel data of 28 provinces.

III. Conclusion

This paper illustrates the impact of logging quota and non-timber products on timber products in Part I by optimal control models. If logging quota is low, a compliant forest owner would harvest timber at a level below optima. The value of non-timber products in a forest can be taken as a tradeoff of timber production. The more non-timber products values, the less timber would be produced. The results are consistent with general understanding and other optimal rotation age models.

Empirical regressions in Part 2 confirm that China's logging quota system is highly restrictive to wood output. Natural Forest Conservation Program is another policy factor that resulted in the reduction of round wood output. The impact of NFCP is mainly on southern China, where most provinces are involving in the program, while the impact of logging quota system is country wide.

Table 3 Estimation results in three regions

	Output of Round Wood					
	Consumption Region		**Northeastern Supply Region**		**Southern Supply Region**	
	POOL	FE	POOL	FE	POOL	FE
Price of round wood	-0.153	0.156	0.290	0.119	0.315	0.378
	(0.89)	(0.99)	(2.61)**	(0.94)	(4.14)***	(2.82)***
NFCP	-1.069	-1.162	0.202	0.050	-1.740	-1.715
	(5.28)***	(8.42)***	(2.25)**	(0.64)	(6.25)***	(9.10)***
Logging quota	0.827	0.314	0.381	0.284	0.433	0.393
	(8.51)***	(3.34)***	(6.73)***	(5.71)***	(3.52)***	(2.55)**
State-owned forests	-0.044	-0.028	-0.002	0.002	-1.258	-0.847
/collectively owned	(2.11)**	(0.22)	(0.81)	(0.40)	(3.02)***	(2.84)***
Forests Inventory	-0.366	1.554	0.381	1.144	0.002	0.075
(one-year lagged)	(3.20)***	(4.39)***	(5.78)***	(2.01)*	(0.05)	(0.95)
Forestry wage	-0.234	-0.464	-0.322	-0.285	0.103	0.195
	(1.88)*	(3.24)***	(3.42)***	(2.78)***	(1.07)	(1.10)
Forestry wage/	0.010	0.007	0.005	0.005	0.020	0.026
Average wage	(2.86)***	(1.96)*	(3.08)***	(3.24)***	(5.53)***	(6.25)***
observations	238	238	56	56	98	98
R^2	0.75	0.49	0.96	0.72	0.80	0.75
Number of provinces		17		4		7

Note: *significant at 10%; **significant at 5%; ***significant at 1%.

State-owned forests seem to have lower productivity than collectively owned forests, particularly in northeastern China, where most forests are traditionally owned by state. But northeastern China is also a region that marginal increase of forestry wage would motivate timber production most. It might be explained by the fact that tertiary industry in northeastern China is less developed and skilled workers do not have many job choices. The value of non-timber products has not been able to be included in the empirical study. The main reason is that few forest owners in China have recognized the importance of environmental value of forests. And non-timber products actually have not been considered when they are making harvest decisions. Another subtle reason is that there is not a proper variable to measure the value of non-timber products. Actually, China has implemented forests ecological benefit compensation system since 2001. The compensation fund, however, is too low to cover the loss of reduced harvest. Moreover, only a small proportion of forests across China have been included in this compensation system. It might be better to perfect the system rather than restricting logging by written quota. Simply put, if the eco-compensation fund is raised to a level that equal to the price of timber, the incentive for forest managers to over logging would naturally die.

In addition, all R^2 of these regressions are over 70%, which means that the explanatory variables of the supply functions can explain more than 70% of the variance of round wood output. Hence, the supply functions introduced in this analysis is reliable to predict future output of round wood in China.

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Projection of Timber Supply & Demand Trends in China

Based on an Econometrics Model

Abstract: Econometrics model (simultaneous regression) is applied to estimate China's round wood supply and demand. The projection of China's round wood supply and demand is made until 2020. Results show that round wood supply in China increases at a higher rate than round wood demand, which results in a gently growth of China's round wood import.

1. Overview of China's timber market

China's timber market became a significant part of the world timber market, with both domestic timber demand and productivity of timber processing industry rising quickly in a very short period. Currently China is the world second largest timber import country behind Japan. The annual value of forest products import in China was more than 10 billion USD in recent years, and it has become the third largest foreign exchange user behind oil and steel. At the same time, China is a large forest product export country as well. At present, with the rapid export growth of wood-based panel, China has become the world second largest panel producing country after US. Comparing export volume in 2002 and 2005, plywood export increased more than 3 times, and moreover, fiberboard export increased more than 17 times in the three year span. In addition, furniture export experienced 30% annual increase in the past ten years, and the total value of furniture export reached 14 billion USD in year 2005. China seems to be on her way to become the largest furniture export country in the very near future. In the context of economic globalization, China's wood production and demand is an influential factor for world forest resource protection and timber price fluctuation. Therefore, dynamics of China's timber market has been of major interest for many scholars and research institutions.

After a long term growth period, the volume of China's timber production[8] dropped abruptly in 2001, according to "*Statistical Yearbook of China's Forestry*" (1989-2003) issued by State Forestry Administration. This can be explained by Nature Forest Protection Program (NFPP) implemented by the Chinese government since 1998. Harvesting of natural forests has been strictly prohibited in western China and

[8] Timber production here includes both timber and fuel-wood. Wood-based panel belongs to secondary production, and will be discussed in later chapter.
Data in this study do not include Hong Kong Special Administrative Region, Macao Special Administrative Regions and Taiwan Province.

restricted in northeast China since NFPP implementation. After 2001, timber production in China increased slightly, but still lower than the highest production level before the implementation of NFPP. In the meantime, China's demand for timber has been steadily rising along with rapid economic growth. The gap between demand and production capacity is another reason accelerating growth of timber import. (Figure 1)

2. Division of Market in China and Overview of Market Trends in the Past Two Decades

Constrained by geographic conditions, China's wood production is mainly from state-owned forest areas in northeast and southwest China and collective-owned forest areas in southeast and south China. Collective-owned forests in southeast and south regions are neighboring area and forest farmers in both regions have similar tenure right. Main forest provinces in the southwest, Yunnan and Sichuan, are formally labeled as state forest regions and have been under the influence of Natural Forest Protection Program (largely logging ban in these areas). Nevertheless, in these two provinces collective owned forest areas are bigger than those owned by the state. Due to geographical closeness and the heavy concentration of productive collective forests, we will merge southwest state forest provinces with the rest of the southern collective forest provinces in our later analysis. Therefore, the consolidated southern regions (including southeast, south and southwest provinces) are to be named as southern timber production area in this study. Other regions including central and northwest China are forest resource scarce area and forestry industries are not prosperous there as well. These regions are considered as net consuming area[9]. Then again, we will put northeast provinces (Helongjiang, Jilin, Inner Monglia and Liaoning) as a separate timber production region. See figure 2.

[9] In my study, the Northeast timber production areas include: Liaoning, Jilin, Heilongjiang, Inner Mongolia. South timber production areas include: Jiangxi, Fujian, Hunan, Yunnan, Guangxi and Sichuan. Other provinces are net timber consuming areas. The criteria to group these areas is the average net production （production less consumption）: the average net production in production area is positive, while the average net production in consumption area is negative. The original data of average net production is listed in Table 3 in Annex.

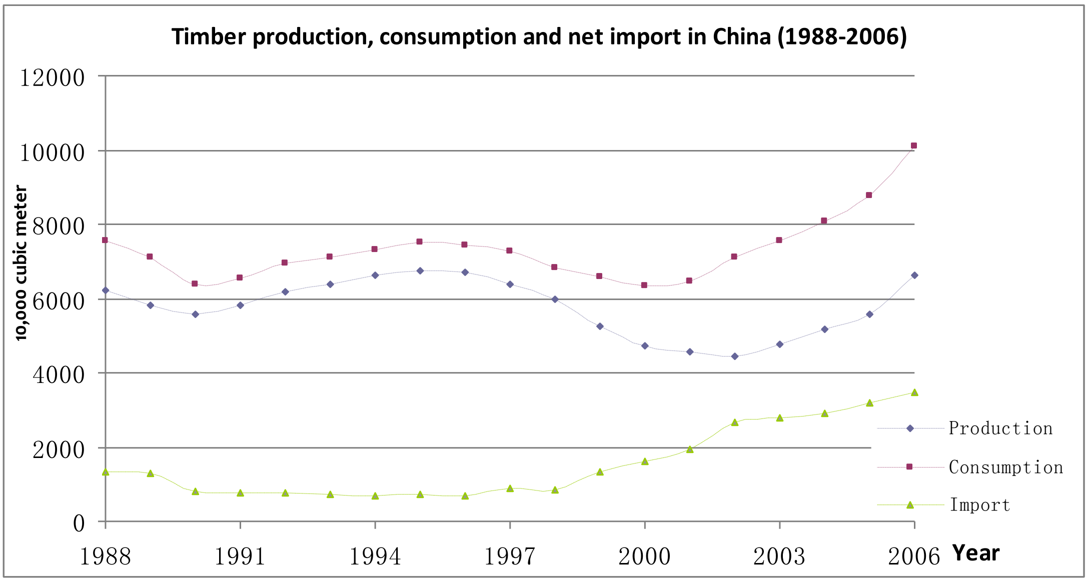

Figure 1 Timber production, consumption and net import in China (1988-2006)

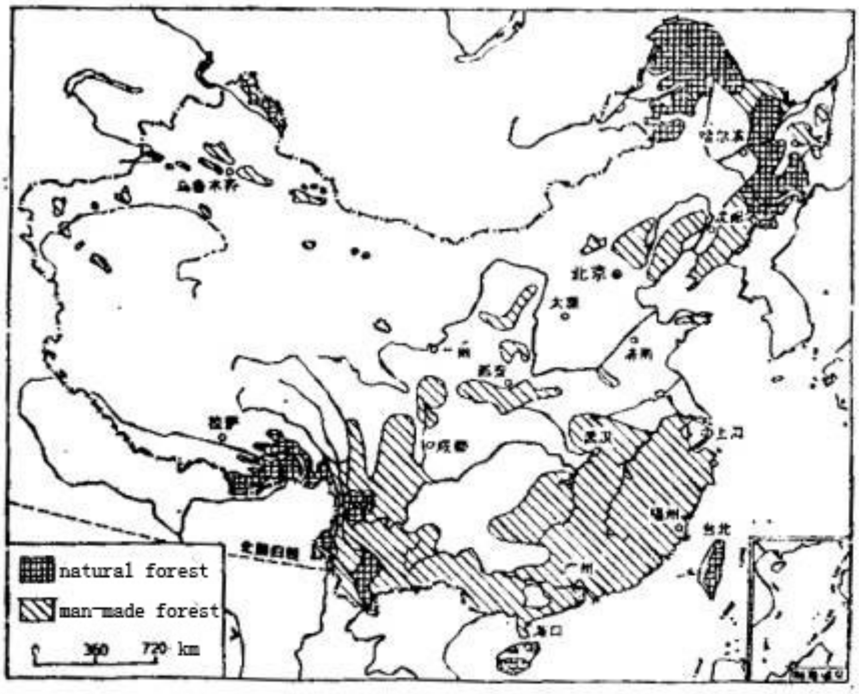

Figure 2 Timber production situation by different areas in China

Analyzing timber production trends based on areas classification， we can see that, timber supply in central consuming region (region one) and northeast state-owned forest region (region two) has been relatively stable. Meanwhile, in southern timber supply region (three), timber production increased significantly since 2000, and has become the main supplier in place of northeast areas. Two reasons lead to this change. Firstly, the decline of timber production in northeast state forest region was persistent due to resource degradation and failure of reforestation. Since year 2000, Natural

Forest Protection Program imposed strict logging restriction and further reduced allowable cut in the region, therefore the greater decline lately. On the other hand, afforestation in southern timber production areas has been rather successful since early 1980s, after the implementation of forest production responsibility reform (individualization of forest tenure) in majority of the collectively owned forest areas. Forest volume in south China as a whole grows significantly, so is the timber production capacity in recent years. Therefore, timber production in southern areas has increased year by year, and has accelerated in the past six years (Figure 3).

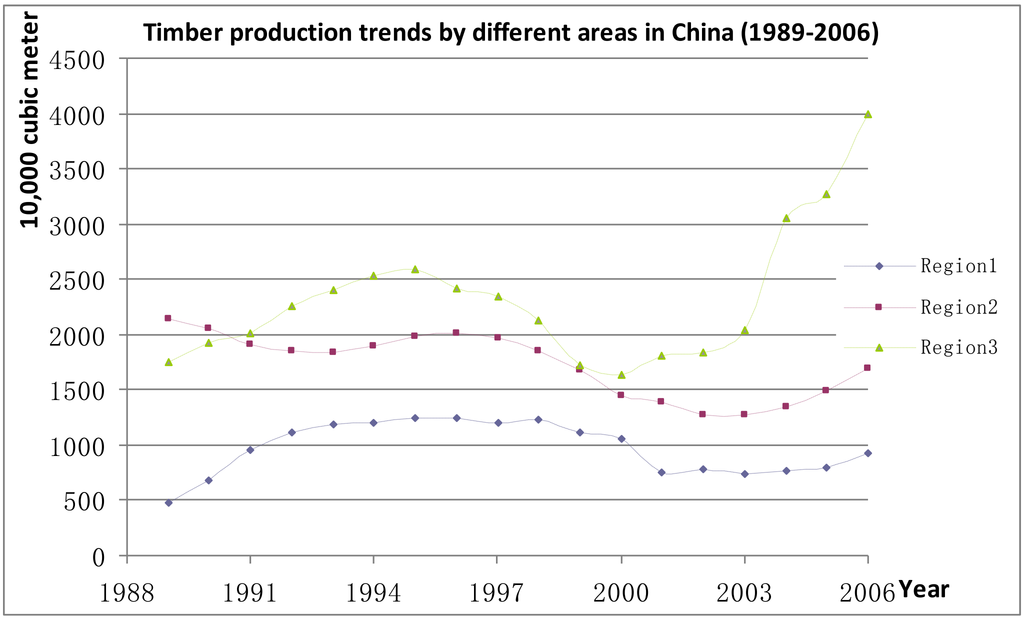

Figure 3 Timber production trends by different areas in China (1989-2006)

(I am assuming regions one=central consuming region; region two=northeast production regions; region three=southern production region)

Analyzing timber consumption trends based on areas classification，we can see that, timber consumption in northeast state-owned forest areas (region two) has been relatively stable. Meanwhile, in southern areas (region three) and central areas (region one) the volume of timber consumption shows apparent increase trends, especially the consumption in central consuming areas, it has maintained at an average 5 per cent growth rate annually since 2001. (Figure 4)

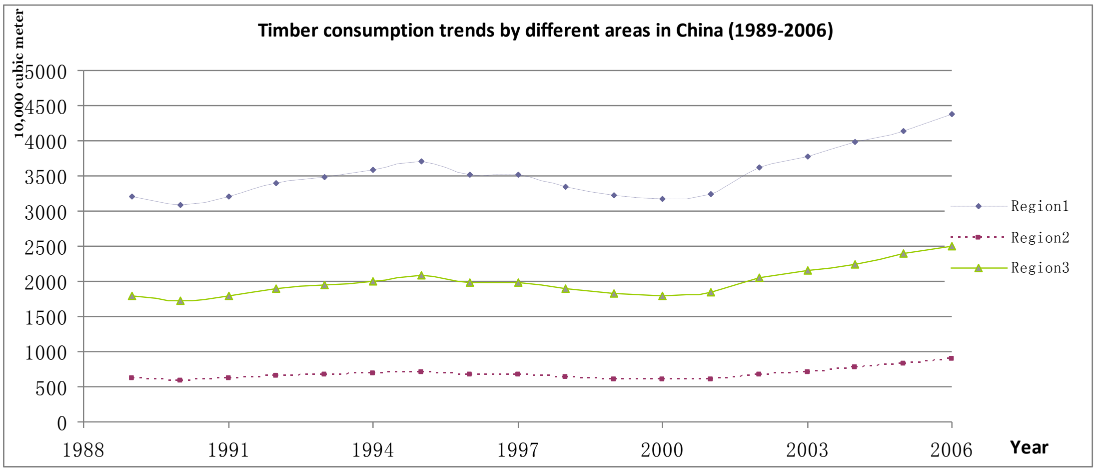

Figure 4 Timber consumption trends by different areas in China (1989-2006)

Sawnwood production in China has experienced more changes than timber production. In 1995, the production volume reached 40 million cubic meters, while in 2000 the number decreased to 6.34 million cubic meters. On the one hand, sawnwood production has been constrained by timber supply, and has been influenced by NFPP as well. On the other hand, the changing trends between sawnwood production and timber supply were similar, but sawnwood fluctuated more. Actually, this is the most important difference between primary market and secondary processed timber market when facing resources constrain. Secondary market could be influenced more by resources scarcity than primary market. Since secondary markets compete to obtain raw material, resource scarcity in one secondary market would be accelerated by the competition for raw material in other secondary markets. Moreover, after China's timber market transited from plan oriented to demand-supply oriented, all kinds of processed timber products are not only experiencing pressures from market demand, but also facing competition with other processed products for primary materials. Thus, the changing trend for timber product is more complicated. (Figure 5)

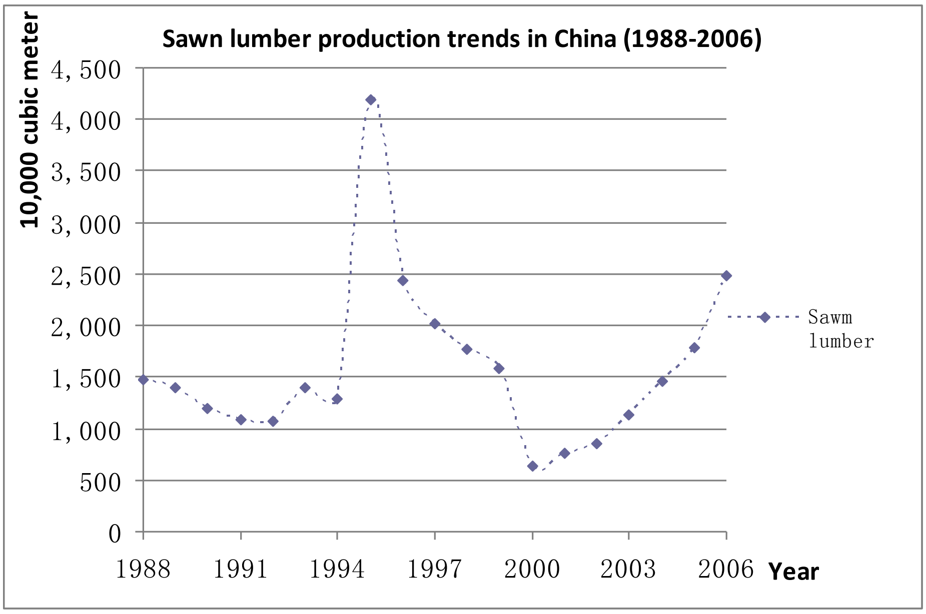

Figure 5 Sawn lumber production trends in China (1988-2006)

Similarly, the production trend of wood-based panel in China is more complicated comparing with timber supply trends. Generally the production of wood-based panel in China can be roughly divided into three periods: 1988-1994, plan-oriented production period of wood-based panel. The market was not yet fully opened up during this period, and production volume was relatively stable; 1995-1999, initial period of market liberalization. The market was not stable, and production was fluctuated, but shown a clear upward trend overall; Since year 2000, the golden period of wood-based panel production. Different from timber production, the wood-based panel has not been affected much by the implementation of NFPP. Actually, the production volume increased rapidly instead. From 2002 to 2006, the production of plywood and particle board has doubled and fiberboard production experienced an astonishing growth of four times. (Figure 6)

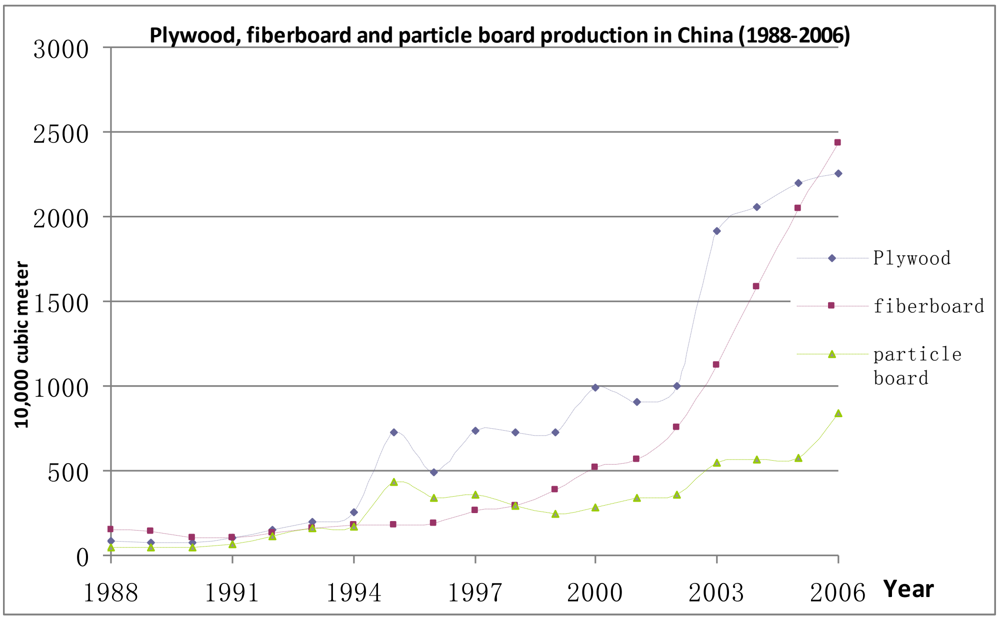

Figure 6 Plywood, fiberboard and particle board production in China (1988-2006)

From the above figures we can see that China's timber production and processed timber product market has discarded plan-economy characteristics gradually and maturated progressively in the recent 20 years. However, how to predict the future changes in China's timber market based on historical information is a more significant issue to be considered. Firstly, influential factors effecting timber market behaviors in previous researches includes macroeconomic situation, forest resources and social preferences, such as government and public awareness to environmental protection, preference of material selection, etc. Secondly, China has a unique forest tenure right system and strict harvest control system, this special context made timber market analysis more complicated. Thirdly, forest resources are abundant in northeast, southeast and southwest China. However, there is a large demand of timber in eastern and central areas in China because of rapid economic development. Therefore, there is not only international timber and processed timber import and export with other countries, but also internal timber trade among different regions. For predicting the future changes in China's timber market, it is important to understand the scale, activities and impact of each sub-trading region separately in the China timber market context.

3. Description of Methodology and the Model

We explored in two directions to make reasonable projection of China's future supply in timber. One is based on a price spatial equilibrium framework (Samuelson 1976) and another is a simple simultaneous system of supply and demand system estimated through econometric methods. In the spatial equilibrium model, the equilibrium price of an efficient market with spatial distribution of producers and consumers would be the result of minimizing the transportation costs, which is also equivalent to that of maximizing the welfare of both consumers and producers less the transportation costs. A spatial equilibrium model hence could solve for the equilibrium price and quantity traded among regions. Before the problem being solved, however, a base estimation of production of the market should be achieved as the initial point to solve spatial distribution.

In the analysis of timber demand and supply behavior in China, the following model is used:

$$\begin{cases} D_{it} = f(P_{it}, \Phi, \varepsilon_{1it}) \\ S_{it} = f(P_{it}, \Theta, \varepsilon_{2it}) \\ D_{it} = S_{it} = Q_{it} \end{cases}$$

Where Sit is the timber production in province i of year t, Dit is the timber consumption in province i of year t. Θ is a vector that denotes the determinants of timber production including average timber price, the inventory of China's forests, ratio of State-owned forests area to collectively owned forests area, average forestry wage, ratio of average forestry wage to average social wage, dummy variable of Natural Forest Protection Program, logging quota. Φ is also a vector that denotes the determinants of timber consumption including average timber price, GDP, price index of metal industry, house area under construction, rural income per capita, urban income per capita, and urbanization index. With the panel data of 30 provinces from 1989-2003, we estimated the supply function of China's timber. (Results are illustrated in table 1).

Table 1. Estimation of China's Timber Production and Consumption System

	China's Timber Consumption	**China's Timber Production**
Average timber price	-0.061	0.370
	(1.82)*	(2.16)**
GDP	0.094	
	(2.90)***	
Price index of	0.039	
metal industries	(1.71)*	
House area under	0.019	
construction	(5.95)***	
Rural income per	-0.199	
capita per year	(8.73)***	
Urban income per	0.099	
capita per year	(3.46)***	

Urbanization index	0.024	
	(2.24)**	
Timber consumption	0.641	
(one year lagged)	(14.33)***	
Dummy variable of NFPP		-1.092
		(10.74)***
Logging quota		0.256
		(3.46)***
Ratio of State-owned forest area		0.022
to collectively owned forest area		(1.42)
Forests inventory		0.159
(one year lagged)		(1.64)*
Average forestry wage		-0.323
		(2.63)***
Ratio of average forestry wage		0.008
to average social wage		(3.67)***
samples	392	392

4. Demonstration of Results

Based on the estimated production and consumption of China's timber market, some rough projection of China's timber markets can be made with some basic hypothesis

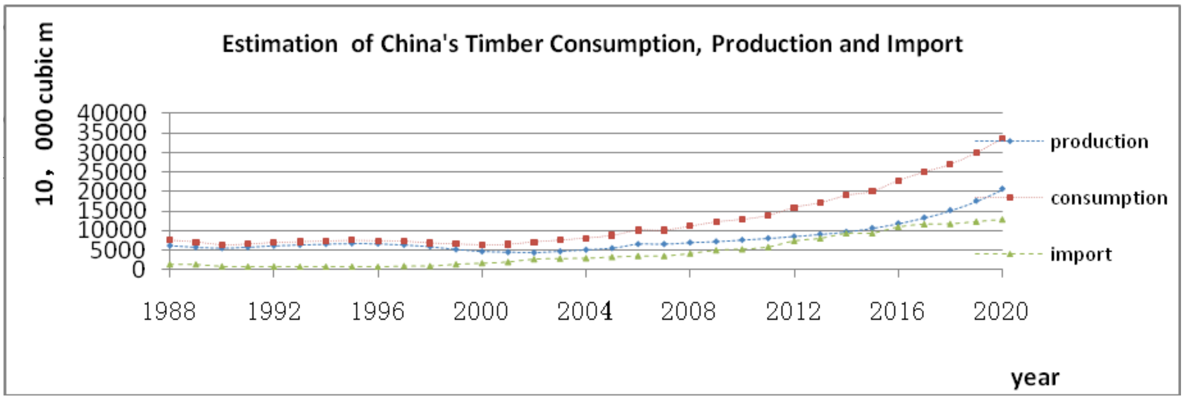

Figure 7 Projection of China's Timber Market to 2020

In this simple but reasonable setting, China would still rely on import timber in the next decade. The difference between domestic timber production and demand would

[10] 5% is the average growth of average forestry wage rate during 1989-2003.

[11] For simplicity, import here is equal to consumption less production, which is also the net import （the real import would be the projected net import plus real export）.

be stabilized from 2015. The difference, however, would be 3 times larger than that in 2005. To cover the shortage of domestic timber production, China may have to lessen the strict logging quota system on one hand and develop new technology in architecture to reduce the use of woods or invent new materials as substitutes of timber on the other hand. The projected quantity of timber production, consumption and import is in table 2:

Table 2. Projected quantity of timber production, consumption and import

Year	**Production(10,000m3)**	**Consumption (10,000m3)**	**Import (10,000m3)**
2007	6611.78	10083.99	3472.21
2008	6997.099	11108.08	4110.978
2009	7268.627	12236.16	4967.537
2010	7653.137	12853.43	5200.293
2011	8079.834	13850.53	5770.696
2012	8556.936	15920.3	7363.364
2013	9094.299	17098.53	8004.231
2014	9703.746	18990.4	9286.654
2015	10654.49	19994.54	9340.054
2016	11836.03	22789.35	10953.32
2017	13317.24	24968.54	11651.3
2018	15187.66	26921.55	11733.89
2019	17563.68	29876.43	12312.75
2020	20596.58	33458.16	12861.58

Admittedly, the projection here did not take into consideration some complex but crucial factors that may significantly change projection results, such as technology innovation and the change of social value. We focused on the economic determinants since they are more visible and can be quantified. The projection of China's timber market in region level and specific projection of timber import of China will come out soon after the SPE model is completed.

Annex: Description of Data used in the econometric model.
Provincial timber production data from 1985-2003 is from "*Statistical Yearbook of China's Forestry*", 1985-2003, China Forestry Press.

Provincial timber consumption data is derived after following steps:
(1) Calculating national consumption, which equals to the sum of domestic timber production and net import (import less export);
(2) For each province, calculating the sum of the production value of wood-processing industry, housing industry and paper industry and weight 1-3

as the proportion of each industry to the sum.

(3) Ranking weight 1-3 among provinces.

(4) Calculating weight 4-6 as the contribution of each province in each of the three industries.

(5) The final weight of each province in the national timber consumption equals to weight 1* weight 4+weight 2* weight 5+weight 3* weight 6.

(6) Provincial consumption = national consumption * final weight.

Part of explanatory variables data in the econometric model – GDP, price index of metal industry, house area under construction, rural and urban income per capita per year, average social income, average social wage – is from "*Statistical 50 years of New China*", China Statistic Press; some explanatory variables data – dummy variable of NFPP, logging quota – is from official documents issued by State Forestry Administration; and other determinants data – average forestry wage, forests inventory – is from "*Statistical Yearbook of China's Forestry*", China Forestry Press as well.

Import and export data is from FAO: the quantity of timber import and export used in this article is that of industrial roundwood in FAO database.

Table 3 Average net production of each province

unit：10,000 cubic meters

Province	Net Production	Province	Net Production
Beijing	-1027.1959	Fujian	4358.693
Tianjin	-715.3702	Jiangxi	1775.495
Hebei	-4004.903	Shandong	-3945.1085
Shanxi	-1409.215	Henan	-2975.6855
Inner Mongolia	5167.0453	Hubei	-1977.046
Liaoning	-1182.414	Hunan	1273.753
Jilin	5757.33	Guangdong	-1813.4535
Heirongjiang	8718.67	Guangxi	2510.687
Shnaghai	-1534.5055	Sichuan	-71.1125
Jiangsu	-4295.464	Guizhou	-894.04415
Zhejiang	-787.0925	Yunnan	1488.2285
Anhui	-344.766	Shan'anxi	-824.44615
Ningxia	-131.3044	Gansu	-742.5993
Xinjiang	-602.2595	Qinghai	-184.14065

Spatial Price Equilibrium Model of China's Round Wood Market

Abstract: Two major modeling approaches for timber market are introduced and a China's round wood model is set up based on SPE theory. Simulation results show that basic trend can be captured by this model and the average deviation from simulation results to real values is less than 10%. However, more work need to be done to improve the present model.

Introduction

To model timber market, there are two typical ways: one is based on Spatial Price Equilibrium (hereinafter as SPE) theory and the other is Optimal Control approach. Table 1 illustrates similarities and differences of the two modeling method.

Table 1. Comparison of SPE and Optimal Control Method

	Objective Function	Demand Function Estimation	Foresight	Assumption	Supply Function Estimation	Track Regional Trade
SPE	Maximize welfare in each period independently	Yes	Yes	No	Yes	Yes
Optimal Control	Maximize net present value of welfare in all periods	Yes	Yes	A rational decision maker who maximize future welfare	Yes	No

Some widely used timber market models are listed as bellow:
(1) North American timber market models: including Timber Assessment Market Model (TAMM) and North American Pulp and Paper Model (NAPAP).
(2) Global timber market models: including CINTRAFOR Global Trade Model (CGTM) and Timber Supply Model (TSM).
A comparison of the four timber market models is demonstrated in Table 2.

Table 2. Comparison of Four Widely-used Timber Market Models

	TAMM	NAPAP	CGTM	TSM
Theory	SPE	SPE	SPE	Optimal Control
Scope	North America	North America	Global	Global
Regions	8	8	40	22
Track Regional Trade	Yes	Yes	Yes	No
Market Structure	Multi-level	Multi-level	Multi-level	Delivered Log

Harvest Mechanism	No	No	No	Oldest Timber
Endogenous Management	No	No	No	Yes

According to Table 1 and 2, optimal control model and SPE model have their own advantages, but optimal control model cannot track regional trade, which is a weakness that should not be ignored for our research purpose. Since China is an important trader in global timber market, we chose SPE as modeling basement to capture possible timber trade trend within China and thereafter between China and rest of the world.

Methodology

SPE theory solves the following objective function:

$$\text{Max} \sum_i \int_0^{D_i} P_i(D_i)dD_i - \sum_j \int_0^{S_i} P_j(S_j)dS_j - \sum_i \sum_j d_{ij}T_{ij}$$

Where i is demand region, j is supply region. P_i and P_j represent adverse supply function and adverse demand function respectively. d_{ij} is transportation cost of unit product from demand region i to supply region j. T_{ij} is the transporting amount from i to j. The objective function subjects to that total supply of supply regions are not more than their production, demand of each demand region can be satisfied and all transportation, demand and supply are not negative, which is as follows:

$$s.t. \quad \sum_i T_{ji} \le S_j \quad \forall j$$

$$\sum_i T_{ij} \ge D_i \quad \forall i$$

$$D_i, S_j, T_{ij} \ge 0 \quad \forall i, j$$

Compared with traditional demand function and supply function, SPE theory can obtain equilibrium price and equilibrium consumption of each region simultaneously, therefore, equilibrium consumption not only relies on local price, but also prices of other regions. It is an advantage of SPE model to optimize consumption of several regions at the same time.

Based on the estimation of demand function, supply function of each region, we can thereby set up a SPE model not only to obtain static equilibrium price and consumption of China's round wood market, but also to simulate the trade within the market and forecast its trend.

Assume demand function of demand region i is:

$$D_{i,t} = (e_{it}P_{it})^{\sigma_{it}} X_{d1it}{}^{\delta_{it}} X_{d2it}{}^{\tau_{it}} X_{d3it}{}^{\alpha_{it}} D_{i,t-1}{}^{\eta}$$

Similarly, assume supply function of supply region *j* is:

$$S_{i,t} = (e_{it}P_{it})^{\lambda_{it}} X_{s1it}{}^{\rho_{it}} X_{s2it}{}^{\mu_{it}} X_{s3it}{}^{\phi_{it}} I_{i,t-1}{}^{\psi} S_{i,t-1}{}^{\xi}$$

Where $D_{i,t}$ and $D_{i,t-1}$ represent round wood demand in region *i* at period *t* and period *t-1* respectively;

$S_{i,t}$ and $S_{i,t-1}$ represent round wood supply in region *i* at period *t* and period *t-1* respectively;

$e_{i,t}$ is the exchange rate, which equals to 1 in our model since we consider China only;

$P_{i,t}$ is round wood price at period *t*;

$X_{d1i,t}$, $X_{d2i,t}$ and $X_{d3i,t}$ represent three exogenous variables influencing round wood demand in region *i* at period *t* respectively;

$X_{s1i,t}$, $X_{s2i,t}$ and $X_{s3i,t}$ represent three exogenous variables influencing round wood supply in region i at period t respectively;

$I_{i,t-1}$ is the stand volume of region *i* at period *t-1*;

$\sigma_{it}, \delta_{it}, \tau_{it}, \alpha_{it}, \eta$ represent demand elasticity to corresponding dependent variables respectively;

$\lambda_{it}, \rho_{it}, \mu_{it}, \phi_{it}, \psi_{it}, \zeta$ represent supply elasticity to corresponding dependent variables respectively.

Then we need to solve a static problem, to find an optimal equilibrium, the key to which is an optimal transportation matrix $T_{ij,t}$ that maximize the following equation:

$$F_t = \sum_i Zd_{it} + \sum_j Zs_{jt} - \sum_i \sum_j 1/2 * (d_{i,j,t} * |T_{ij,t}|)$$

Where Zd_{it} is consumer surplus in region *i*; Zs_{jt} is producer surplus in region *j*; d_{ij} is the transporting cost between *i* and *j* for one unit round wood; T_{ij} is a vector to represent transportation amount between *i* and *j*.

The process of modeling can be briefly described as bellow:

(1) Set start time points (at least two years).
(2) Set end time point of simulation.
(3) Initial parameters input including elasticity, initial exogenous variables, transporting cost matrix.
(4) Set outside loop iterations according to the end time point as to output simulation results.
(5) Call inside loop iterations as to solve static SPE problem.
(6) Call outside loop iterations to output simulation results by year.

The simulation results consist of three parts: transportation matrix by year, equilibrium price by year and equilibrium consumption by year.

Results

According forestry resources and historical trade information, we divide China's round wood markets into three regions: Northeastern China as region 1; Southern China as region 2; the rest of China as region 3[12].

We chose the first two years, 1989 and 1990, as the start time point. The three explanatory variables of round wood demand in our model are floor space under construction, annual income per capita and urbanization rate, and the three explanatory variables of round wood supply are state-owned forest area to total forest area, average forestry wage and cutting quota.

The simulation results are demonstrated in Figure 1 to Figure 6.

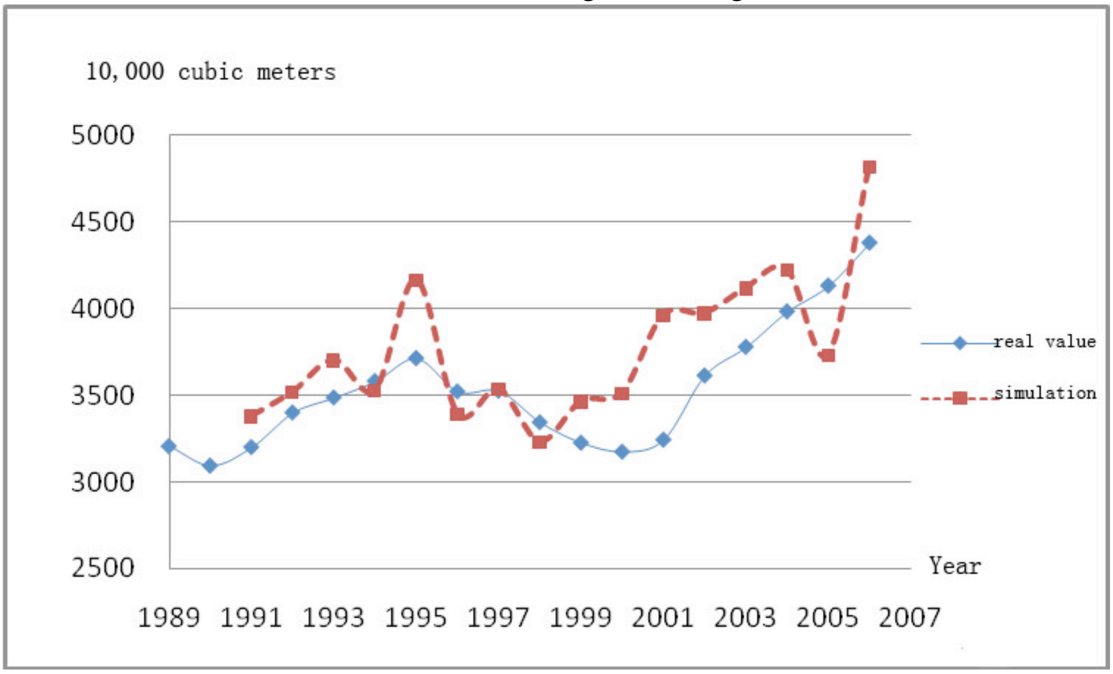

Figure 1. Estimated Equilibrium Consumption of Region 1

[12] Region 1 includes Heilongjiang, Liaoning, Jilin and Inner Mongolia;
Region 2 includes Jiangxi, Fujian, Hunan, Yunnan, Guangdong, Guangxi and Sichuan.
Due to the data Scarcity, Tibet, Hainan, Macau, Hong Kong and Taiwan are not included in our model.

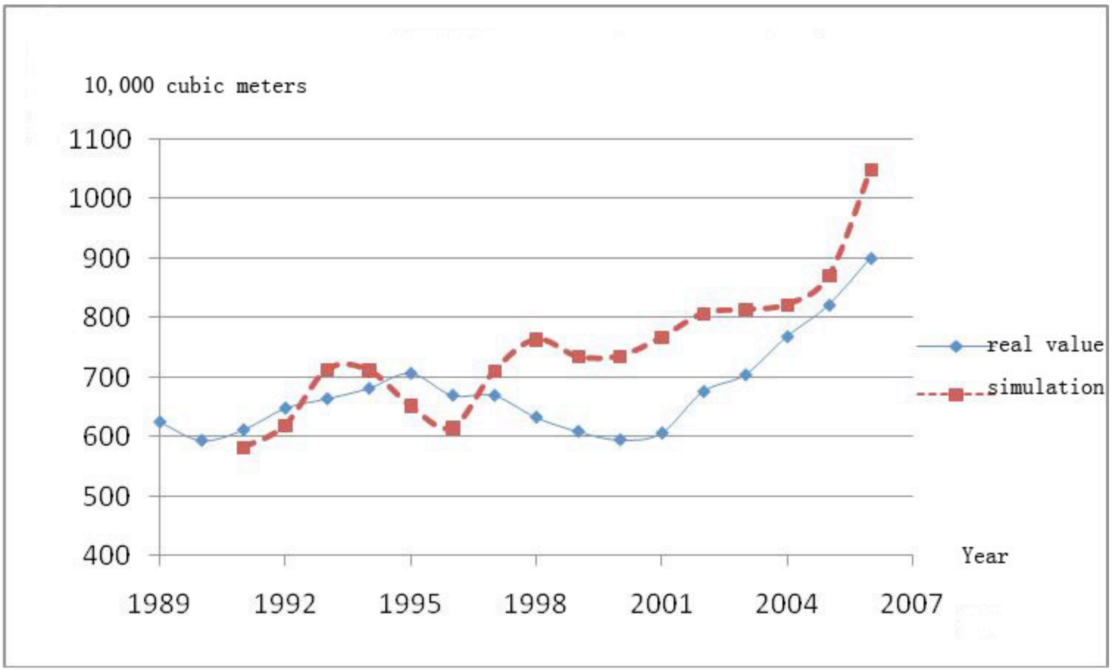

Figure 2. Estimated Equilibrium Consumption of Region 2

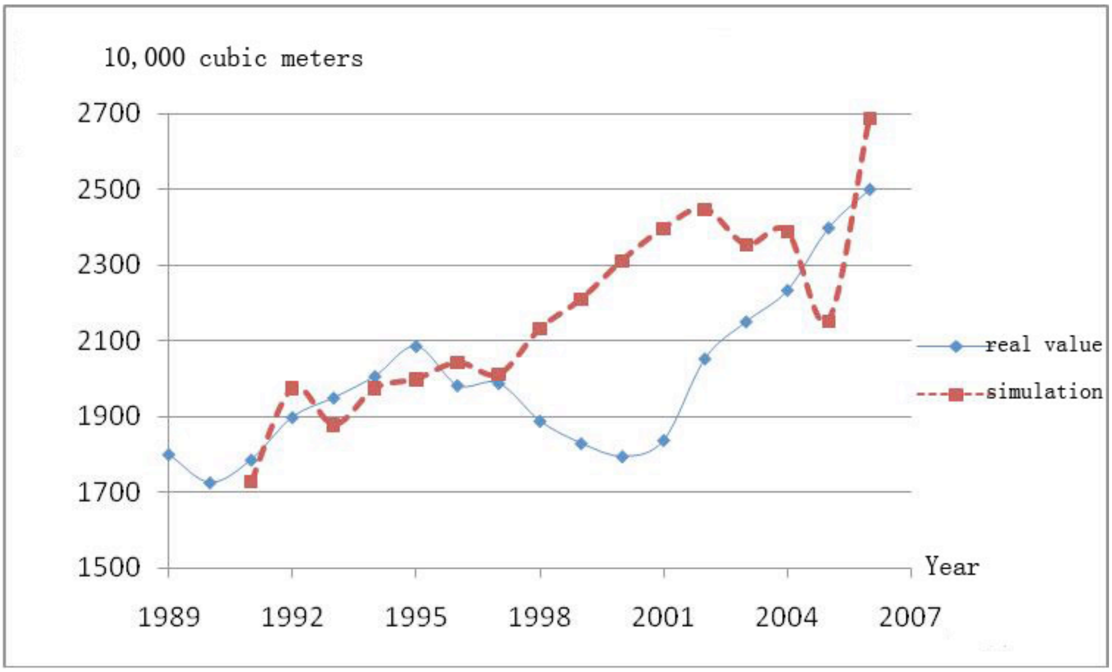

Figure 3. Estimated Equilibrium Consumption of Region 3

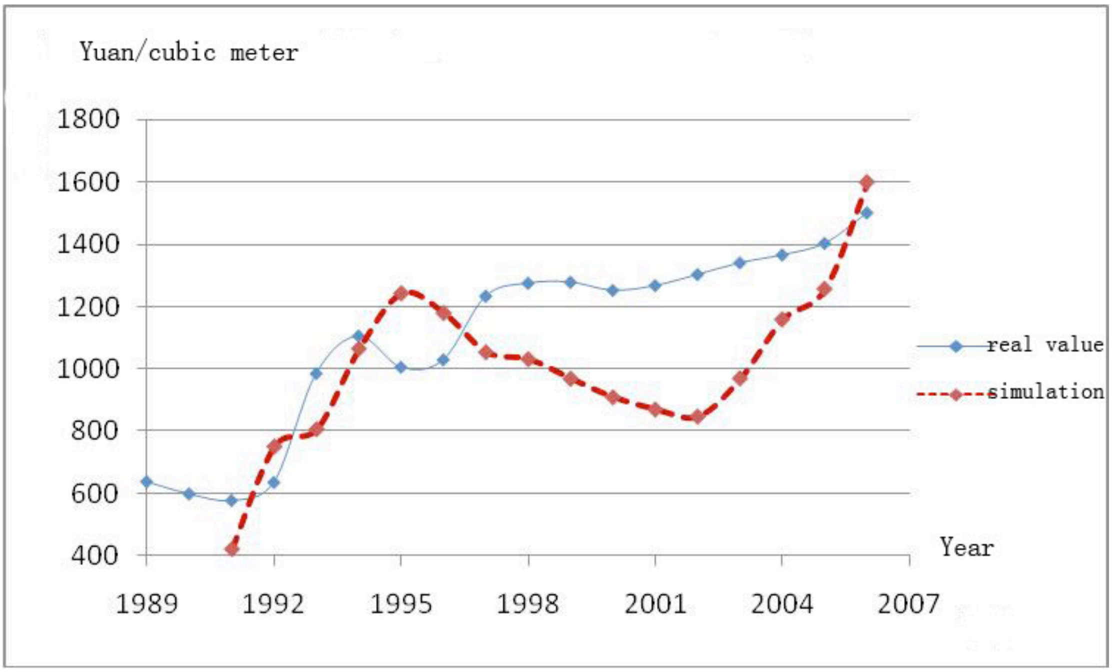

Figure 4. Estimated Equilibrium Price of Region 1

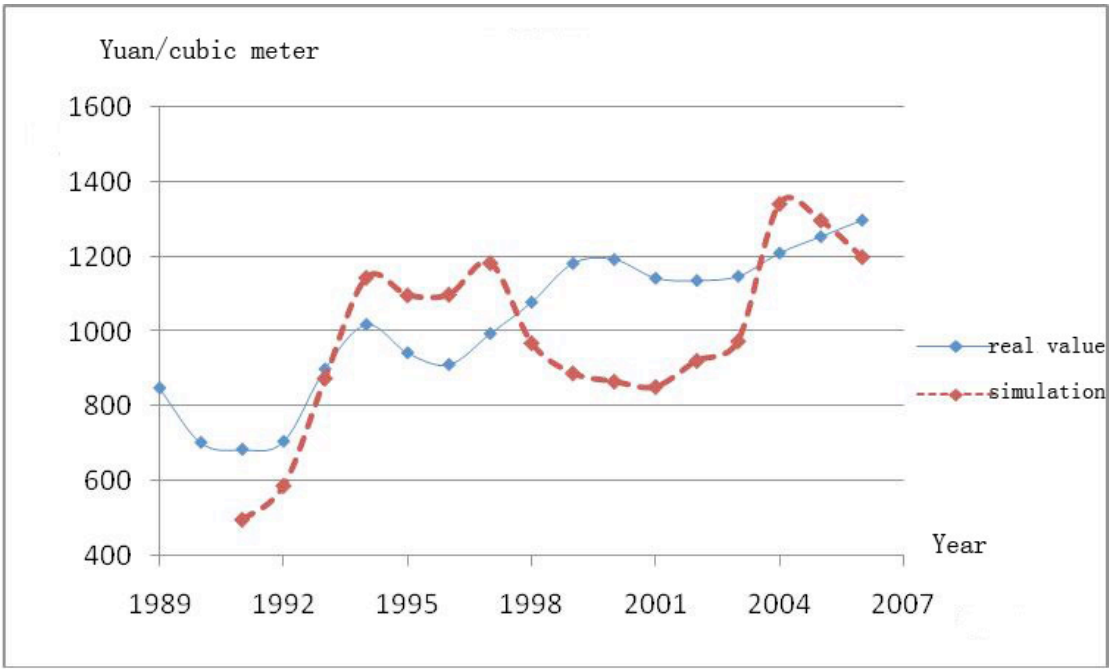

Figure 5. Estimated Equilibrium Price of Region 2

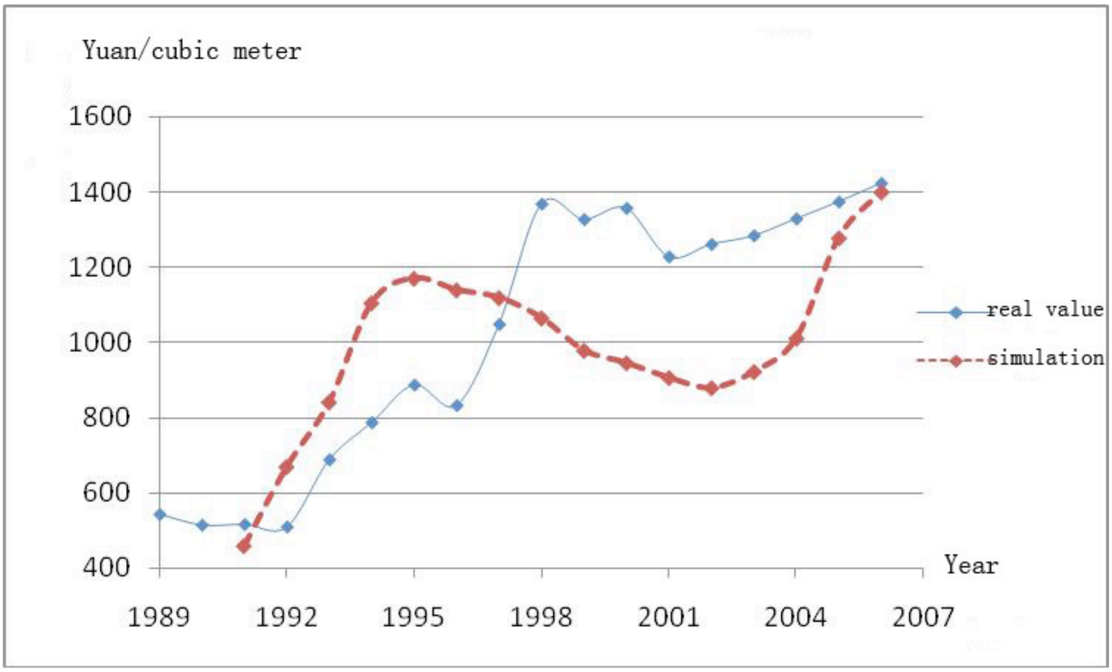

Figure 6. Estimated Equilibrium Price of Region 3

Conclusion

According to Figure 1 to Figure 6, we can see obvious fluctuations and deviations of simulation results compared to real values. The possible reasons are various. The first one may be the choice of explanatory variables. Actually, both round wood demand and supply rely on far more than three variables. It is tricky to select explanatory variables to balance between simulation accuracy and algorithm complexity. The trend and amount of simulation, however, are basically trustable. The average deviation of simulation is less than 10% of real values. By including more explanatory variables and taking transportation cost change into consideration, the simulation accuracy can be highly improved.

Moreover, the present model only focuses on China, which is not a closed system in fact. In the context of globalization, the model is certainly imperfect. The future work of modeling China's round wood market need to include the rest of world as Region 4. In that case, exchange rate and tariff would be another two important variables deserving carefully examination.

Finally, round wood market is only a part of the whole timer market. To set up a China's timber market model, it is still a long way to go even after the round wood market model is well built up. The final timber market model may include component of forest resources, component of wood processing products and macroeconomic environment as well.