Study on the Price Fluctuation and Dynamic Relationship between Log and Sawn Timber

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Abstract

The rapid economic and social growth of China has significantly increased its timber demand, resulting in a heavy reliance on foreign timber supply. Thus, price fluctuation in the international market poses a great risk to domestic timber production and processing enterprises. This study analyzed the dynamic conduction relationship between domestic and international logs and sawn timber markets and how to reduce risks by adjusting the structure of imported products' portfolios. In this article, the multivariate generalized autoregressive conditional heteroskedasticity model is applied to analyze the relationship between domestic and import prices of logs and sawn timber. The study found that among four markets, except one where the short-term spillover effect between domestic logs and sawn timber is large with statistical significance, spillover effects are small. In the long run, there are significant spillover effects between the four markets. Thus, changes in the international log market are very easy to transfer to the domestic log market through trade and then to the downstream domestic and international sawn timber markets. Therefore, in order to ensure timber security in China, this study uses the theory of portfolios to calculate product proportion with minimum risks. The proportion of portfolios indicates that, even though Chinese companies prefer logs, they have to import a great amount of sawn timber due to restrictions on log exports from sourcing countries, which increases the risk of timber supply.

China's economic and social development fueled a substantial increase in timber demand. It is estimated that China's domestic timber consumption will reach 800 million m^3 in 2020, of which 50 percent will be imported. However, China is a country with scarce forest resources. The results of the Eighth National Forest Inventory show that China's forest coverage is only 21.63 percent, which is far lower than the world average of 31 percent (State Forestry Administration 2014). The per capita forest area of China is only 1/4 of the world average, and per capita forest stock volume is only 1/7 of the world average. Among production forests, forests with mature timber for harvesting only account for 13 percent, and the stock volume of mature timber for harvesting only accounts for 23 percent (State Forestry Administration 2014). At the same time, the Chinese government will completely ban commercial logging in all-natural forests during the ''13th Five-Year Plan'' period, which has exacerbated the contradiction between timber supply and demand. In order to alleviate this contradiction, China will need to import a large number of logs and sawn timber. China imported 44.55 and 26.88 million m^3 of logs and sawn timber, respectively, in 2015, accounting for 36.1 and 19.9 percent of the world's total log trade (FAO 2017).

The transmission of volatility is known as spillover volatility (Apergis and Rezitis 2001). The arbitrage of stock and commodity prices across markets should result in volatility transmission between markets. Likewise, arbitrage of a physical commodity between markets may lead to volatility transmission as well (Natcher and Weaver 1999). With the increasing import of logs, the volatility of timber prices in the international market has significantly affected

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the Chinese timber market through trade channels and information transmission. If the volatility does spill over through market channels, policy changes in the primary input market that alter price volatility will have impacts on price volatility through the vertical market chain (Buguk et al. 2003, Lin 2018). For example, in order to protect forest resources, exporting countries represented by Russia have developed their own wood processing industry, and trade protection policies against log export have been issued. Due to a heavy dependence on foreign timber supply, China's timber imports are vulnerable to these impacts on the international market and their effects on the sawn timber market that is the primary source of logs. In order to meet domestic timber demand, Chinese enterprises expanded the amount of imported sawn timber to make up for the shortage of imported logs. So, the spillover of both logs and sawn timber markets, and domestic and international markets shall be considered for decision making.

Increased integration between countries and commodity markets is providing investors with new ways to diversify their investment portfolios. The conditional volatilities from the dynamic conditional correlation generalized autoregressive conditional heteroskedasticity (GARCH) model were used to construct optimal portfolio weights subject to a no-shorting constraint (Kroner and Ng 1998). Sadorsky (2014) used this method to calculate the optimal portfolio between emerging market stock prices and the prices of copper, oil, and wheat. Sharp fluctuation of commodity prices in international and domestic markets has caused risks for both domestic producers and processing enterprises (Lin 2018). Therefore, the optimal portfolio method can be used to determine the proportion of imported products to minimize risks. The study of relations between domestic and import prices of logs and sawn timber in China can point to the volatility characteristics and conduction effect of prices, in order to better manage the risks of importing logs and sawn timber.

Studies on import prices of timber abroad mainly focus on import elasticity; Turner and Buongiorno (2004) analyzed the panel data of 64 countries and concluded that log imports are inelastic in regard to the price. Noce et al. (2010) studied the price elasticity of sawn timber in Brazil and also found a lack of elasticity between price and demand. As the Chinese timber market has been adjusted by the government, early studies on timber price were more focused on the price formation mechanism, including a study by Su and Qi (1994) as well as those of Wang and Li (2002), who analyzed the impact of macro factors on timber price, and Wang and Tian (2013), who studied factors that affect the volatility of timber prices. Chen et al. (2010) used the Cobweb model to analyze the dynamic equilibrium of timber prices.

At present, there are few studies on timber price fluctuation, but research on fluctuations and spillover effects of commodities, stocks, oil, and futures prices can be used for reference. Baffes (2007, 2010), Alghalith et al. (2010), Chang and Su (2010), and other researchers calculated the spillover effect between oil price and 35 primary products on the international market. Hassouneh et al. (2012) verified the spillover effect between Spanish food and energy. At the same time, the study of price fluctuation and spillover has been applied in asset risk management; Kroner and Sultan (1993) calculated the long- and short-term asset hedge ratio based on the dynamic volatility model. Using the multivariate generalized autoregressive conditional heteroskedasticity (multivariate GARCH) model, Kroner and Ng (1998) calculated the dynamic conditional correlation coefficient between variables and the optimal asset portfolio.

Since logs and sawn timber are the main raw materials used in the wood processing industry, and imported logs and sawn timber are necessary for the protection of the timber supply in China, it is significantly important to analyze the impact of domestic and imported logs and sawn timber, as well as how to achieve an effective product mix to solve the contradiction of China's timber supply. This study analyzed the dynamic relationship between domestic and import prices of logs and sawn timber from the perspective of ensuring the security of the Chinese timber supply and calculated the minimum risk portfolio to help enterprises reduce the risks of timber supply.

The Empirical Model

The multivariate GARCH model is widely used in conditional variance matrix analysis, which includes the vech-GARCH[1] model of Bollerslev et al. (1988), the constant conditional correlation GARCH model with fixed coefficients of Bollerslev (1990), the BEKK-GARCH model[2] of Engle and Kroner (1995), and the dynamic conditional correlation GARCH model of Engle (2002). Those models have the same ability as the GARCH model to analyze the fluctuation characteristics of time-series variables in addition to analyzing the spillover relation between multiple time series. Zhang et al. (2009) studied the fluctuating relations of ethanol, corn, and soybean prices to the automotive fuel market. Serra et al. (2011) and others use the multivariate GARCH model to analyze the spillover effect of the alcohol market in Brazil. Nazlioglu et al. (2013) studied the spillover effect between oil and major agricultural products. In this study, we use the vech-GARCH model and the BEKK-GARCH model to analyze the price fluctuation characteristics of the log and sawn timber markets and relations between them and to calculate how to select the appropriate product mix through trading.

The multivariate conditional variance model is given by Equations 1 and 2, where Equation 1 is the mean equation, t is the period, R_t is the random variable of $N \times 1$, μ is the mean value, and e is the random error; H in Equation 2 is the variance matrix of the historical information function, and z is the normalized residual.

Multivariate GARCH model:

$$R_t = \mu_t + e_t \tag{1}$$

Conditional variance of multivariate GARCH model:

$$e_t = H_t^{0.5} z_t \; z_t \sim N(0, I) \tag{2}$$

The main differences among different multivariate GARCH models are the settings of the conditional variance matrix. This study uses the vech model (see Eq. 3) of Bollerslev et al. (1988) and the BEKK model (see Eq. 4) of Engle and Kroner (1995). In Equation 3, *vech* denotes the N

[1] Vech is an operator that stacks the columns of the lower triangular part of its argument square matrix (Silvennoinen and Teräsvirta 2007).

[2] The BEKK model was the Baba-Engle-Kraft-Kroner (BEKK) model defined in Engle and Kroner (1995).

$\times (N+1)/2$ vector of all the unique elements obtained by stacking the lower triangle of the $N \times N$ symmetric matrix, c is the parameter vector, and A and B are the parameter matrices. In Equation 4, C is a lower triangular matrix, and A and B are the square matrices with N^2 parameters.

vech − GARCH(1, 1) model:

$$vech(H_t) = c + Avech(e_{t-1} \cdot e'_{t-1}) + Bvech(H_{t-1}) \quad (3)$$

BEKK − GARCH(1, 1) model:

$$H_t = C \cdot C' + Ae_{t-1}e'_{t-1}A' + BH_{t-1}B' \quad (4)$$

The nondiagonal elements of the coefficient matrices A and B reflect the spillover effect between the various products.

The threshold GARCH (TGARCH) model is an extension of the GARCH model. This model can examine the sudden changes in volatility, indicating that price decline has greater impacts on the fluctuation than price increase, i.e., the leverage effect. In order to analyze whether there is a leverage effect, an asymmetric variable can be added to Equations 3 and 4: $D \odot (v_{t-1}v'_t)$, where $v_t = e_t \odot I$ (I is the identity matrix, $e_t < 0$) and matrix D is the coefficient to be estimated. The asymmetric GARCH model describes the effect on volatility when both $e_{t-1,i}$ and $e_{t-1,j}$ are less than zero. If the coefficient of matrix D is significant, the leverage effect exists; otherwise it does not exist. The leverage effect mainly tests whether the effects of negative price fluctuation and positive fluctuation are the same.

Data Sources and Processing Methods

This study uses the daily data of the price indices for domestic logs, imported logs, domestic sawn timber, and imported sawn timber between July 1, 2014, and January 9, 2017, using June 2010 as the basis. As the GARCH model generally uses the form of returns ratio, the data of price indices are used to calculate the returns ratio, and the results are shown in Figure 1. It can be seen that the volatility of returns ratio for domestic logs (DLPR) and imported logs (ILPR) is more consistent, becoming violent before the second quarter of 2015 and slowing down afterwards. The returns ratio of domestic sawn timber (DSPR) fluctuated aggressively in 2014, but stabilized during the other period. The returns ratio of imported sawn timber (ISPR) is more volatile than that of domestic sawn timber for a longer period.

$$\text{Returns ratio of price: } R_t = \ln\left(\frac{P_t}{P_{t-1}}\right) \times 100 \quad (5)$$

The summary statistics for daily returns show that the mean and median values of the four products are very close to zero, and the standard deviations are greater than the mean; the values of both DLPR and ISPR are left-skewed, while the values of both ILPR and DSPR are right-skewed. The kurtosis of all returns ratios is greater than three, showing a phenomenon of a sharp kurtosis and thick tail. The results of the Jarque-Bera test for returns ratio strongly reject the original hypothesis of normal distribution (Table 1).

Since the GARCH model requires that the data are stationary, this study uses the Phillips-Perron (PP) unit root test to measure the stability of returns ratio under the following situations: (1) intercept and tendency parts excluded; (2) intercept only contained; and (3) intercept and tendency parts included. PP test results strongly reject the original hypothesis, indicating that DLPR, ILPR, DSPR, and ISPR are stable (Table 2).

Model Regression Results and Discussion

In this part, we used Eviews 9.0 to estimate the GARCH model and the GARCH model with the leverage effect. We used regression results of the model to calculate the dynamic conditional correlation coefficient of the two products and the minimum risk of the asset portfolio.

The results of multivariate GARCH regression models

The regression models give the calculation results of vech-GARCH, vech-TGARCH, BEKK-GARCH, and BEKK-TGARCH models (Table 3), where vech-TGARCH and BEKK-TGARCH reflect leverage effect. The estimated results of the model are divided into two parts: the mean value and the variance value. In terms of the calculation results for Akaike information criterion and Schwarz information criterion, both values of the vech-TGARCH and BEKK-TGARCH models are relatively small without significant difference; therefore, the results of the vech-TGARCH and BEKK-TGARCH models are ideal.

The coefficients μ_1 to μ_4 of the mean values for the four models fail to reject the null hypothesis. This result is consistent with that of the descriptive statistical analysis, indicating that the returns ratio of the four products fluctuates around an average value of zero.

Coefficient matrix A is the estimation result for the autoregressive conditional heteroskedasticity (ARCH) term, which measures the short-term fluctuation of a time series. In the vech-GARCH model, A is a symmetric matrix, so the result only shows elements on the diagonal and below; the BEKK-GARCH model estimates the elements on the diagonal of the matrix in order to reduce the number of the estimated parameters. The diagonal elements of matrix A reflect the short-term volatility effect of the returns ratio itself, and the nondiagonal elements in the matrix reflect the short-term spillover effect. Among the returns ratio of the four products, only the imported logs ratio is insignificant in the vech-TGARCH model, and it is significant under the 10 percent level in the BEKK-TGARCH model; the ARCH effect of the other three products is significant under the 1 percent level. In both the vech-GARCH and vech-TGARCH models, the significance of the nondiagonal elements of matrix A is different. The spillover effect of DLPR and ILPR, ILPR and ISPR is very significant in the vech-GARCH model, but is insignificant in vech-TGARCH model.

B is a matrix of coefficients capturing the GARCH effect, which measures the long-term fluctuation effect of a time series. All GARCH effects of the four models strongly reject the original hypothesis, indicating that there is a GARCH effect of returns ratio for the four products, and there is a spillover effect between products. Also, the coefficients of the four models are more consistent. The regression results showed that the GARCH effect of imported logs, domestic sawn timber, and imported sawn timber is greater than 0.9, indicating that the fluctuation of the above three products would impact the market for a longer period. Meanwhile, the spillover effect between imported logs and domestic

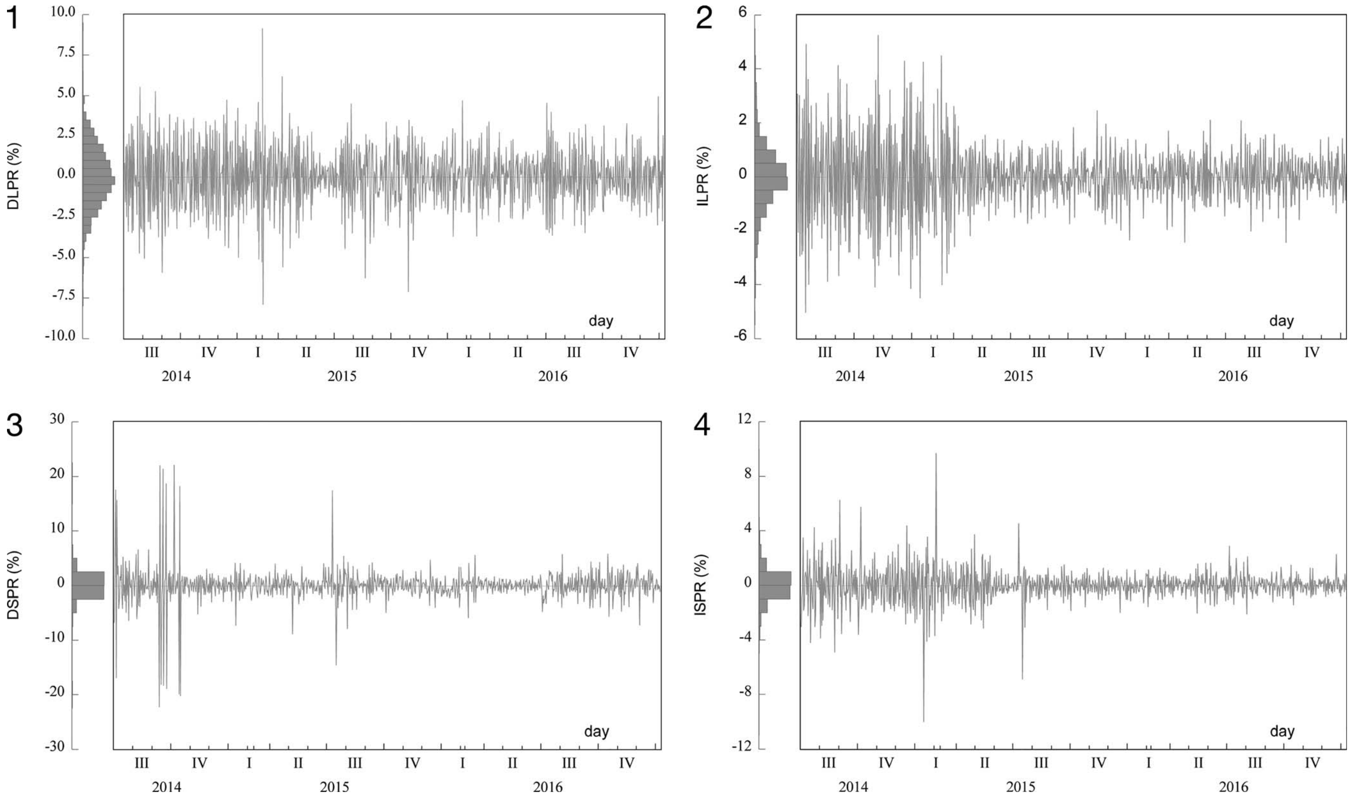

Figure 1.—The returns ratios of log and sawn timber. (1-1) Returns ratios of domestic logs (DLPR). (1-2) Returns ratios of imported logs (ILPR). (1-3) Returns ratios of domestic sawn timber (DSPR). (1-4) Returns ratios of imported sawn timber (ISPR).

Table 1.—The descriptive statistical analysis of returns ratios of logs and sawn timber.

Statistics	DLPR[a]	ILPR	DSPR	ISPR
Observations	878	878	878	878
Mean (SD)	−0.007 (1.910)	−0.010 (1.250)	−0.002 (3.170)	−0.008 (1.229)
Median	−0.031	−0.001	0.027	0.001
Maximum	9.145	5.246	22.008	9.665
Minimum	−7.895	−5.036	−22.275	−10.014
Skewness	−0.047	0.067	0.088	−0.051
Kurtosis	3.890	5.080	25.482	15.208
Jarque-Bera test	29.285***[b]	158.892***	18,492.510***	5,452.926***

[a] DLPR = returns ratio for domestic logs; ILPR = returns ratio for imported logs; DSPR = returns ratio of domestic sawn timber; ISPR = returns ratio of imported sawn timber.
[b] *** = Significantly under the 1 percent level.

Table 2.—The unit root test on returns ratios of logs and sawn timber.

Statistics	DLPR[a]	ILPR	DSPR	ISPR
Intercept and tendency parts excluded				
t statistic	−147.638	−90.261	−44.965	−55.052
Probability	0.000	0.000	0.000	0.000
Intercept only contained				
t statistic	−151.090	−93.650	−44.936	−55.876
Probability	0.000	0.000	0.000	0.000
Intercept and tendency parts included				
t statistic	−143.741	−88.758	−44.993	−54.981
Probability	0.000	0.000	0.000	0.000

[a] DLPR = returns ratio for domestic logs; ILPR = returns ratio for imported logs; DSPR = returns ratio of domestic sawn timber; ISPR = returns ratio of imported sawn timber.

sawn timber as well as imported sawn timber is very close to 1, indicating that the price fluctuation of imported logs has a significant impact on the other two products; a strong spillover relation is also found between domestic sawn timber and imported sawn timber.

The coefficient matrix D describes the regression results of the leverage effect in the multivariate GARCH model. In the regression results, there was a leverage effect in the returns ratio of imported logs and sawn timber, which means that when the market changes suddenly at the same level, price dropping has a greater impact than price increase. However, the regression results of vech-TGARCH and BEKK-TGARCH are quite different, and the estimation results of the two models for the leverage effect of imported log are 0.064 and 0.252, respectively. The leverage effect of the returns ratio of imported sawn timber is only significant in the BEKK-TGARCH model, at 0.060.

Table 3.—The results of multivariate GARCH regression models.[a,b]

	Vech-GARCH Coefficient (SE)	Vech-TGARCH Coefficient (SE)	BEKK-GARCH Coefficient (SE)	BEKK-TGARCH Coefficient (SE)
The part of the average value				
μ_{DLPR}	0.007 (0.047)	−0.009 (0.053)	−0.007 (0.037)	−0.009 (0.053)
μ_{ILPR}	−0.005 (0.029)	−0.029 (0.031)	−0.010 (0.025)	−0.029 (0.031)
μ_{DSPR}	−0.066 (0.051)	−0..069 (0.051)	−0.002 (0.039)	−0.069 (0.051)
μ_{ISPR}	0.002 (0.029)	−0.003 (0.029)	−0.008 (0.020)	−0.003 (0.029)
Variance equation coefficients				
$C_{DLPR,\ DLPR}$	1.419 (0.252)***	1.294 (0.253)***	0.344 (0.057)***	1.294 (0.253)***
$C_{DLPR,\ ILPR}$	0.002 (0.025)	−0.005 (0.024)	0.001 (0.008)	−0.005 (0.024)
$C_{DLPR,\ DSPR}$	0.056 (0.066)	0.052 (0.062)	0.010 (0.020)	0.052 (0.062)
$C_{DLPR,\ ISPR}$	−0.013 (0.026)	−0.012 (0.025)	−0.002 (0.009)	−0.012 (0.025)
$C_{ILPR,\ ILPR}$	0.005 (0.002)***	0.008 (0.003)**	0.008 (0.003)***	0.008 (0.003)***
$C_{ILPR,\ DSPR}$	0.002 (0.006)	0.006 (0.008)	0.001 (0.005)	0.006 (0.008)
$C_{ILPR,\ ISPR}$	0.000 (0.001)	0.000 (0.001)	0.000 (0.002)	0.000 (0.001)
$C_{DSPR,\ DSPR}$	0.190 (0.030)***	0.168 (0.028)***	0.134 (0.021)***	0.168 (0.028)***
$C_{DSPR,\ ISPR}$	0.007 (0.004)	0.008 (0.005)*	0.008 (0.005)*	0.008 (0.005)*
$C_{ISPR,\ ISPR}$	0.002 (0.001)***	0.002 (0.001)**	0.034 (0.004)***	0.002 (0.001)**
$A_{DLPR,\ DLPR}$	0.311 (0.053)***	0.287 (0.062)***	0.474 (0.032)***	0.536 (0.058)***
$A_{DLPR,\ ILPR}$	0.079 (0.012)***	0.031 (0.020)		
$A_{DLPR,\ DSPR}$	0.237 (0.023)***	0.227 (0.026)***		
$A_{DLPR,\ ISPR}$	0.074 (0.008)***	0.074 (0.010)***		
$A_{ILPR,\ ILPR}$	0.020 (0.005)***	0.003 (0.004)	0.209 (0.018)***	0.057 (0.035)*
$A_{ILPR,\ DSPR}$	0.060 (0.008)***	0.024 (0.015)*		
$A_{ILPR,\ ISPR}$	0.019 (0.003)***	0.008 (0.005)		
$A_{DSPR,\ DSPR}$	0.180 (0.015)***	0.179 (0.016)***	0.448 (0.012)***	0.423 (0.018)***
$A_{DSPR,\ ISPR}$	0.056 (0.004)***	0.059 (0.005)***		
$A_{ISPR,\ ISPR}$	0.017 (0.002)***	0.019 (0.003)***	0.421 (0.021)***	0.139 (0.011)***
$B_{DLPR,\ DLPR}$	0.317 (0.081)***	0.355 (0.081)***	0.833 (0.017)***	0.596 (0.068)***
$B_{DLPR,\ ILPR}$	0.555 (0.071)***	0.582 (0.067)***		
$B_{DLPR,\ DSPR}$	0.511 (0.066)***	0.541 (0.063)***		
$B_{DLPR,\ ISPR}$	0.556 (0.07)***	0.588 (0.067)***		
$B_{ILPR,\ ILPR}$	0.972 (0.006)***	0.955 (0.011)***	0.972 (0.004)***	0.977 (0.005)***
$B_{ILPR,\ DSPR}$	0.895 (0.006)***	0.887 (0.007)***		
$B_{ILPR,\ ISPR}$	0.975 (0.003)***	0.965 (0.005)***		
$B_{DSPR,\ DSPR}$	0.824 (0.009)***	0.824 (0.009)***	0.905 (0.004)***	0.908 (0.005)***
$B_{DSPR,\ ISPR}$	0.898 (0.005)***	0.896 (0.005)***		
$B_{ISPR,\ ISPR}$	0.978 (0.002)***	0.975 (0.002)***	0.903 (0.006)***	0.987 (0.001)***
$D_{DLPR,\ DLPR}$		0.043 (0.067)		0.207 (0.162)
$D_{DLPR,\ ILPR}$		0.052 (0.042)		
$D_{DLPR,\ DSPR}$		−0.022 (0.024)		
$D_{DLPR,\ ISPR}$		0.012 (0.012)		
$D_{ILPR,\ ILPR}$		0.064 (0.021)**		0.252 (0.042)***
$D_{ILPR,\ DSPR}$		−0.027 (0.025)		
$D_{ILPR,\ ISPR}$		0.015 (0.008)		
$D_{DSPR,\ DSPR}$		0.011 (0.022)		−0.107 (0.100)
$D_{DSPR,\ ISPR}$		−0.006 (0.006)		
$D_{ISPR,\ ISPR}$		0.004 (0.004)		0.060 (0.030)**
Log likelihood	−6234.529	−6226.233	−6314.052	−6226.233
AIC	14.252	14.242	14.433	14.242
SIC	14.371	14.383	14.553	14.383

[a] GARCH = generalized autoregressive conditional heteroscedasticity; TGARCH = threshold GARCH; BEKK = Baba-Engle-Kraft-Kroner; DLPR = returns ratio for domestic logs; ILPR = returns ratio for imported logs; DSPR = returns ratio of domestic sawn timber; ISPR = returns ratio of imported sawn timber; AIC = Akaike information criterion; SIC = Schwarz information criterion.

[b] * = Significantly under the 10 percent level, ** = significantly under the 5 percent level, *** = significantly under the 1 percent level.

The dynamic conditional correlation coefficient of returns ratio

Figure 2 depicts the dynamic conditional correlation coefficient calculated using the BEKK-TARCH model. The dynamic conditional correlation coefficient reflects the dynamic correlation between the two products, and it can be used to calculate the optimal asset ratio. The dynamic conditional correlation coefficients of DLPR, ILPR, DSPR, and ISPR have been oscillating around 0, and there is no obvious trend of change. With the increasing internationalization of China's log and sawn timber markets, relations between logs, imported logs, sawn timber, and imported sawn timber are influenced by domestic policies and international trade. If domestic logs and imported logs are

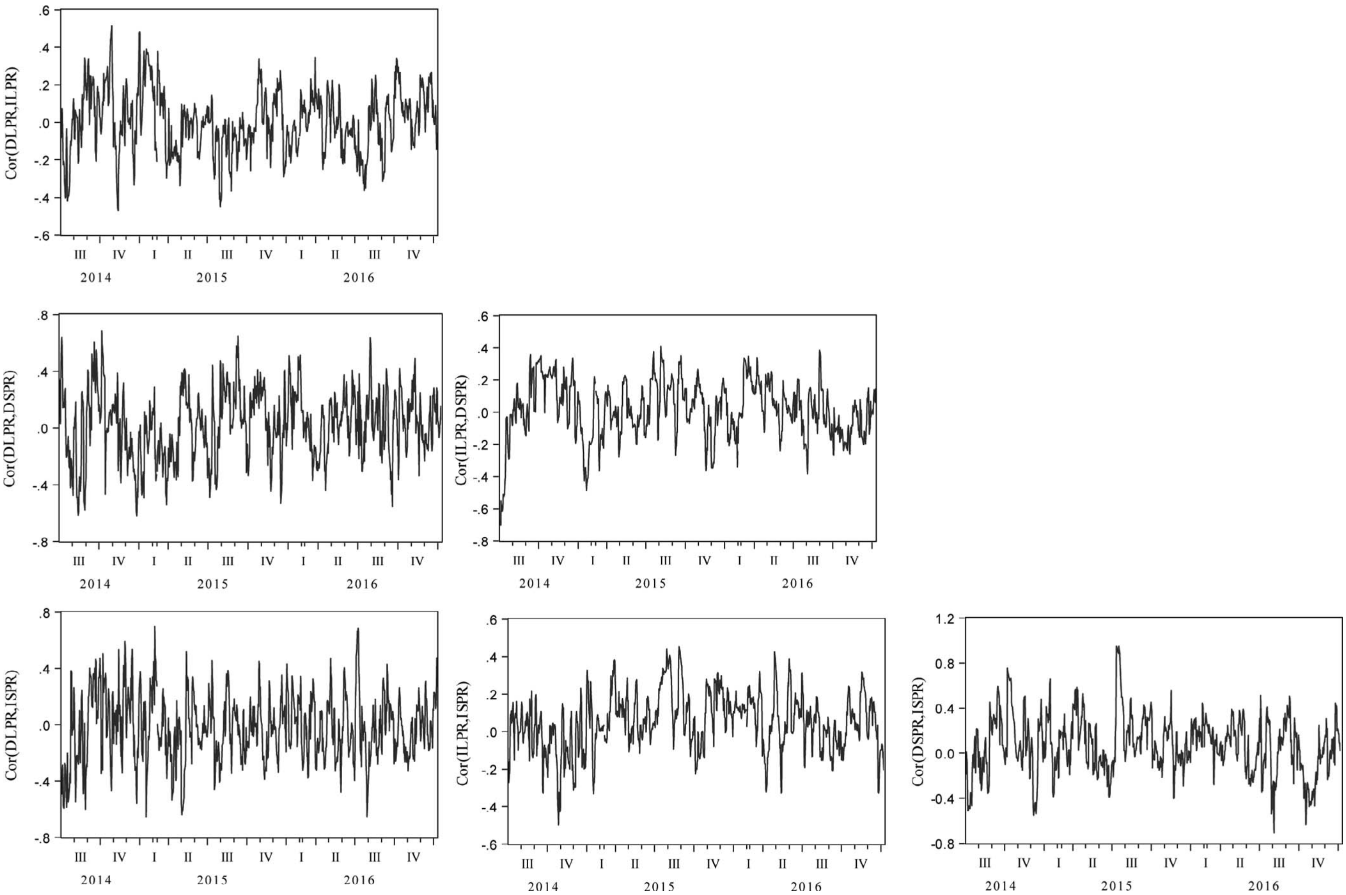

Figure 2.—The conditional correlation coefficient based on multivariate generalized autoregressive conditional heteroskedasticity model.

interchangeable, there should be a negative correlation between them. However, a positive correlation has been found between the price of domestic logs and imported logs due to long-term insufficient timber supply resulting from domestic logging quota, as well as dependence on international market for imported logs. The dynamic correlation coefficient also supports this view. The relations between other products also show similar results, but by different factors.

Portfolio weights

Kroner and Ng (1998) argued that a minimal risk of asset portfolio can be obtained through a multivariate GARCH model assuming that the expected returns ratio for each asset is zero. Equation 6 gives a formula to calculate an asset portfolio of the two products: w_{ij} is the proportion of i in the combination of products i and j, the proportion of product j is $1 - w_{ij}$, h_{ij} is the conditional covariance of product i and j, and h_{ii} and h_{jj} are the variances of product i and j respectively. This asset portfolio is often used by investment managers to select the optimal asset portfolio, and this study uses this product portfolio to analyze how to select the right product mix to avoid trade and resource risks:

$$w_{ijt} = \begin{cases} 0 & w_{ijt} < 0 \\ \dfrac{h_{jjt} - h_{ijt}}{h_{iit} - 2h_{ijt} + h_{jjt}} & 0 \le w_{ijt} \le 1 \\ 1 & w_{ijt} > 1 \end{cases} \quad (6)$$

Using the dynamic conditional correlation coefficients of the vech-TGARCH and BEKK-TGARCH models, six pairs of different products were calculated (Table 4). The mean and median values of ratios for product mix calculated by these two models are relatively similar. As shown in the table, the ratios of product mix for domestic logs and imported logs show that, during the process of resource acquisition, an average proportion of 26.1 percent for domestic logs and 73.9 percent for imported logs is the minimum risk portfolio of these two products. The results are consistent with the fact that about 50 percent of China's timber supply relies on imports. If the optimal asset portfolio is applied, the volume of imported logs should be further increased to reduce the risk of log supply. The asset ratios of imported logs and domestic sawn timber show that the proportion of logs and sawn timber in China during the acquisition of timber resources should be 77.3 and 22.7 percent, respectively.

Discussion

In this study, a multivariate GARCH model is used to analyze the relationship between domestic and import prices of logs as well as domestic and import prices of sawn timber. The short-term spillover effect (ARCH effect) calculated by the vech-TGARCH model shows that the spillover effect (0.227) between domestic logs and sawn timber is large, and the spillover effect between other variables is less than 1 percent. The results show that there is a strong spillover effect between the domestic logs and

Table 4.—The ratios of product mixes of log and sawn timber.

	Vech-TGARCH[a]				BEKK-TGARCH			
	Mean	Median	Maximum	Minimum	SD	Median	Maximum	Minimum
Domestic log/imported log	0.261	0.239	0.770	0.000	0.262	0.210	0.722	0.003
Domestic log/domestic sawn timber	0.579	0.563	1.000	0.039	0.578	0.557	1.000	0.056
Domestic log/imported sawn timber	0.256	0.225	1.000	0.000	0.264	0.203	0.654	0.000
Imported log/domestic log	0.773	0.831	1.000	0.000	0.805	0.856	1.000	0.000
Imported log/imported sawn timber	0.479	0.421	1.000	0.000	0.450	0.443	1.000	0.000
Domestic sawn timber/ Imported sawn timber	0.805	0.861	1.000	0.044	0.809	0.861	1.000	0.307

[a] TGARCH = threshold generalized autoregressive conditional heteroscedasticity; BEKK = Baba-Engle-Kraft-Kroner.

sawn timber in the short term, while the spillover effect between other markets is weak. Therefore, changes in domestic log prices will affect the downstream sawn timber processing market in China, while the impact on the international log and sawn timber market is relatively low. The long-term spillover effects of domestic log price and imported log, domestic sawn timber, and imported sawn timber prices are 0.582, 0.541, and 0.588, respectively. The long-term spillover effects of imported log price and domestic sawn timber and imported sawn timber prices are 0.887 and 0.965, respectively. The long-term spillover effect of domestic sawn timber price and imported sawn timber price is 0.896. The results of the long-term spillover effect indicate that if the price of one of the products changes, it will be transmitted to the market of other products, and this transmission has a strong effect. As China depends heavily on foreign timber supply, the volume of China's imported logs in 2017 reached 48.542 million m^3, accounting for 23.0 percent of the total domestic demand for logs; the volume of China's imported sawn timber was 31.494 million m^3, accounting for 29.1 percent of the total domestic demand. Therefore, when the exporting country adopts tariffs or quota limitation measures on the logs, it will first cause the price fluctuation of the international log market, and then transmit to the domestic log market, the downstream sawn timber processing market, and finally the international sawn timber market. At the same time, there is a certain degree of substitution between logs and sawn timber. When Chinese companies have difficulty obtaining logs from the international market, they use sawn timber instead of logs to meet domestic timber demand. Therefore, it also shows a strong spillover effect between logs and sawn timber.

Since the main risks of the market are closely related to price fluctuations, price fluctuations in any of the four markets will be transmitted to other markets through various channels, resulting in China's log suppliers and processing enterprises becoming vulnerable to the international market and upstream/downstream markets, which would increase their risk. This study uses the optimal portfolio theory to determine how to adjust the proportion of imported logs and sawn timber to reduce the risk in the domestic market. In practice, affected by restriction policies on log exports of sourcing countries, China has imported large amounts of sawn timber instead of logs to avoid trade risk, resulting in a greater risk for the current structure of imported timber. China's forestry industry is highly dependent on international raw materials and the product market. By calculating the optimal asset portfolio, it can be found that in the process of obtaining logs and sawn timber, the industry is more likely to have a smaller number of processing products, using its own competitive advantage for processing. At the same time, the low proportion of domestic logs also proved that the current wood supply in China is seriously inadequate, and relying on the domestic market to meet the demand will increase the risk of raw material supply.

Conclusion

China's growing timber demand coupled with insufficient forest resources results in a heavy dependence on international timber markets. In this article, the multivariate GARCH model was applied to study the characteristics of price changes of logs and sawn timber in China. The short-term and long-term spillover effects of returns ratio of domestic logs, imported logs, domestic sawn timber, and imported sawn timber were analyzed. Furthermore, the dynamic conditional correlation coefficient was used to examine the dynamic conditional correlation coefficient between the products and the minimum risk of asset portfolio.

The results of the empirical analysis show that the ARCH and GARCH effects of returns ratio of domestic logs, imported logs, domestic sawn timber, and imported sawn timber are significant, and the GARCH effect is greater than the ARCH effect. In the short term, although there is a spillover relationship between the four markets, only the spillover effect between domestic logs' and sawn timber's price is large, and the spillover effects between other products are statistically significant, but with small values. The results show that, in the short term, domestic timber prices are mainly transmitted between the upstream and downstream markets, namely domestic logs and primary processed sawn timber, while the international market has a small spillover effect on Chinese timber prices. In the long run, the four markets have very strong spillover effects, and price fluctuations in one market will be transmitted to other markets through multiple channels. This is mainly due to China's heavy dependence on the international timber supply market. Changes in the international log market will not only be transmitted to the domestic log market, but also to the domestic and international sawn timber markets due to the alternative relationship between logs and sawn timber. Therefore, China's timber supply is greatly affected by the international market and corresponding risks will be transmitted between the upstream and downstream markets, which makes Chinese timber suppliers and processing enterprises vulnerable to multiple risks.

This study applies the vech-GARCH and BEKK-GARCH models to calculate the optimal product portfolio to evaluate whether the current timber supply is reasonable in terms of product proportions. The calculated results of the optimal asset portfolio show the proportion of different products at the minimum risk, indicating that it is preferential for China's forestry industry to import more logs and sawn timber to pursue the minimum risk in the lower level of processing products. Restricted by timber-sourcing countries' policies, China's sawn timber imports have been expanded to make up for the shortage of log imports. This shows a significant difference from the optimal portfolio of imported logs and sawn timber, which increased the overall risk of timber supply. Therefore, an intervention should be carried out in which a strategic timber reserve is established to prevent drastic risks. Meanwhile, given the current condition of forest resources in China, forest cultivation should be further strengthened to reduce the dependence on foreign resources, forestry enterprises should be encouraged to pursue local production and sales in the sourcing countries by using overseas resources, and the proportion of products should be adjusted to reduce risks.

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