Vertical price linkage between timber and forest products prices in the South

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Abstract

Timber market and forest product market are linked and integrated through prices of their own. In this study, the presence of price transmission asymmetry is investigated for wood products sector in southern United States. Threshold cointegration and an asymmetric error correction model are employed to analyze the price dynamics between prices of standing timber, delivered timber and also two representative lumber prices. Cointegration tests confirm the integration and efficiency of timber market in the South. The estimated results of error correction model reveal that the asymmetric price transmissions exist only when price of the lumber board is linked with upstream prices. While generally, cumulative effects are symmetric. Moreover, if there is any adjustment path asymmetry, adjustment from positive deviations always requires longer time than that from negative deviations when lumber prices are set as driving forces. But asymmetric transmission is not a prevalent phenomenon in southern timber market.

Keywords: Asymmetric price transmission; Timber market; Engle-Granger two-step approach, Threshold cointegration; Asymmetric error correction

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1. Introduction

Price is considered to be the principal mechanism connecting the different market stages. A study by Yin and Caulfield with timber prices shows that real prices in timber market have become more volatile after early 1990s (2002).The controversial harvesting restrictions in Pacific Northwest, lumber trade dispute with Canada, damage on timber production caused by Hurricane Hugo and Katrina, as well as the demand shock brought by debt crisis have thrown more concern on the volatility. No matter a supply or demand shock occurs in any stage along the linkage, it would be vertically transmitted to other stages upward or downward in some measure.

Traditionally, economic theory has assumed that prices adjust rapidly to equate demand and supply (Brännlund 1991). However, symmetric price transmission is not a natural result of market dynamics. Recent literature provides evidence of asymmetric price transmission (APT) in agriculture, gasoline, and financial markets (Meyer and Cramon-Taubadel 2004), with the phenomenon occurring when downstream prices react in a different manner to upstream price changes, depending on the characteristics of upstream prices or changes in those prices. It brings the consequence that that a group is not benefiting from a price reduction (buyers), or increase (sellers) that would under conditions of symmetry have taken place sooner and / or have been of greater magnitude than observed (Meyer and Cramon-Taubadel 2004). In spite of one among the most fundamental questions, whether it exists in timber market of southern U.S. is still indistinct so far. If it is the case, quite a lot of previous public programs need to be revised accordingly.

Depending on the issue and study purpose, APT has been classified and analyzed in several ways. One typical classification is positive versus negative APT. If one price (e.g., price of petrol) reacts more fully or rapidly to an increase in another price (e.g., price of crude oil) than to a decrease, then the price transmission is referred to as positive asymmetry (Meyer and von Cramon-Taubadel 2004). More generally, with positive APT, price movement that squeezes the margin is transmitted more rapidly or completely than the equivalent movement that stretches the margin. Conversely, APT is negative when price movements that stretch the margin are transmitted more rapidly or completely. However, it is self-evident that this classification of APT would become inverse if assumed causality between variables changes. According to the conclusion drawn from former research, positive APT is more widespread in natural resource market than the contrary situation. In addition, APT can also be classified as vertical or spatial. A typical example of vertical APT is that consumers often feel increases in farm prices are more fully and rapidly transmitted to retail levels than equivalent decreases (Kinnucan and Forker 1987). And a spatial ATP could be seen when price of central market transmits differently to peripheral markets. When this classification is associated to this study, vertical APT among stages in southern timber market would be our concern.

Various sources of APT have been discussed in the literature (Frey and Manera 2007), one among them widely approved is downstream traders' market power: giant retailers try to maintain their "normal" profit margin when prices rise, but they try to capture the larger margins that arise, at least temporarily, when upstream prices fall (Ben-Kaabia 2007). Another cause of spatial APT often cited is the asymmetric flow of information between central and peripheral markets (Abdulai 2000). Prices at a central market, by virtue of its size and the fact that it is at the center or a network of information, may tend to be less responsive to price changes in individual peripheral market than vice versa. Other causes of APT include political intervention, inventory management (Meyer and Cramon-Taubadel 2004) and inflation (Ball and Mankiw 1994). In spite of potential causes of asymmetric price transmission, empirical analyses of this phenomenon typically do not allow differentiation among the different possible causes (Capps and Sherwell 2007).

The assumed causality that refers to the direction of price movements along the supply chain is another issue should be cared about. According to price determination theory, producer price changes determine retail price changes; that is price transmission flows downward along the supply chain and the direction of causality runs from upstream to downstream. However, the empirical results of studies applied to different commodities in different countries regarding this issue are mixed (Saghaian 2007). For example, Tiffin and Dawson (2000), studying the UK lamb market, found that lamb prices were determined in the retail market and then passed upward along the supply chain; that is, the direction of causality is from retail to producer prices. However, Ben-Kaabia, Gill, and Boshnjaku (2002) found both supply and demand shocks were fully passed through the marketing linkage, i.e., they found complete price transmission. So previous assumption toward causality direction is not necessary; upstream and downstream prices would both be set as dependent variable to one another at first, and significance of the causality assumption would be tested by econometric models.

Price transmission dynamics has been the subject of several papers in forest products sector across different areas, but generally speaking, previous studies of linkage between forest product and factor markets are rare (Hanninen, Toppinen et al. 2007). Early works emphasized the determinants of southern pine stumpage prices (Guttenberg and Fasick, 1965; Anderson, 1969; Guttenberg, 1970). Among these early studies with the issue of price transmission between stumpage price and forest products prices, Haynes (1977) linked regional stumpage and national sawnwood markets using the derived demand approach. Regionally, Luppold and Baumgras (1996) and Luppold et al. (1998) analyzed how price margins between stumpage and national sawnwood changed in Ohio, concluding that the shrinking market margin is a result of competitive market forces, and although stumpage and sawnwood prices follow each other, short-term deviation is still possible due to insufficient market information. Most recently, Zhou and Buongiorno (2005) conduct a research with the issue of price transmission between products at different stages of manufacturing in forest industries in the South from 1977 to 2002. All prices are found to be nonstationary, and there is no evidence of cointegration between prices. When price transmission is significant, the full adjustment takes about two years. Considering achievements got in this field so far, clearly, fresh research is needed in this field.

And therefore, the overall objective is to examine dynamics between upstream and downstream prices among three stages in forestry sector in southern US, and furthermore, to provide an understanding of market information efficiency and welfare distribution between timber suppliers, processors and consumers. Under the objective, three questions are involved: firstly, whether this phenomenon exists in forestry sector in the South; secondly, if it exists, what's its magnitude and direction; and finally, whether the deviation would return to equilibrium, and if yes, how long would it be required.

2. Methodology

2.1. Linear cointegration analysis

Upstream prices and downstream prices' properties of nonstationarity and order of integration can be assessed using the Augmented Dickey-Fuller (ADF) Test (Dickey and Fuller 1979). The original test was extended by Perron (1989) to overcome the problems associated with which deterministic components should enter DF test, by requiring adding lagged terms of the dependent variable to the test equation. If both the price series appear to have a unit root, then it is appropriate to conduct cointegration analysis to evaluate their interaction. Following testing procedure (Pfaff 2008), the ADF equation would be tested without neither constant nor trend. The null hypothesis is that the series are nonstationary in their levels. The nonstationary series are I(1) with the first differences being I(0).

The Johansen approach is a multivariate generalization of the Dickey-Fuller test (Johansen 1988; Johansen and Juselius 1990). The test is a procedure for testing cointegration of several I(1) time series. According to Johansen and Juselius, any p-dimensional vector autoregression can be written in the following models:

$$X_t = \pi_1 X_{t-1} + \cdots + \pi_K X_{t-K} + \varepsilon_t \tag{1a}$$

$$\Delta X_t = \sum_{i=1}^{K-1} \Gamma_i \Delta X_{t-i} + \Pi X_{t-K} + \varepsilon_t \tag{1b}$$

where X_t is a vector of price series of one pair of downstream price and upstream price, with K as the number of lags, and ε_t as the error term. While the connection between equation 1a and equation 1b is $\Gamma_i = -I + \sum_{j=1}^{i} \pi_i$ and $= -I + \sum_{k=1}^{K} \pi_k$, with I as an identity matrix.

To do the cointegration test, Two specific models would be adopted, one with trend, the other with constant. Johansen proposes two different likelihood ratio tests of the significance of these canonical correlations and thereby the reduced rank of the coefficient matrix Π in each model: the trace test and maximum eigenvalue test. The trace one tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of n cointegrating vectors; on the other hand, the maximum eigenvalue one, tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of r +1 cointegrating vectors. Given that the time series studied are I(1), according to the results of the ADF test we can use Johansen test to examine whether there is a linear relation among the variables which are stationary.

Another linear cointegration test, the Engle-Granger two-stage approach, practices on the residuals from the long-term equilibrium relationship (Engel and Granger 1987). During the first stage, long-run relationship between prices series would be estimated, and the price of upstream price is chosen to be placed on the right side as the driving force, which could be expressed as:

$D = \alpha_0 + \alpha_1 U + \xi_t$

or $U = \alpha_0 + \alpha_1 D + \xi_t$ (2)

where U and D represent upstream prices and downstream prices separately, α_0 and α_1 are coefficients, ξ_t is error term. In the next step, an augmented Dickey-Fuller test is adopted to check the residuals to see whether the price series of each equation are cointegrated with a unit root test (Engel and Granger 1987). There would be no serial correlation in the regression residuals with lags involved; Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC) could be used as rule for selection. Equation for step 2 could be in form of:

$$\Delta\hat{\xi}_t = \rho \Delta\hat{\xi}_{t-1} + \sum_{i=1}^{L} \phi_i \Delta\hat{\xi}_{t-i} + \mu_t \tag{3}$$

where ρ and ϕ_i are coefficients, $\hat{\xi}_t$ is the estimated residuals, Δ indicates the first difference, μ_t is a white noise disturbance term, and L is the number of lags. Five pairs of prices would be analyzed through this model. If the null hypothesis of $\rho = 0$ is rejected, then the residual series from the long-term equilibrium is stationary and that pair of upstream price and downstream price would be cointegrated with each other.

2.2. Threshold cointegration analysis

Linear cointegration analysis potentially implies a symmetric transmission progress; Enders and Granger (1998) argue that the Dickey Fuller test and its extensions are mis-specified if adjustment is asymmetric. And therefore, Enders and Siklos (2001) propose a two-regime threshold cointegration approach to entail asymmetric adjustment in cointegration analysis, among which TAR and MTAR are the most popular models.

$$\Delta\hat{\xi}_t = \rho_1 I_t \hat{\xi}_{t-1} + \rho_2(1 - I_t)\hat{\xi}_{t-1} + \sum_{i=1}^{L} \phi_i \, \Delta\hat{\xi}_{t-i} + \mu_t \tag{4}$$

I_t=1 if $\hat{\xi}_{t-1} \geq \tau$, 0 otherwise; or (5a)

I_t=1 if $\Delta\hat{\xi}_{t-1} \geq \tau$, 0 otherwise (5b)

where I_t is the Heaviside indicator, P the number of lags, ρ_1, ρ_2 and φ_i the coefficients, and τ the threshold value. The lag P is specified to account serially correlated residuals and it can be selected using AIC or BIC.

The Heaviside indicator I_t can be specified with two alternative definitions of the threshold variable, either the lagged residual ($\hat{\xi}_{t-1}$) or the change of the lagged residual ($\Delta\hat{\xi}_{t-1}$). Equations (4) and (5a) together are referred to as the Threshold Autoregression (TAR) model, and Equations (4) and (5b) are named as the Momentum Threshold Autoregression (MTAR) model. The TAR model is designed to capture potential asymmetric deep movements in the residuals (Enders and Granger 1998; Enders and Siklos 2001). The MTAR model is useful to take into account steep variations in the residuals; it is especially valuable when the adjustment is believed to exhibit more "momentum" in one direction than the other.

The threshold value τ can be specified as zero, given the regression deals with the residual series. However, Chan (1993) proposes a search method for obtaining a consistent estimate of the threshold value, which could offer stronger power with an estimated threshold. Given A total of four models are entertained in this study. They are TAR Equation with τ = 0; consistent TAR Equation with τ estimated; MTAR Equation with τ = 0; and consistent MTAR Equation with τ estimated. Since there is generally no presumption on which specification is used, it is recommended to choose the appropriate adjustment mechanism via model selection criteria of AIC and BIC (Enders and Siklos 2001). A model with the lowest AIC and BIC will be used for further analysis.

Insights into the asymmetric adjustments in the context of a long-term cointegration relation can be obtained with two tests. First, it is determined whether downstream price and upstream price are cointegrated in the TAR and MTAR models: an *F*-test is employed to examine the null hypothesis H_0: ρ_1=ρ_2=0 against the alternative of cointegration with either TAR or MTAR threshold adjustment. Secondly, the asymmetric adjustment is tested when the null hypothesis above is rejected: a standard *F*-test would be adopted to evaluate the null hypothesis of symmetric adjustment in the long-term equilibrium (H_0: ρ_1=ρ_2). Rejection of the null hypothesis indicates the existence of an asymmetric adjustment process.

2.3. Error correction model with threshold cointegration

The Granger representation theorem (Engel and Granger 1987) states that an error correction model can be estimated when all the variables have been proved to be cointegrated. Two extensions on the standard specification in the error correction model have been made for analyzing asymmetric price transmission. Granger and Lee (1989) first extend the specification to the case of asymmetric adjustments. Error correction terms and first differences on the variables are decomposed into positive and negative components. This allows detailed examinations on whether positive and negative price differences have asymmetric effects on the dynamic behavior of prices. The second extension follows the development of threshold cointegration (Engel and Granger 1987; Balke and Fomby 1997). When the presence of threshold cointegration is validated, the error correction terms are modified further.

The error correction models with threshold employed in this study could be expressed as:

$$\Delta D = \theta_D + \delta_D^+ E_{t-1}^+ + \delta_D^- E_{t-1}^- + \sum_{j=1}^{J} \alpha_{Dj}^+ \Delta D_{t-j}^+ + \sum_{j=1}^{J} \alpha_{Dj}^- \Delta D_{t-j}^- + \sum_{j=1}^{J} \beta_{Dj}^+ \Delta U_{t-j}^+ + \sum_{j=1}^{J} \beta_{Dj}^- \Delta U_{t-j}^- + \vartheta_{Dt} \tag{6a}$$

$$\Delta U = \theta_U + \delta_U^+ E_{t-1}^+ + \delta_U^- E_{t-1}^- + \sum_{j=1}^{J} \alpha_{Uj}^+ \Delta U_{t-j}^+ + \sum_{j=1}^{J} \alpha_{Uj}^- \Delta U_{t-j}^- + \sum_{j=1}^{J} \beta_{Uj}^+ \Delta D_{t-j}^+ + \sum_{j=1}^{J} \beta_{Uj}^- \Delta D_{t-j}^- + \vartheta_{Ut} \tag{6b}$$

where ΔU and ΔD are the upstream prices and downstream prices in first difference, E error correction terms, θ, δ, α and β coefficients, and ϑ error terms. The subscript $_U$ and $_D$ differentiate the coefficients by stages, t denotes time, and j represents lags. All the lagged price variables in the first difference are split into positive and negative components, as indicated by the superscripts $^+$ and $^-$. The maximum lag J is chosen with the AIC statistic so the residuals have no serial correlation. The two error correction terms are defined as $E_{t-1}^{+} = I_t\hat{\xi}_{t-1}$ and $E_{t-1}^{-} = (1 - I_t)\hat{\xi}_{t-1}$, which in turn are constructed from the threshold cointegration regressions in Equations (4) and (5).

Possible presence of asymmetric price behavior could be examined with simple inspection on the coefficients as a first insight. The signs for the driving variables should be positive; while the signs for price-takers are expected to be negative. Furthermore, three types of several single or joint hypotheses (Frey and Manera 2007) could be formed as following. The first type hypothesis would be two the Granger causality tests by employing F-tests: H_{01}: $\alpha_i^+ = \alpha_i^- = 0$ and H_{02}: $\beta_i^+ = \beta_i^- = 0$ for all lags i at the same time, so that the stage of price driver could be judged. The second type of hypothesis would be the cumulative symmetric effect as H_{03}: $\sum_{i=1}^{j} \alpha_i^+ = \sum_{i=1}^{j} \alpha_i^-$ and H_{04}: $\sum_{i=1}^{j} \beta_i^+ = \sum_{i=1}^{j} \beta_i^-$, which is a relatively long run test for asymmetry. And finally, the equilibrium adjustment path asymmetry would be tested with null hypothesis of H_{05}: $\delta^+ = \delta^-$, to examine whether it is possible to get back to equilibrium after a shock, and if it is the case, how long it will take.

3. Data and variables

In the upstream stage, stumpage and delivered timber prices are collected from Timber-Mart South from 1977 to 2009 by states. Because reporting frequency has changed from month to quarter since January 1988, the mean of each quarter before 1988 is used as quarterly observation, and therefore, the upstream prices are collected quarterly. Prices in 11 southern states are averaged to match data range of downstream prices. The prices of lumbers, lumber boards of Southern pine 1×4#3 (LA) and selects of Southern pine1×4 (LB), are obtained as downstream prices, from the Forest Products Market Price and Statistics Yearbook published by Rand Lengths during the same period. Although monthly data is available with Rand Lengths Yearbook, only mid-month data of each quarter are reported to gain consistency with stumpage and delivered timber prices. To summarize, the data frequency of this study is quarterly with all 11 states in the South as a whole.

4. Empirical results

4.1. Descriptive statistics and unit root test

The descriptive statistics of the four variables involved in this study are reported in Table 1. With upstream prices, delivered timber price is higher than stumpage price on each observation, and the gap between them is relatively stable. On the other hand, downstream prices, due to diverse sizes and qualities of different products, are not proper for direct comparison. The trend and fluctuation during the period of study could be observed in Figure 1; roughly speaking, the group of prices seems to change synchronously, with a generally upward tendency and an unstable development during the most two recent decades. Furthermore, covariances between variables have partly approved the initial thought: the one between stumpage price and delivered timber price is as high as 0.99; and covariances between upstream prices and price of LB are higher than those connecting with LA. Additionally, that between the two lumbers is 0.87.

Table 1 Descriptive statistics and unit root test results for the prices

Name	LA	LB	PD	PS
Definition	Lumber boards of Southern pine 1×4#3	Lumber selects of Southern pine1×6	Average delivered price of Southern pine sawtimber	Average standing price of Southern pine sawtimber
Mean	235.4	735.6	273.9	201.4
Std. Dev.	64.1	231.6	94.2	73.1
Minimum	134	342	120	80
Maximum	408	1147	439	344
ADF test	0.26 [6]	0.11 [9]	0.20 [11]	-0.37 [11]
1^{ST} Diff(Δ)	-5.22*** [6]	-3.48*** [9]	-2.24** [11]	-2.17** [11]

Notes: The critical values are 2.58 -1.95 -1.62 for ADF test at the 1%, 5%, and 10% levels, respectively (Enders, 2004). ** and *** denote significance at the 5% and 1% level, respectively. The numbers in the bracket are lags used in the test.

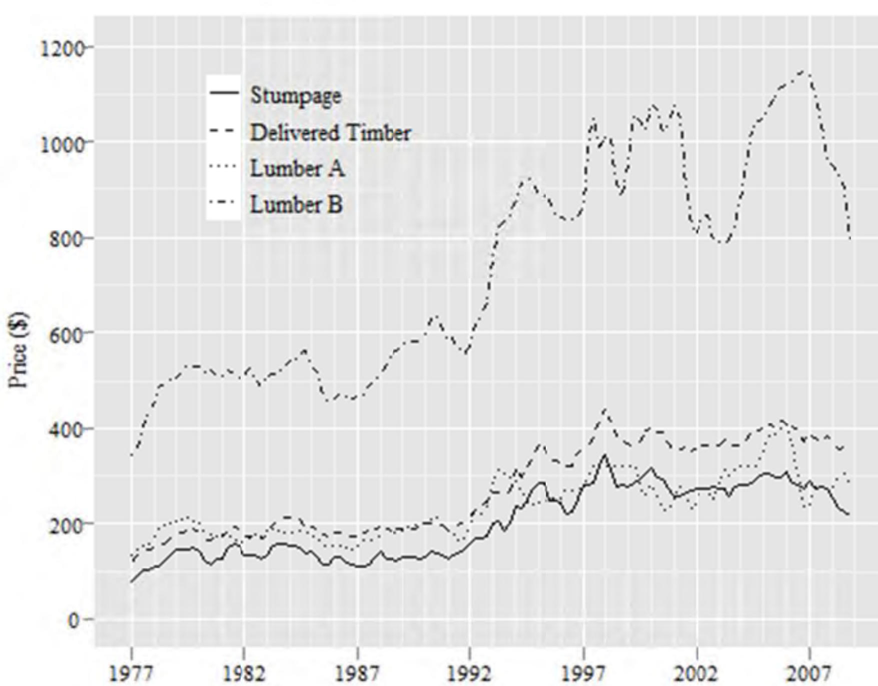

Fig. 1. Quarterly prices of timber and forest products in the South (1q. 1977 – 4q. 2009).

As mentioned above, the ADF test is employed to examine nonstationarity of the four prices. The lag length for ADF test is determined by the AIC statistic and Ljung-Box Q test. The procedures proposed by Enders (2004) are followed to perform the regression. As reported in Table 1, the statistics reveal that unit roots cannot be rejected at the 10% level for all the four prices but all can be rejected at the 1% level for the first difference form. Thus, it could be concluded that stumpage price, delivered timber price and the two selected lumber prices in southern timber market are integrated of order one.

4.2. Results of linear cointegration analysis

Cointegration could be investigated among each pair of upstream and downstream variables; moreover, although delivered timber price is an upstream price when it is matched with lumber prices, it turns to be a downstream price when it is compared with stumpage price. So finally, five pairs of prices (LA~PD, LB~PD, LA~PS, LB~PS, PD~PS) would be under price transmission analysis in this study. To begin with, the linear cointegration between the five pairs of prices could be conducted by both Johansen test and Engle-Granger two-step approach.

Firstly, cointegration between pairs of prices would be determined by Johansen test. Two specific models with two tests respectively would be involved as mentioned in methodology section. Lag length for all the four test types is three, based on lowest AIC and BIC. As reported in Table 2, conclusions drawn from each test are quite different from one another: although none of the null hypothesis of one cointegration could be rejected by either maximum eigenvalue or trace statistics, only one null hypothesis of on cointegration could be rejected at 10% significance level when there is a trend in the model, implying only stumpage price and delivered timber price out of the five pairs are cointegrated if only this model is taken into consideration. Nevertheless, both null hypotheses could be rejected when pairs of prices include the price of LA with the Johansen approach model with a constant. However, pairs of prices with LB could not be proved to be cointegrated with upstream prices with this test, maybe due to the price gap between LB and other wood products, and also to the linear and symmetric transmission hypothesis rooted in the model per se.

Table 2 Results of the Johansen cointegration tests on the prices

Pairs of Prices	Johansen λ_{max}				Johansen λ_{trace}			
	Trend		Constant		Trend		Constant	
LA~PD	r = 1	3.52	r = 1	3.32	r = 1	3.52	r = 1	3.32
	r = 0	15.77	r = 0	15.99**	r = 0	19.29	r = 0	19.31*
LB~PD	r = 1	2.93	r = 1	2.90	r = 1	2.93	r = 1	2.90
	r = 0	10.09	r = 0	9.33	r = 0	13.02	r = 0	12.24
LA~PS	r = 1	3.10	r = 1	3.09	r = 1	3.10	r = 1	3.09
	r = 0	16.71	r = 0	16.01**	r = 0	19.81	r = 0	19.10*
LB~PS	r = 1	3.04	r = 1	2.71	r = 1	3.04	r = 1	2.71
	r = 0	10.40	r = 0	10.31	r = 0	13.44	r = 0	13.02
PD~PS	r = 1	2.83	r = 1	2.98	r = 1	2.83	r = 1	2.98
	r = 0	26.01***	r = 0	9.44	r = 0	28.84**	r = 0	12.43

Note: r is the number of cointegrating vectors. *, **, and *** denote significance at the 10%, 5% and 1% level, respectively. The critical values are from Enders (2004).

As the second linear cointegration test, the implement of Engle-Granger approach involves two steps. The first step is a long-term relationship regression between upstream price and downstream price, with specification as Equation (2); without prior information of market drive, either upstream or downstream price could be independent variable. And the second step would be a unit root test conducted on the residual obtained from step one, as specified in Equation (3). Two to seven are proved to be the proper lag lengths for conducting the tests respectively indicated by AIC and Ljung-Box *Q*. The statistic results are described in Table 3, except the pair of stumpage price and delivered timber price, null hypotheses of no cointegration could all be rejected at least with 5% significance level.

4.3. Results of the threshold cointegration analysis

As explained in the methodology part, four threshold autoregression models, TAR, MTAR, and their consistent specifications are planned to conduct the nonlinear cointegration

Table 3 Results of the Engle-Granger tests

Pairs of Prices	ρ (t-value)		AIC	BIC	Q_{LB} (4)	Q_{LB} (8)	Q_{LB} (12)
LA~PD	-0.242***	(-4.962)	1005.322	1019.582	0.9931	0.9094	0.9312
PD~LA	-0.182***	(-4.096)	1087.792	1102.052	0.9963	0.8014	0.7429
LB~PD	-0.345***	(-4.861)	1199.430	1225.098	0.9893	0.999	0.9952
PD~LB	-0.215***	(-3.630)	1027.817	1042.077	0.9285	0.3243	0.2167
LA~PS	-0.262***	(-4.971)	1028.159	1042.419	0.6063	0.5054	0.605
PS~LA	-0.183**	(-3.276)	1034.589	1054.553	0.8523	0.7934	0.6905
LB~PS	-0.201**	(-3.044)	1256.774	1276.738	0.767	0.1618	0.1924
PS~LB	-0.192**	(-2.924)	978.4	998.3643	0.7644	0.1935	0.2915
PD~PS	-0.089	(-0.924)	907.5305	930.3467	0.968	0.9025	0.2779
PS~PD	-0.182*	(-2.327)	871.2878	882.6959	0.7645	0.78	0.1406

Note: ρ refers to ρ in Equation (3); *, ** and *** denote significance at the 10%, 5% and 1% level. The critical values are from Enders (2004).

analysis; procedure by Chan is followed to estimate the threshold. When appropriate lag length is being chosen to address the serial correction in residual series, AIC, BIC and Ljung-Box *Q* statistics are selected to perform as rules of thumb. Under first estimation of the four models, lower AIC and BIC could be acquired when the model are consistent, which is a symbol of better performance, so only statistics of consistent TAR and MTAR are reported in Table 4, with threshold τ, estimation of ρ_1 and ρ_2, as well as two null hypotheses. Furthermore, the consistent MTAR seem to be better performed than consistent TAR.

Table 4 Results of threshold cointegration tests

	Method	Threshold	ρ_1	ρ_2	Φ (H_0: $\rho_1 = \rho_2 = 0$)	F (H_0: $\rho_1 = \rho_2$)
LA~PD	TAR	-26.014	-0.191***	-0.387***	15.343***	5.205**
	MTAR	9	0.023	-0.302***	19.01***	11.29***
PD~LA	TAR	32.571	-0.209***	-0.155***	8.6***	0.495
	MTAR	-22.908	-0.238***	0.137	16.036***	13.542***
LB~PD	TAR	44.164	-0.404***	-0.277***	12.819***	1.832
	MTAR	3	-0.254***	0.463***	14.464***	4.548**
PD~LB	TAR	-16.655	-0.226***	-0.375***	9.754***	2.342
	MTAR	5.885	-0.362***	0.249***	9.12***	1.242
LA~PS	TAR	-25.087	-0.17**	-0.37***	7.415***	4.828**
	MTAR	10	0.002	-0.331***	13.063***	15.241***
PS~LA	TAR	-18.642	-0.174**	-0.111	3.518**	0.545
	MTAR	-12.916	-0.199***	0.132	8.783***	10.505***
LB~PS	TAR	33.501	-0.273***	-0.242***	7.407***	0.108
	MTAR	-31.022	-0.263***	-0.257***	7.347***	0.003
PS~LB	TAR	10.147	-0.185**	-0.268***	5.878***	0.755
	MTAR	10.803	-0.069	-0.262***	7.049***	2.889*
PD~PS	TAR	6.326	-0.146*	-0.265***	5.795***	0.907
	MTAR	2	-0.107	-0.325***	6.917***	3.055*
PS~PD	TAR	-5.475	-0.279***	-0.152*	6.303***	1.027
	MTAR	-1.7	-0.106	-0.207**	7.426***	3.188*

Note: *, **, and *** denote significance at the 10%, 5% and 1% level, respectively. The critical values are from Enders (2004).

When cointegrations are investigated with these nonlinear models, all relationships between upstream prices and downstream prices have been testified to be cointegrated at 5% level regardless of transmission direction. Even two pairs have not proved to be cointegrated very well with former tests are included, verifying the conclusion that Enders and Granger model with threshold fits data better, particularly when asymmetric transmission possibly exists.

Moreover, asymmetric price transmission has been proved to be the result at least on one lumber price with consistent MTAR model: from the statistics generated by F-test, most significant asymmetric transmission appear in the two pairs of prices including LA, especially upstream prices are set as driving force. Yet the asymmetry is not quite severe, if there is any, when the other three pairs without LA are taken into consideration. Specifically, point estimate have demonstrated that positive deviation converges more slowly from long-term equilibrium than negative deviations, when LA is a dependent variable in the model. For example, when price transmission is estimated by consistent TAR model from delivered timber price to LA price, positive deviations resulting from increases in the LA price or decreases in the delivered timber price are eliminated at 19.1% per quarter; negative deviations from the long-term equilibrium resulting from decrease in the LA price or increases in the delivered timber price are eliminated at a rate of 38.7% per quarter, twice as fast as that of the positive deviation. In other words, positive deviations take about more than fifteen months (1/19.1% = 5.24 quarters) to be fully digested while negative deviations take less than eight months only. Almost all other significant point estimates have shown positive asymmetry on price transmission when lumber prices are set as dependent variable.

4.4. Results of error correction model

Given the consistent MTAR model is the best among these from the threshold cointegration analyses, the error correction terms are constructed using Equations (4) and (5b). The asymmetric error correction model with threshold cointegration is estimated, with three to seven lags selected by AIC, BIC and Ljung-Box Q statistics with each model respectively. Key statistics are reported in Table 5, including null hypothesis of Granger causality tests, cumulative asymmetric effects, as well as symmetric momentum equilibrium adjustment path.

The hypotheses of Granger causality between the prices are assessed with F-tests. Generally speaking, causality interactions between stumpage prices, delivered timber prices and lumber prices are not as strong as that between stumpage price and delivered timber price. Specifically, although most prices have strong impact on themselves' evolution, only three out of five pairs of prices are proved to have brought price fluctuation to the corresponding price. Among the three pairs, causality between delivered timber price and price of LB, as well as between stumpage price and delivered timber price seem to be bidirectional, in other words, change of either price significantly causes change of the other one. But the causality between stumpage price and price of LA seem to exist only when downstream price is transmitted to upstream price. That is to say, the price of LA evolves more independently or it is driven by factors other than upstream prices; while the price of stumpage price has been dependent on price of LA.

Furthermore, the cumulative asymmetric effects are also examined. Little evidence of asymmetric cumulative effect has been found neither upward nor downward. Except that when the transmission is between stumpage price and delivered timber price: null hypothesis of symmetric cumulative effect could be rejected at 10% level when delivered timber price is transmitted to stumpage price, which is not extremely significant.

Table 5 Results of the asymmetric error correction model with threshold cointegration

Pairs of Prices		δ^+	δ^-	H_1	H_2	H_3	H_4	H_5
1	PD	-0.097	0.089*	1.811†	0.641	0.990	0.838	3.268*
	LA	0.085	-0.250***	0.495	13.151***	2.223†	0.269	8.223***
	LA	0.187***	-0.177**	9.034***	1.143	3.990**	1.091	15.726***
	PD	-0.113***	0.014	1.313	2.377**	2.477†	2.897*	2.591†
2	PD	0.007	0.047*	1.442	1.134	0.157	0.043	1.260
	LB	-0.224***	-0.127*	1.977*	14.372***	0.235	1.591	1.345
	LB	0.575***	0.588***	9.835***	1.714*	3.645*	0.342	0.003
	PD	-0.097	-0.093	1.981**	1.619*	0.000	0.251	0.001
3	PS	-0.023	0.140**	4.363***	0.429	2.745†	0.535	4.728**
	LA	-0.059	-0.335***	2.095**	7.505***	0	0.018	8.698***
	LA	0.189***	-0.102	6.200***	1.833*	1.914	1.594	7.607***
	PS	-0.154***	-0.033	0.549	5.072***	2.490†	6.424**	2.302†
4	PS	0.034	0.013	2.310**	1.071	0.154	1.198	0.414
	LB	-0.084†	-0.213***	1.450	12.779***	1.082	4.521**	3.220*
	LB	0.644**	0.368***	10.048***	1.153	4.451**	0.295	0.987
	PS	0.058	-0.097†	0.898	2.676***	0.049	0.980	1.650
5	PS	-0.093	0.070	3.247***	3.653***	2.909*	0.416	0.087
	PD	0.006	-0.098	1.792*	1.818**	3.308*	0.926	0.423
	PD	0.117	-0.012	1.823**	1.708*	0.905	3.163*	0.396
	PS	-0.137	0.118	3.659***	3.266***	0.384	3.015*	1.322

Note: §, *, **, and *** denote significance at the15%, 10%, 5% and 1% level, respectively. H_{01} and H_{02}, $\alpha_i^+ = \alpha_i^-=0$ and $\beta_i^+ = \beta_i^-=0$ for all lags respectively, which are Granger causality tests. H_{03} and H_{04} assess the cumulative asymmetric effect: $\sum_{i=1}^J \alpha_i^+ = \sum_{i=1}^J \alpha_i^-$ and $\sum_{i=1}^J \beta_i^+ = \sum_{i=1}^J \beta_i^-$. H_{05} is about equilibrium adjustment path asymmetric effect $\delta^+ = \delta^-$.

The final type of asymmetry examined is the momentum equilibrium adjustment path asymmetries. Two pairs with the price of LA have shown this type of asymmetric price transmission with consistent MTAR model, which is a similar conclusion drawn from nonlinear cointegration analysis. For instance, when the transmission from delivered timber price to lumber board's price is investigated, the point estimates of the coefficients for the error correction terms are -0.097 for positive error correction term and 0.089 for the negative one for delivered timber price: the first sign is wrong while it is not significantly different from zero; the second coefficient is only significant at 10% level. It implies that in the short term the delivered timber price has some different responding speed to positive and negative deviations but the difference is weak. However, for price of LA, coefficient from negative deviation is -0.25, which is significant at 1% level while the coefficient from positive deviation is not significant at all, demonstrating that the price of LA responds to shock bringing negative deviation much faster, which takes about one year to fully digest, than the one in opposite direction. On the other hand, when lumber price is set as the driving force, positive deviation seems to be digested more quickly; actually, this is the coin's other side of the last results. This is also what happens between stumpage price and price of LA. However, generally speaking, momentum equilibrium adjustment path asymmetry is not true when other three pairs are mentioned.

5. Conclusion

Pine timber market plays a significant role among industries in the South, and is also an essential component of national timber market. And therefore, its mechanism, especially price transmission dynamics, should be under thorough investigation, to make timberland investment less risky and more attractive. Thus, the present paper aims to survey integrity and causality between different stages of forest products and examine possible existence of asymmetry in vertical price transmission mechanism in southern timber market of the US.

Three main conclusions could be drawn from the analyses among stumpage price, delivered timber price as well as two lumber prices. Firstly, although Johansen test could not arrive at the conclusion of cointegration between prices of different stages, Engle-Granger two-step approach shows much higher significance on market cointegration particularly with a threshold in the model. The conclusion suggests that generally speaking, southern timber market is efficient and could achieve equilibrium among vertical stages in long term even after shocks. This conclusion is different from that drawn from Zhou and Buongiorno's paper (2005), which may be due to the fact that dimension of upstream price and downstream price in that paper are not chosen to be compatible.

Secondly, when Granger causality tests are employed to examine timber market in the South, causation does not appear to be a prevailing phenomenon among prices of different stages. Unidirectional causation only exists in one out of five pairs of prices: from price of LA upward to stumpage price; two pairs seem to be causes of price fluctuation to one another; nevertheless, price of the left two pairs tend to evolve independently. It implies that the power on price change is not solely downward, sometimes lumber prices have strong influence on the prices of upstream prices, confirming the assumption at the very beginning; while on the other hand, some prices of forest products are independent, or more reasonably, are more liable to be impacted by exogenous variables rather than upstream / downstream prices, such like forestry policy, forestry programs, international trade, etc. This is consistent with one of assumptions claiming "timber demand is subject to exogenous i.i.d. shocks" in a paper discussing dynamic behavior of efficient timber market (Mcgough, Plantinga et al. 2004). However, Mohanty et al. (1996) argued that Granger causality focuses on short run dynamics rather than long run equilibrium relationships, and when long period of forest cultivation is added, this conclusion should not be overstated.

Last but not least, both consistent threshold autoregression model and error correction model confirmed asymmetric price transmission when price of LA is set as dependent variable: adjustment from positive deviations, i.e., increases in the LA price or decreases in upstream prices, always requires longer time than that from negative deviations. That is also to say, prices of forest products among vertical linkage are more sensitive and act more swiftly when the price margin is squeezed than stretched, price of the selected board being mentioned. But it is not the case when other three transmission relationships are under examination. As a result, whether price transmission is symmetric or not depends on the specific products; while at least it is symmetric when price is transmitted between the first two stages: from stumpage price to delivered timber price and backward. And when asymmetry comes to existence, lumber manufacturers are the benefit takers. It is sensible to deduce that market power in this stage along the chain would be an explanation.

On one hand, with the probable expanding demand on lumber consumption in the long run and the relatively stable supply in timber market, international trade may play even a more important role in the approaching future. Vertical market linkage might be altered and lumber prices would be cointegrated with import prices instead of upstream prices. The conclusions drawn from this study may be a hint of this tendency. On the other hand, enormous lumber producers have power over small mills as well as small industry and private timberland owners. The power may influence not only on the margin between stages, but also on the change of margin when there are shocks in timber market, causing more economic loss to the price-takers.

It becomes to be a much more important issue when the recent debt crisis knocked housing market severely, and left loss distribution in timber market a big problem. And therefore, forestry policy and programs are required to improve welfare of small-mill and small-tract owners in this intensely competitive market, moreover, to maintain and even attract investors in forestry sector.

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