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DYNAMICS OF SPRUCE AND PINE MARKET INTEGRATION IN SWEDEN

The paper addresses the performance of the spruce and pine market by evaluating the order of market integration in three Swedish regions namely the Central, Northern and Southern ones. Quarterly data of delivery prices are employed over the period 1999Q1-2012Q4. Various unit root and cointegration tests have been computed. The variables are found to be integrated of first order and cointegrated, especially after controlling for a structural break. This lends support to the Law of One Price (LOP). However, the effects of structural shocks on the forestry are arguably significant and these are controlled while performing a vector error-correction mechanism (VECM)-based Granger-causality test. Bi-directional causality between the Northern and Central markets is uncovered in the short-run. In the long-run, similar causal effect is detected between Northern and Southern markets whilst the Central market emerges as the price leader. Further investigation is carried out using variance decompositions and impulse response functions and these approaches also tend to confirm the existence of a single market well as price interdependence between markets.

Keywords: Spruce and pine sawlogs, spatial price integration, structural break, causality.

Introduction

The Swedish forest industry is one of the oldest and predominant industries together with iron and ore industries in Sweden. Productive forests cover around 56% of the land in Sweden and the forest industry remains a cornerstone for sustaining economic development. While providing employment, the forestry produces newsprint, packaging, cardboard, hygiene products, sawn products, energy, bio-energy products and manages forests. It also conducts research in a variety of different areas, including biofuels, new chemicals and cellulose-based plastic

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[Swedish Forest Industry 2010]. The sawmilling industry holds a particular key-role in Swedish economy. It is the third-largest producer worldwide and largest exporter of sawn timber in Europe. The majority of sawmills in Sweden are owned and managed as private as saw-milling enterprises [Roos *et al*. 2000]. The sawn timber consists mainly of Norwegian spruce (whitewood) and Scots pine (redwood).

The extent to which the sawn wood markets are integrated is a vital indicator of efficiency and performance of the Swedish economy's pricing system of wood products. Market integration can be referred to as the "*… co-movement of price, and more generally, to the smooth transmission of price signals and information across spatially separated markets* [Goletti *et al*., 1995]." As maintained by Hussain *et al*. [2010], in the event a market is well integrated, the government can stabilize prices in one key market only and depend on arbitrage to produce the comparable outcome in other markets. With the avoidance of duplication of intervention, price stabilization cost can be reduced significantly.

To evaluate the market performance and to assist government market interventions, knowledge of the degree of spatial market integration is of utmost relevance. Thus the purpose of the study is to determine to what extent the Swedish spruce and pine market is integrated.

Review of literature

The extent to which the integration of geographical markets can be analyzed is by means of prices rather than trade flows. Price can be seen as the best variable to reflect market development because it is a determinant of both demand and supply [Toivonen, *et al*. 2000]. Correlations of price movements have been investigated for analyzing market integration [Mäki-Hakola, 2004]. A positive and statistically significant correlation coefficient close to one provides support to the hypothesis that two markets are linked. But, this method tends to suffer from inferences bias originating from serial correlation, omitted variables or simultaneity among the prices [Goodwin *et al*., 1999].

The notion of market integration is closely connected to the law-of-one-price (LOP). According to LOP, a commodity price, expressed in a common currency, should be similar in two markets after necessary adjustment on transaction cost has been made. Perfect commodity arbitrage ensures similar price level in different markets. According to Richardson [1978], the following model can be used to test the LOP:

$$P^1_{it} = \delta_0 P^{2\,\delta_1}_{it} C_{it}^{\delta_2} \quad \text{----- (1a)}$$

where P^1_{it} and P^2_{it} reflect the prices for commodity *i* in time *t* in markets 1 and 2 respectively. C_{it} denotes the transaction costs of trade between the two markets. Estimation is done by transforming equation 1(a) into a linear specification using natural logarithm (ln) as follows:

$$\ln P^1_{it} = \delta_0 + \delta_1 \ln P^2_{it} + \delta_2 \ln C_{it} + \mu_{it} \quad \text{----- (1b)}$$

Arbitrage of commodity may not occur instantly but after several months or years. The LOP will tend to hold in the long-run rather in the short-run. In other words, prices will not drift apart in the long-run and should be cointegrated. The strong form of LOP implies δ_0=0 and δ_1=1 and the weak form simply removes these restrictions [Baharumshah and Habibullah, 1995].

The market integration of forest products literature is quite extensive. Buongiorno and Uusivuori [1992] analyze the LOP for the US export price of pulp and paper vis-à-vis six European countries and Japan over the period January 1978 to December 1988. In general, they found evidence of the LOP. Jung and Doroodian [1994] find support for the LOP for four softwood lumber regional markets period 1950-1985 in United States. Baharumshah and Habibullah [1995] find evidence of the LOP for Malaysian timber exports of plywood, sawn timber and wooden moulding vis-à-vis Singapore, United Kingdom, Germany, United States, Hong Kong Japan and Australia over the monthly period January 1985 to December 1992. Riis [1996] finds evidence of market integration between the Danish and Swedish spruce timber over the period 1954-1992.

Hänninen [1998] tests the LOP for imports of soft sawnwood to the United Kingdom from Finland, Sweden, Canada and Russia. Her results do not support the LOP. Thorsen [1998] discover the coniferous timber markets in Denmark, Finland, Norway and Sweden to be integrated, with Sweden and Finland being the price-leaders. Nanang [2000] test the LOP for five regional markets (Atlantic Canada, Quebec, Ontario, Prairies and British Columbia) of softwood lumber in Canada using quarterly data for the period 1981-1997. The LOP is not supported. Toivonen *et al*. [2002] examine roundwood markets in Austria, Finland and Sweden by using annual delivery prices of pine and spruce sawlogs and pulpwood from

1980 to 1997. The Swedish and Finish markets are found to be integrated, with Finland acting as the price-leader. Tang and Laaksonen-Craig [2007] test the LOP for five regional markets (British Columbia, Ontario, Quebec, US east, and US west) of newsprint using monthly data for 1988-2004. No evidence for the LOP is found for these regional markets. For national markets the LOP was valid for the US only.

Data and Research Methodology

Nominal quarterly delivery price data[1] of spruce and pine sawlogs for three regions, namely the Central, Northern and Southern region, over the period 1999Q1 to 2012Q4 are obtained from the Swedish Forest Agency (Swedish Forest Agency, 2012). As per the Timber Measurement Associations [VMF, 2013] that collect harvesting data for roundwood in the three regions, a total of 76.6 million m^3 (solid excluding bark) of roundwood was harvested in 2012, of which 32% came from the northern region, 43.2% from the central region and 24.8% from the southern region. A summary of the data is presented in Table 1. LPN, LPM and LPS denote the real delivery prices in the Northern, Central and Southern region respectively in natural logarithm forms. A quarterly producer price index data [SCB, 2013] is used to compute the real prices. Figure 1 shows the trend of each variable over time.

When markets are poorly integrated, prices tend to be highly volatile. The degree of price volatility is measured by the standard deviation in Table 1. The prices in the three regions tend to be moderately volatile, especially in the Northern and Southern regions. Other results can be obtained by investigating the degree of correlation among the prices. As reported in Table 2, all the Spearman's [1904] correlation coefficients are found to be negative. Only the correlation between LPN and LPM is found to be statistically significant.

Further testing frameworks need to be considered. The preliminary tests, such as unit root[2] and cointegration tests are performed to assess

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[1] Price data for 2002Q3 was not available for Northern Sweden. Consequently, price for the 2002Q3 period was calculated by interpolating the prices for 2002Q2 and 2002Q4.

[2] Two specifications are considered for a unit root test. One test applies a regression which includes a constant term only, while the other a regression which contains both a constant term and a time trend. Since time series data tend to exhibit a trend over time it is more appropriate to consider a regression with both a constant term and a trend. First differencing is likely to remove any deterministic trends. Therefore, the regression should include a constant only.

whether the regional prices follow a common or separate stochastic trend in the long-run. The augmented Dickey-Fuller (ADF) unit root test as developed by Dickey and Fuller [1981] are first computed. The ADF test tests the null hypothesis (H_0) of non-stationarity and can be supplemented with a test of the H_0 of stationarity such as the Kwiatkowski *et al*. [KPSS, 1992] test. But, when data of higher frequency such as monthly or quarterly are analyzed, the spurious regression problem may arise due to seasonality in the series [Han and Thury, 1997]. Hylleberg *et al*. [HEGY, 1990] recommend a test which allows the simultaneous testing for a unit root at frequency zero i.e. a non-seasonal unit root when a unit root may be present at some or all of the seasonal frequencies.

The above tests ignore the occurrence of structural breaks. This can lead to a fall in power of the test to reject a unit root even if the trend stationarity holds [Perron, 1989]. Narayan and Popp [2010] suggest a test which allows for the presence of two endogenous breaks. Their test is argued to have correct size, stable power and is able to identify structural breaks accurately. Apart from a few studies [Andersson *et al*, 2011], most of the studies done in relation to forest product prices have ignored the impact of breaks. P_t is said to be integrated order of d, i.e., $P_t \sim I(d)$, if it were to be differenced by d times to become stationary.

Next, Gregory and Hansen [1996] advocate an ADF cointegration test which accounts for a break. The H_0 of no cointegration with a structural break is tested against the alternative hypothesis (H_1) of the existence of one break in the cointegrating vector.

The leader-follower connection is of particular interest when evaluating market integration. Granger causality test allows us to evaluate which market is leading others in terms of price adjustment. The ρ^{th} order of the VECM structure can be represented as in the following equation:

$$\begin{bmatrix} \Delta LPN_t \\ \Delta LPM_t \\ \Delta LPS_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_2 \end{bmatrix} + \sum_{k=1}^{\rho} \begin{bmatrix} \beta_{11,1k} & \beta_{12,1k} & \beta_{13,1k} \\ \beta_{21,1k} & \beta_{22,2k} & \beta_{23,1k} \\ \beta_{31,1k} & \beta_{32,1k} & \beta_{33,1k} \end{bmatrix} \begin{bmatrix} \Delta LPN_{t-k} \\ \Delta LPM_{t-k} \\ \Delta LPS_{t-k} \end{bmatrix} + \begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{bmatrix} \left[ECM_{t-1} \right] + \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} D_{tb} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_2 \end{bmatrix} \quad \text{----- (2a)}$$

where t = 1, 2, …., T; The α's, β_k's, ϕ's and θ's are parameters to be estimated. $ECM_{it\text{-}1}$ represents the one period lagged error-term derived from the cointegrating vector. ε_1, ε_2 and ε_3 are the error terms The coefficients on the *ECM*s represent how fast deviations from the long run equilibrium are eliminated. The dummy variable D_{tb} captures any structural break arising at a given point in time t. The break dates are obtained from the Narayan-Popp time-series unit root tests of two breaks in the level and slope of the trending series.

A Wald test for the joint significance can be used to examine the direction of any causal relationship[3] among the variables. For instance, *LPM* does not Granger-cause *LPN* if and only if all the coefficients $\beta_{12,1k}; \forall = 1, \ldots, \rho$ are not significantly different from zero in equation 2(a). The dependent variable reacts only to short-term shocks. This can be referred to as the "*short-run Granger causality*" test. Long-run causality can be studied via weak exogeneity test by testing for e.g. H_0: $\phi_1 = 0$. This test can be referred to as the "*long-run Granger causality*" test. The statistical significance of the lagged error-correction term can be to be measured by applying separate *t*-tests on the adjustment coefficients. If the null is not rejected, then *LPM* and *LPS* do not Granger-cause *LPN* in the long-run. It is necessary to check whether the two sources of causation are significant. If all the coefficients $\beta_{12,1k}; \forall = 1, \ldots, \rho$ and ϕ_1 are jointly not significantly different from zero, then *LPM* does not strongly Granger-cause *LPN* in the long-run. This test can be referred as the "*strong Granger causality*" test. If no causality is found, then the "*neutrality hypothesis*" holds.

The causality test does not provide any information about the dynamic properties of the system of equations and relative strength of a variable beyond the sample period. These properties can be indicated by computing both[4] the forecast error variance decompositions and impulse

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[3] The direction of causality among the three price variables has significant policy implications especially when designing in price stabilization policies. If there is no causality, adopting a price controls can be implemented, without the concern of any impact across regions. If a unidirectional causality running from at least one price to the other prevails, this can be interpreted as price leadership for the price which does not change. As such, some form of price regulations can impact in the former market. Obviously, price regulations will affect the overall market in case of bidirectional causality.

[4] The two approaches are based on the Cholesky decomposition method to orthogonalize the exogenous shocks [Sims, 1980]. They also allow a study of the short-run and long-run dynamics among the economic variables and inferences about the direction of causal flows can be done.

response functions. Variance decomposition refers to the breakdown of the change in value of a variable in a given period arising from its own shocks and shocks in other variables. Impulse response functions trace any persistent or transient temporal responses of a shock in one market as well as in other markets. If a shock dies out quickly and the impulse responses convergences after a quarter or two, then the markets can be considered highly integrated but also highly independent from of each other. However, if the shocks accumulate over time, then the markets can be considered as interdependent.

Results

The results of the various time-series test[5] are discussed in the section. Following the discussion above about the order of integration of a time-series, the ADF tests reveal an I(1) process for the LPN_t and LPS_t series, while LPM_t is found to be stationary. However, the KPSS tests confirm a non-stationary and I(1) process for all three series. Indeed, the KPSS test tends to have superior properties in small sample. The ADF and KPSS statistics are reported in Table 3(a). From Table 3(b), the HEGY *t*-statistics of π_1 for all the price series are found to be insignificant at 5% level. Hence, the H_0 of non-stationarity cannot be rejected and these series are found be I(1). The *t*-statistics of π_2 and the joint F-statistics of π_3 and π_4 are significant at 5% level. This implies an absence of seasonal unit roots in the LPN_t, LPS_t and LPM_t series. Next, unit root tests which control for structural breaks are considered. As illustrated in Table 3(c), the Narayan-Popp tests reveal an I(1) process for the three price series.

Since the variables are I(1), cointegration test can be performed. Table 4 exposes the Gregory-Hansen minimum *t*-statistics. Three model specifications, denoted by level, trend and regime, are used to compute the cointegration test. The H_0 of no cointegration is rejected. Hence, evidence of a long-run relationship among the spatial prices is obtained after controlling for a structural break. This result is consistent with the weak form of the LOP.

Referring to the $M2_{B,L}$ test for the price series at level form, the break dates tend to fall mainly around the 2005-2006 period. The Gregory-Hansen test also reveals a break occurring in the 2006 period. These

[5] The maximum lag length (k_{max}) for all unit root and cointegration tests is chosen according to the Bartlett kernel i.e. $4(T/100)^{2/9}$, where $T = 56$. Since the latter is less than 4, k_{max} is set to 3.

breaks tend to coincide with the passing of hurricane Gudrun over Sweden in early January 2005. The storm hit mainly the southern parts of Sweden and about 70 million m^3 trees fell after its passage which is equivalent to twice the amount of normal annual cut in the damaged area [Swedish Forest Agency, 2006]. Most probably, the aftermath of Gudrun had been root breakage of spruce and pine trees which had caused a fall in the vitality of these trees and an increased susceptibility to spruce bark beetle in the following periods [Bolte *at al*., 2012].

A break can also be detected for the LPN_t series in the fourth quarter of 2009. The great recession in the United States during 2007-2009 period resulted in an international financial crisis and sharp drop in global economic activity. However, the Swedish forest industry benefited from the weak krona during this recession. The demand for sawn products fell but raw materials shortages, production cutbacks and closure of mills had lead to supply contracting even further. Consequently, sawn product prices rose during the second quarter of 2009 to the benefits of Swedish sawmills [Swedish Forest Industry, 2010].

Given evidence of cointegration, we next proceed to testing causality using the VECM framework. The optimal order of lag of the VECM for the is chosen according to the Schwarz's Bayesian information criterion (SBIC) and is found to be one. The estimates of the VECM-based trivariate causality test are given in Table 5(a). The VECMs display reasonable goodness-of-fit based on the R^2 and pass most of the diagnostic tests. These tests include the omitted-variable bias regression equation specification error test (RESET) of DeBenedictis and Giles [1998], the Jarque and Bera [1987] normality test, the Breusch and Pagan [1979] heteroskedasticity test and the Breush [1978] and Godfrey [1978] serial correlation test. In most cases, the null of these tests cannot be rejected at the conventional levels. The variance inflation factor (VIF) is found to be lower than 5, implying no multicollinearity. As per O'Brien [2007], a VIF of 5 or 10 and above indicates multicollinearity problem.

Some potential econometric problems are nonetheless detected. The RESET test rejects the null of no omitted variables for the LPN equation at 5% level. However, given the relative limitations in quality and availability of data, the results obtained from the causality test should be considered with some caution [David, 2007]. In addition, although the normality assumption of residuals for equation LPM is rejected at 1%

level, asymptotic results can still hold for a wider class of distributions [von Cramon-Taubadel, 1998].

The structural break dummy is found to be statistically significant for the LPS equation. By and large, since the market is integrated, the effects of shocks tend to be mitigated because it induces trade between surplus and deficit areas. According to Persson [1999], the scope for arbitrage across markets results in the "... *spatial cancelling of harvest disturbances*." Since the timber market is integrated and a harvest failure leads to a rise in one region, then producers exploit arbitrage opportunities by selling their goods in such region. This will eventually lower the price in the latter, while prices in other regions rise until an equilibrium is reached. But even with an integrated market, a major disturbance like Gudrun can severely disrupt the price equilibrium and lead to drastic shortages. Consequently, this displays the importance of controlling for shocks when performing the causality test.

Table 5(b) presents the causality results which are obtained from the VECM. A bi-directional causality between LPN and LPM is found to prevail in the short-run. However, LPS is found to have no impact on the two other spatial prices in the short-run. The coefficients of the ECM variables are found to be statistically significant for the LPN and LPS equations. Thus, both LPM and LPS are found to Granger-cause LPN while LPN and LPS Granger-cause LPS in the long-run. The joint short-run and long-run joint causality test show a strong bi-directionality between LPN and LPS. A strong unidirectional causality running from LPM to LPN prevails. LPM is also found to strongly Granger-cause LPS.

The Central spruce and pine market occupy the leadership position in price formation and transmission. This result is not too surprising as the Central market is the largest of the three in terms of harvesting volumes [Swedish Forest Agency, 2013] and will therefore exert significant influence in the evolution of other market prices.

Table 6 presents the results for the variance decompositions. The assessment is made over a decade or 40-quarter horizon. In the case of LPN, about 74% of the forecast error variance is explained by its own innovations or shocks while LPM and LPS account for about 5% and 21% of the in the forecast error of LPN respectively. Next, LPM explains most of their own forecast error variance by about 68%. LPN and LPS contribute for roughly 25% and 7% in the forecast error variance of LPM correspondingly. In addition, LPM and LPN contribute for roughly 16%

and 8% in the forecast error variance of LPS respectively while about 76% is explained by its own innovations.

The impulse response functions are graphically illustrated in Figure 2. A one standard-error (SE) shock to LPN has an initial positive effect on LPN and LPS, while it has negative one on LPM. The shock has eventually a negative impact on LPN and this tends to die out after ten quarters. LPS is hardly affected by the shock which tends to die out very rapidly after three quarters. The shock on LPM is more pronounced and dies out after approximately 14 quarters. A one SE shock on LPM has an immediate positive effect on LPM, which reaches a peak after two quarters then starts to decline steadily. The shock has also a positive impact on LPS which increases for about five quarters and then begins to fall. However, the shock has practically no initial impact on LPN, a negative impact after one quarter, a positive impact after seven quarters. The shock on the prices tends to die out after 27 quarters. A one SE shock on LPS also tends to die out after similar period. In general, these results confirm the markets to be integrated and also suggest some degree of interdependency among them.

Conclusions

The paper outlines to assess the spatial price linkages in the spruce and pine markets in Central, Northern and Southern Sweden using quarterly data over the period 1999Q1-2012Q4. Several unit root and cointegration tests have been computed. No evidence of seasonal effects is found and the variables are found to be integrated of first order and cointegrated. As such, the weak form of the LOP hypothesis is supported. This has interesting implication for the forecasted expansion of forest-based biofuel production. Firstly, since the LOP holds, the local or regional price effects from an increased utilization will diffuse and will thus not be as large as expected if the regional markets were not integrated. Secondly, an increased utilization in areas with a currently low utilization will nevertheless affect the market prices in the other regions.

A VECM-based Granger-causality test is performed to determine price leadership. Bi-directional causality between the Northern and Central markets is uncovered in the short-run. In the long-run, similar causal effect is detected between Northern and Southern markets whilst the Central market emerges as the price leader. Moreover, variance decompositions and impulse response functions tend to confirm the above results about an integrated market and provide some evidence of price interdependency across markets.

Aggregation at regional, national or international level is often unavoidable. Since the market of spruce and pine is integrated, long-run aggregate market analysis is feasible [Yin and Xu, 2003]. Moreover, the causality results have shed light on process of price formation across regions and could be used in forecasting. Since the Central market is acting as the price leader, spruce and pine prices can be used to predict future prices in the Northern and Southern markets. Such knowledge can be helpful in designing price stabilization programmes whereby policies affecting the Central market will affect other markets and not vice versa. In essence, market integration analysis can assist policymakers in efficient long-term decision making.

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Acknowledgements

We thank the Kempe Foundation and Bio4Energy, a strategic research environment appointed by the Swedish government, for their financial support. Errors, if any, are the authors' own.

Table 1. Descriptive statistics

Series	Mean	Standard Deviation	Minimum	Maximum
LPN	5.793	0.064	5.696	5.994
LPM	4.851	0.159	4.383	5.211
LPS	5.810	0.078	5.549	6.010

Table 2. Spearman's rank correlation matrix

	LPN	LPM	LPS
LPN	1.000	-	-
	[-]		
LPM	-0.685	1.000	-
	[0.000]*	[-]	
LPS	-0.059	-0.008	1.000
	[0.109]	[0.955]	[-]

Note: The p-values are in square brackets. *, + and ‡ denote 1%, 5% and 10% levels respectively.

Table 3(a). Time series unit root tests without break

Series	ADF				KPSS			
	Level Form		First Difference		Level Form		First Difference	
	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend
LPN_t	-2.806(0)‡	-2.842(0)	-7.673(0)*	-7.610(0)	0.220(2)	0.210(2)+	0.043(3)	0.037(3)
LPM_t	-2.429(1)	-3.219(1)‡	-5.318(0)*	-5.268(0)	0.847(2)*	0.216(2)+	0.054(2)	0.042(2)
LPS_t	-2.686(0)‡	-2.690(0)	-8.180(0)*	-8.096(0)	0.210(2)	0.190(2)+	0.071(3)	0.054(3)

Note: The ADF test tests for the H_0 of non-stationarity. ADF critical values without and with a trend are -3.57, -2.93 and -2.60; and -4.14, -3.50 and -3.18 at 1%, 5% and 10% significance levels respectively (MacKinnon, 1991). The optimal lag is chosen as per the SBIC. As per the KPSS test, the H_0 of stationarity is tested. KPSS one-sided critical values without a trend at 1%, 5% and 10% levels are 0.739, 0.463 and 0.347 and with a trend, these are 0.216, 0.146 and 0.119 respectively. The optimal lag is in parentheses.

Table 3(b). Seasonal time series unit root tests

Parameters	HEGY				
	Series			Critical Values	
	LPN_t	LPM_t	LPS_t	5%	10%
Level Form:					
π_1	-2.621	-3.042	-2.191	-3.696	-3.358
π_2	-4.186+	-4.534+	-4.350+	-3.069	-2.722
π_3	-3.520‡	-2.789	-4.337+	-3.646	-3.269
π_4	-3.714+	-4.489+	-2.796+	-1.912	-1.482
$\pi_3 = \pi_4$	18.642+	19.229+	18.094+	6.554	5.382
First					
Difference:	-3.826+	-3.372+	-3.784+	-3.700	-3.361
π_1	-3.499+	-3.655+	-3.705+	-3.072	-2.724
π_2	-4.433+	-4.559+	-4.546+	-3.650	-3.272
π_3	-0.818	-1.986+	0.474	-1.912	-1.482
π_4	10.528+	14.720+	10.588+	6.553	5.379

$\pi_3 = \pi_4$					

Note: The test tests for the presence of a unit root by testing H_0: $\pi_1 = 0$ against H_0: $\pi_1 < 0$, and for the existence of a seasonal unit root by testing H_0: $\pi_2 = 0$ against H_1: $\pi_2 < 0$ and simultaneously testing H_0: $\pi_3 = \pi_4 = 0$ against H_0: $\pi_3 < 0$, $\pi_4 \neq 0$. The H_0 of seasonal unit root is only rejected when the *t*-test for π_2 and the joint F-test for π_3 and π_4 are rejected. The test includes seasonal dummies, constant and a trend. The optimal lag is chosen as per the SBIC.

Table 3(c). Time series unit root test with two breaks

Series	$M1_{B,L}$						$M2_{B,L}$					
	Level Form			First Difference			Level Form			First Difference		
	t-value	T_{B1}	T_{B2}	*t*-value	T_{B1}	T_{B2}	*t*-value	T_{B1}	T_{B2}	*t*-value	T_{B1}	T_{B2}
LPN_t	-3.2(0)	05Q1	06Q2	-9.9(0)*	04Q4	06Q4	-3.6(2)	05Q1	09Q4	-9.3(0)*	04Q4	06Q4
LPM_t	-3.6(0)	05Q1	06Q2	-7.7(0)*	04Q4	06Q4	-2.7(1)	05Q1	06Q2	-3.1(0)*	05Q1	06Q1
LPS_t	-2.8(0)	05Q2	05Q4	-9.5(0)*	05Q3	06Q1	-1.8(0)	05Q4	06Q3	-8.1(0)*	05Q3	06Q2

Note: $M1_{B,L}$: Test equation for two breaks in the level of a trending series. $M2_{B,L}$: Test equation for two breaks in the level and slope of a trending series. T_{B1} and T_{B2} are the dates of the structural breaks. The one-sided critical values are -5.259, -4.514 and -4.143 respectively for model $M1_{B,L}$ and -5.949, -5.181 and -4.789 at 1%, 5% and 10% level of significance (*T*=50) for model $M2_{B,L}$.

Table 4. Cointegration test with one break

Model	Gregory-Hansen				
	Minimum *t*-statistics	T_{B1}	Critical Values		
			1%	5%	10%
Level	-5.74(0)*	2006Q4	-5.44	-4.92	-4.69
Trend	-5.87(0)*	2006Q4	-5.80	-5.29	-5.03
Regime	-5.62(0)+	2006Q4	-5.97	-5.50	-5.23

Note: Level specifies a break in the constant term. Trend specifies a break in the constant and the trend. Regime specifies a break in the constant and the slope. The ADF test is employed to estimate the minimum *t*-statistics.

Table 5(a). VECM estimates

Independent Variable	Dependent Variable		
	ΔLPN_t	ΔLPM_t	ΔLPS_t
ΔLPN_{t-1}	-0.361 (0.246)	0.856 (0.101)+	-0.356 (0.225)
ΔLPM_{t-1}	-0.297 (0.142)+	0.650 (0.243)+	0.076 (0.136)
ΔLPS_{t-1}	-0.150 (0.118)	-0.037 (0.199)	0.158 (0.168)
ECM_{t-1}	-0.304 (0.167)‡	-0.036 (0.111)	-0.318 (0.118)+
D_{tk}	-0.004 (0.021)	0.034 (0.035)	-0.077 (0.030)+
Constant	0.006 (0.006)	-0.003 (0.011)	0.007 (0.007)

Observations	54	54	54
R^2	0.24	0.17	0.31
DeBenedictis-Giles Test	2.92 [0.018]$^{+}$	1.10 [0.377]	1.63 [0.162]
Jarque-Bera Test	3.27 [0.195]	15.65 [0.000]*	3.53 [0.171]
Breush-Pagan LM Test	0.74 [0.389]	0.47 [0.494]	0.23 [0.631]
Breusch-Godfrey Test	3.77 [0.287]	5.17 [0.160]	0.20 [0.977]
VIF	2.15	2.08	2.12

Table 5(b). VECM-based trivariate Granger causality test

Equation	Short-Run			Long-Run			
	F-statistics			*t*-statistics	Joint F-statistics		
	LPN	LPM	LPS	ECM	LPN, ECM	LPM, ECM	LPS, ECM
LPN	-	4.36 [0.042]$^{+}$	1.63 [0.207]	-1.83 [0.074]‡	-	5.16 [0.009]*	2.78 [0.072]‡
LPM	4.56 [0.038]$^{+}$	-	0.04 [0.852]	-0.33 [0.744]	2.29 [0.112]	-	0.08 [0.924]
LPS	1.80 [0.187]	0.26 [0.616]	-	-3.31 [0.002]*	5.67 [0.006]*	6.26 [0.004]*	-

Table 6. Orthogonalized forecast error variance decomposition

Error in:	Time Horizon	Explained by Innovations in:		
		LPN	LPM	LPS
LPN	0	1.000	0.000	0.000
	8	0.827	0.042	0.131
	16	0.757	0.044	0.199
	24	0.742	0.049	0.209
	32	0.741	0.050	0.209
	40	0.741	0.050	0.209
LPM	0	0.650	0.350	0.000
	8	0.306	0.673	0.021
	16	0.259	0.684	0.057
	24	0.253	0.681	0.066
	32	0.253	0.680	0.067
	40	0.253	0.680	0.067
LPS	0	0.130	0.004	0.866
	8	0.084	0.100	0.816
	16	0.081	0.149	0.771
	24	0.079	0.156	0.765
	32	0.079	0.156	0.764
	40	0.079	0.156	0.764

Figure 1. Trend in the spatial prices of spruce and pine sawlogs

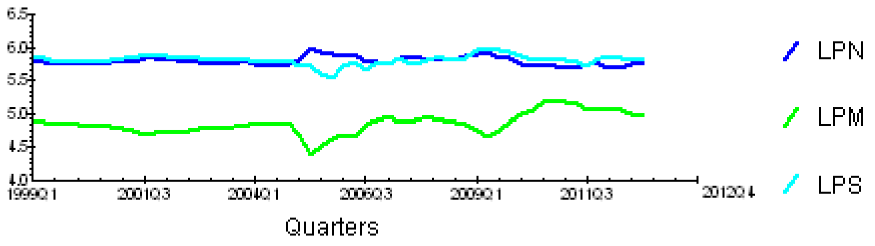
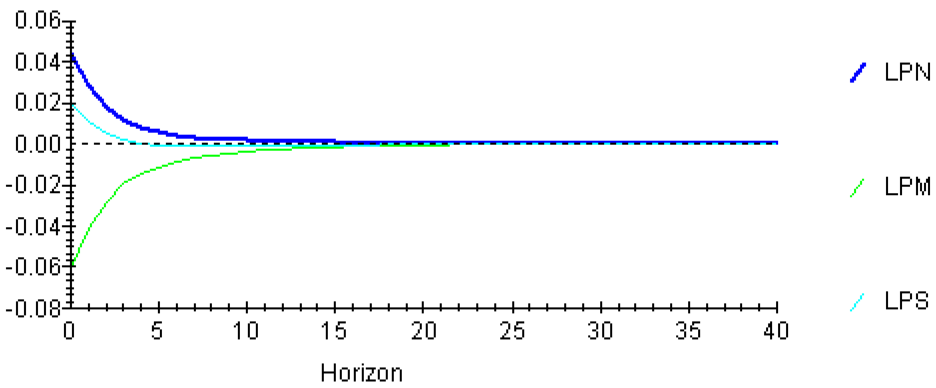
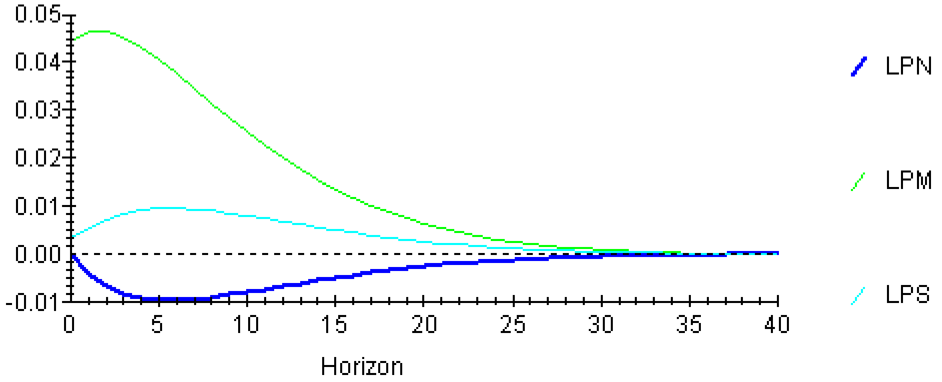


Figure 2. Orthogonalized impulse responses to one se shock in the equations for lpn, lpm and lps respectively

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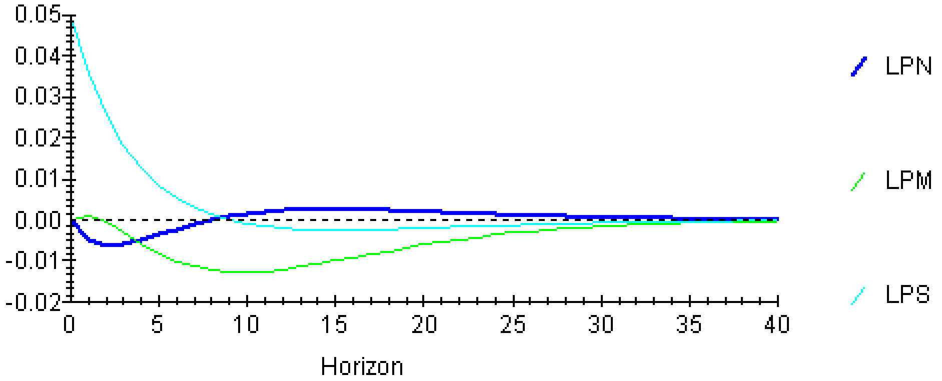
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