ARTICLE

Common integrating factor in softwood log exports from the United States

Changyou Sun, Jean M. Daniels, and Kate C. Marcille

Abstract: Softwood logs comprise a large portion of forest product exports from the United States. Most of these exports have occurred between the Pacific Northwest region of the United States and several Asian countries. In this study, the extent and degree of market integration of softwood log exports from 1996 to 2018 are examined by co-integration analyses and permanent–transitory decomposition. Softwood log exports to Japan and South Korea appear to be in the same economic market and show a high degree of integration, while trade between the United States and China has evolved more independently. A detailed analysis is conducted on five prices related to Japan and South Korea with full-time coverage, and one common integrating factor is found and estimated. The price of export from the Columbia-Snake Customs District to Japan is identified as the driving force. Price responses to market shocks usually occur within four months. These findings have implications for government agencies and participants in the market of softwood log trade.

Key words: common integrating factor, impulse response, multivariate linear co-integration, permanent–transitory decomposition, vector error correction model.

Résumé : Les billes de résineux représentent une grande proportion des produits forestiers exportés par les États-Unis. La plupart de ces exportations ont eu lieu entre la région Pacifique Nord-Ouest des États-Unis et plusieurs pays asiatiques. Dans cette étude, l'étendue et le niveau d'intégration des marchés d'exportation des billes de résineux entre 1996 et 2018 sont examinés grâce à des analyses de cointégration et de décomposition en composantes permanente et transitoire. Les exportations de billes de résineux vers le Japon et la Corée du Sud semblent faire partie du même marché économique et montrent un degré élevé d'intégration, tandis que le commerce entre les États-Unis et la Chine a évolué de manière indépendante. Une analyse détaillée a été réalisée sur cinq prix associés au Japon et à la Corée du Sud selon une couverture à plein temps. Un facteur d'intégration commun a été trouvé et estimé. Le prix à l'exportation du district douanier de Columbia-Snake vers le Japon est le facteur déterminant. La réaction des prix aux chocs du marché survient généralement en dedans de quatre mois. Ces résultats ont des répercussions pour les organismes gouvernementaux et les participants impliqués dans le commerce des billes de résineux. [Traduit par la Rédaction]

Mots-clés : facteur d'intégration commun, réponse impulsionnelle, cointégration linéaire multivariée, décomposition en composantes permanente et transitoire, modèle vectoriel à correction d'erreurs.

1. Introduction

The United States has been a large exporter of softwood logs to the Pacific Rim (Daniels 2005, 2008). Based on the statistics from the U.S. International Trade Commission (U.S. ITC 2019), the mean annual export value of softwood logs in recent years has been well above one billion dollars (US currency is used throughout this paper). Most exports have occurred between ports in the Pacific Northwest region of the United States and several importing countries in Asia (e.g., Japan, South Korea, and China). Before 1998, this market was maintained mainly owing to Japan's strong demand from its construction industry for high-quality logs. In recent years and especially after the 2008 global financial crisis, Russia imposed various restrictions on its log (i.e., roundwood) exports (Sun 2014). As a result, China has turned to the United States for more log imports and has since become the leading importer. Furthermore, since 2018, China and the United States have entered an intensive trade war that has affected the transac-

tion of all goods and services between the world's two major economies. Given the massive trade volume and unstable business environment, there has been a critical need to examine the dynamics and integration in this market of softwood log trade.

Market integration has been examined extensively in the literature. Several similar issues have also been covered, including market efficiency, the law of one price, and price transmission (Barrett 2001; Baulch 1997; Frey and Manera 2007). Among the many approaches adopted in previous studies, multivariate linear co-integration analysis has been utilized most frequently. The main advantage of this approach is the ability to handle multiple markets or variables at the same time in comparison with other methods (e.g., threshold co-integration analysis). However, in the applications of multivariate linear co-integration analysis, past studies have usually focused on estimating the co-integrating vectors only. The common integrating factor is eliminated when the co-integrating relation is calculated, and little attention has been paid to finding the common long-run component that gives rise to

C. Sun. Department of Forestry, Mississippi State University, Mississippi State, MS 39762, USA.
J.M. Daniels. Forest Service, Pacific Northwest Research Station, Portland, OR 97205, USA.
K.C. Marcille. Bureau of Business and Economic Research, University of Montana, Missoula, MT 59812, USA.
Corresponding author: Changyou Sun (email: cs258@msstate.edu).

co-integrated variables (Gonzalo and Granger 1995). Furthermore, a market is usually defined based on a set of geographical locations where a commodity is produced or traded. González-Rivera and Helfand (2001) argued that multivariate linear co-integration analysis could be extended to search and define the exact boundary of an integrated economic market.

In the forest sector, market integration has also been evaluated for several forest products, e.g., Buongiorno and Uusivuori (1992) for pulp and paper products, Hänninen et al. (1997) for newsprint, and Shahi and Kant (2009) for softwood lumber. In particular, two studies have closely examined the log market in the Pacific Northwest. Stevens and Brooks (2003) analyzed whether markets for Alaska lumber and logs were integrated with those of similar products from the Pacific Northwest of the United States and Canada through co-integration analyses on paired price data. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carrière) logs from Alaska were found to share an integrated market with logs produced in the other two regions. Yin and Xu (2003) identified several intermarket relationships of forest products using co-integration and causality tests between domestic and export sawlog and lumber markets in the Pacific Northwest. The log markets were found to be integrated, and the causality tests revealed that export lumber prices led to the movement of domestic sawlog prices. However, both of these log market studies focused on price pairs. González-Rivera and Helfand (2001) compared the results from bivariate versus multivariate linear co-integration analyses on 15 price series. The shortcoming of a bivariate approach to market integration lies in the misspecification of the vector error correction representation of a co-integrated system. When relevant variables are omitted, the estimators become inconsistent. The inconsistency is carried forward to any other statistic that is based on the vector error correction model. Given that multiple ports and destinations are involved in the softwood log exports from the United States, a multivariate linear co-integration analysis is necessary.

The objective of this study is to examine the extent and degree of market integration of softwood log exports from the Pacific Northwest in the United States. The study covers the period of 1996 to 2018, five customs districts (Anchorage, Seattle, Columbia-Snake, San Francisco, and Los Angeles), and three destination countries (Japan, South Korea, and mainland China). A set of time series econometric methods is employed in the analysis (Gonzalo and Granger 1995; Johansen 1988; Pesaran and Shin 1996). Multivariate linear co-integration analyses are used to identify the boundary of an integrated economic market. A permanent–transitory decomposition is applied to reveal the common integrating factor in the integrated market. The persistent profile and generalized impulse response function are used to illustrate the short-run adjustment in the market and the degree of market integration.

The findings from this study will make several contributions to the literature. First, the assessment not only covers the recent two decades, but also accommodates detailed space variation in trade. Five customs districts and three destination countries are considered explicitly in the study design, which allows us to have a thorough examination of the spatial dimension of the softwood log export market. Second, the market boundary within the economic context will be established by co-integration techniques, instead of being solely defined by geographical borders and trade flow. The findings will reveal which set of trade volumes are more relevant and thus can form an integrated market. Finally, the common integrating factor will be estimated through the decomposition of observed price variables. The outcome is particularly

insightful because it will identify the price variable and associated locations that contribute the most to the long-run behavior of softwood log exports from the United States.

2. Methodology

To assess the market integration of softwood log exports from the United States, several time series econometric methods are employed in this study. In the beginning, multivariate linear co-integration analysis (Johansen and Juselius 1990) is used to evaluate the co-integration relationship among export prices of softwood logs. The boundary of the export market is determined, and interdependence within the softwood log market is analyzed (González-Rivera and Helfand, 2001). Then the method proposed by Gonzalo and Granger (1995) is followed to decompose export price series into permanent and transitory components. The driving force in the softwood log market is identified, and its magnitude is quantified. Finally, the persistence profile and generalized impulse response function are used to reveal short-run dynamics in the export market of softwood logs (Pesaran and Shin 1998; Pesaran and Shin 1996).

2.1. Co-integration analysis

Consider a vector of X_t with N nonstationary price variables of interest (e.g., the price series of softwood log exports in this study). Variation in the price variables can be explained by a general polynomial distributed lag process (i.e., a vector autoregressive model). A multivariate linear co-integration analysis involves reformulating the vector autoregressive model as

$$(1) \qquad \Delta X_t = \Pi X_{t-K} + \sum_{i=1}^{K-1} \Gamma_i \Delta X_{t-i} + \epsilon_t$$

where Π and Γ_i are coefficients; ϵ_t is the error term; and i, j, and h are indexes. The lag order of K for the vector autoregressive model can be selected with the Akaike information criterion (Johansen 1988; Johansen and Juselius 1990).[1]

The above equation contains information on both the short- and long-run adjustments to changes in X_t via the estimates of Γ_i and Π, respectively. The number of distinct co-integrating vectors (r) that exists among the variables of X_t is given by the rank of Π. This matrix also can be expressed as $\Pi = \alpha\beta'$, where α represents the speed of adjustment to a market shock, and β is the matrix of long-run coefficients. The existence of co-integrating relationships indicates that although X_t is nonstationary, the linear combinations of $\beta'X_{t-K}$ are indeed stationary, and hence the columns of β form r distinct co-integrating vectors among the vector of X_t.

The application of co-integration analysis in the multivariate context involves several steps. First, the integration order of individual price series needs to be evaluated. The unit root test by Zivot and Andrews (1992) can accommodate a potential breakpoint at an unknown time, and it will be utilized to examine whether a time series has a unit root. If the unit root test reveals that all the variables are integrated of the same order of one, then the long-run equilibrium relationship can be estimated. With the Johansen method (Johansen 1988), the trace or maximum eigenvalue statistics can be employed to determine the number of co-integrating vectors.

If the variables are co-integrated, the dynamic behavior of the model can be further examined by specifying and estimating a vector error correction model, which includes an error correction term to characterize disturbance on the long-run equilibrium.

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[1]The trade dispute between the United States and China since 2018 can affect the export of softwood log exports. Using a dummy variable in the regression to represent the dispute was considered but avoided because the dispute contains multiple events without distinct contents and boundaries and the relevant period is too short.

The correspondence between co-integration and the error correction model is formalized in the Granger representation theorem (Engle and Granger 1987). The size of the error correction term measures the speed of adjustment from any market shock towards a long-term equilibrium state.

2.2. Common integrating factor

The above analysis focuses on finding the number of co-integrating vectors. A co-integrated system also implies the existence of underlying, common, integrating factors. In many applications of multivariate co-integration analysis, the integrating factor is often eliminated when the co-integrating relationship is estimated, and the common long-run component that gives rise to the co-integrated price variables is ignored. In the seminal study by Gonzalo and Granger (1995), the issue was addressed by estimating the common integrating factor separately and explicitly from a co-integrating system. This approach is particularly attractive because the common integrating factor is derived from observable price variables and allows for the identification of variables with a major contribution to the long-run equilibrium, as shown in several applications (e.g., Flad and Jung 2008; Rashid 2004; Shahi and Kant 2009).

Specifically, the approach by Gonzalo and Granger (1995) provides an alternative form for the system of co-integrated variables. If the vector of X_t contains r co-integrating vectors, then the number of common integrating factor (s) among the variables is equal to $(N - r)$, where N is the dimension of X_t. Based on the Granger representation theorem, the co-integrated system can be decomposed into two parts: one is the nonstationary permanent component of f_t (i.e., the common integrating factor), and the other is the transitory component of z_t:

(2) $\qquad X_t = A_1 f_t + A_2 z_t$

where f_t and z_t are of dimension $s \times 1$ and $r \times 1$, respectively; A_1 is an $N \times s$ loading matrix; and A_2 is an $N \times r$ loading matrix. The identifying restrictions are that f_t is a linear combination of X_t and that the transitory part $A_2 z_t$ does not Granger-cause the permanent part $A_1 f_t$ in the long run. The decomposition can be further expressed in detail as

(3) $\qquad X_t = \beta_\perp \left(\alpha'_\perp \beta_\perp \right)^{-1} \alpha'_\perp X_t + \alpha(\beta'\alpha)^{-1}\beta'_\perp X_t$

where $\alpha_\perp$ and $\beta_\perp$ are the orthogonal complements to α and β, respectively; $A_1 = \beta_\perp(\alpha'_\perp \beta_\perp)^{-1}$, $f_t = \alpha'_\perp X_t$, $A_2 = \alpha(\beta'\alpha)^{-1}$, and $z_t = \beta'_\perp X_t$; and the transpose of a matrix is denoted with the prime sign. The estimate of f_t will allow us to gauge the nature and magnitude of the common permanent trend. When the vector of X_t is decomposed, the two components can be plotted to reveal their evolution over time.

In addition, the permanent–transitory decomposition can be used to identify whether information from one market contributes to the permanent component, as well as which price variable is the driving force in the system. A hypothesis on f_t can be examined by using a likelihood ratio test on $\alpha_\perp$ as $\alpha_\perp = G\theta$, where G is a $N \times m$ restriction matrix on $\alpha_\perp$; m is the number of restrictions that are imposed on the common integrating factor; and θ is the $m \times s$ matrix of restricted coefficients. The test statistic has a χ^2 distribution with $s \times (N - m)$ degrees of freedom.

In applying the above techniques on the Brazilian rice market, González-Rivera and Helfand (2001) expanded the approach to establish the boundary of an integrated economic market, which is followed in this study. Specifically, a market with N price variables in geographically distinct locations is considered integrated if two conditions are satisfied. First, there must be physical flows of goods connecting all N locations, either directly or indirectly.

Second, there is only one common integrating factor (i.e., $s = 1$) among the N price variables corresponding to the locations of interest. Thus, the number of co-integrating vectors is equal to $r = N - s = N - 1$. In our application, sequential multivariate searches will be employed to identify a single common integrating factor and establish the boundary of an economic market.

2.3. The persistence profile and impulse response

An analysis of the short-run dynamics in an integrated market is always critical because it can help illustrate how the market responds to shocks and ultimately returns to the long-run state. Several techniques for analysis are available in time series econometrics. They differ by where a shock originates and what market response is of interest. In this study, the persistence profile and generalized impulse response function are employed. Given the study focus on identifying the market with only one common integrating factor, these techniques are well suited to reveal the response of individual co-integrating vectors to a shock on the whole system.

The persistence profile developed by Pesaran and Shin (1996) can be used to analyze the time profile of the long-run impact of a shock to the whole system or market. It characterizes the response of a co-integrating relationship among several price pairs to a system-wide shock (scaled and normalized to one), rather than to a shock on an individual variable. It can measure the reaction time of each long-run equilibrium relationship to absorb the shock. The persistence profile is a unique function that quantifies the degree of integration of all locations that belong to the same economic market. It does not require prior orthogonalization of the shock (e.g., by a Cholesky factorization) and is invariant to the ordering of the variables in the system. It provides valuable information as to the speed with which the effect of a system-wide shock eventually disappears when the system returns to its steady state.

The generalized impulse response function differs by investigating the effect of a variable-specific shock on each of the co-integrating vectors. Based on the error correction model, Pesaran and Shin (1998) developed the generalized impulse response function to measure the impact of the shock on a variable, with the magnitude of the shock being one standard error of the variable. This generalized function is also invariant to the ordering of the variables in the system. In this study, the shock will be generated by the price variable that serves as the main driving force in the integrated market.

3. Features of softwood log exports

In this section, the definition of softwood log exports and the data source are presented. The descriptive statistics of total export value and prices are computed and compared across the customs districts in the United States and destination countries. This information will help us understand softwood log exports from the United States and later facilitate the application of time series methods on this market.

3.1. Data sources

The prices of softwood log exports from the United States will be used directly in the time series analyses, while the export values provide support to decision-making throughout the process. Trade data are collected from the database maintained by the U.S. International Trade Commission (U.S. ITC 2019). Data are reported in the form of dollar value and quantity, and a price series is calculated as the ratio of value over quantity over time. To download the raw data, four dimensions of the data need to be determined: product code, time, customs districts in the United States, and destination countries.

The product codes for softwood logs are defined on the basis of the Harmonized Tariff Schedule (HTS) of the United States at the 10-digit level. All the selected products have the unit of a cubic

Table 1. Total softwood log export values, mean monthly prices, and species by customs district and destination pair from January 1996 to December 2018.

Pair	Total value		Mean price		Top products			
	Value	Share (%)	Price	SD	HTS 1	HTS 2	Share 1 (%)	Share 2 (%)
ColJA	6940	28	184	25	Douglas-fir	Douglas-fir-2	97	1
SeaJA	3487	14	186	33	Douglas-fir	Hemlock	88	9
ColCH	2326	9	173	49	Douglas-fir	Hemlock	49	29
SeaCH	2001	8	147	49	Hemlock	Douglas-fir	41	39
AncJA	1513	6	125	31	Spruce	Hemlock	60	23
SeaSO	968	4	132	29	Hemlock	Other logs	50	22
AncCH	778	3	114	25	Spruce	Hemlock	78	17
AncSO	708	3	108	26	Spruce	Hemlock	52	40
ColSO	369	1	159	41	Hemlock	Douglas-fir	76	16
SanCH	287	1	181	79	Ponderosa	Douglas-fir	46	28
LosCH	155	1	369	169	Other logs	Other wood	81	11
Sum	19 532	78						
All	25 199	100						

Note: Units: export value, US$ million; price, US$·m⁻³. SD, standard deviation. The shares of the top two products are computed for each export value series individually. Top products: Ponderosa = HTS 4403200025 Ponderosa pine, logs and timber, in the rough, not treated; Spruce = HTS 4403200035 Spruce; Douglas-fir = HTS 4403200040 Douglas-fir; Hemlock = HTS 4403200050 Western hemlock; Other logs = HTS 4403200060 Logs and timber, in the rough, coniferous, not treated, nesoi; Other wood = HTS 4403200065 Wood in the rough, coniferous, not treated, nesoi; Douglas-fir-2 = HTS 4403250040 Douglas-fir logs and timber in the rough not treated, of which any cross-sectional dimension is 15 cm (5.9 in.) or more, where nesoi means not elsewhere specified or included.

metre. Several pole products (e.g., HTS 4403200010) are measured by number directly, so they are excluded. In addition, softwood pulpwood products are excluded because their volume is very small. In the end, a total of 34 product codes at the 10-digit level are selected and aggregated to represent softwood logs in this study. The study period covered is from January 1996 to December 2018, and monthly frequency is used. The United States initially adopted the HTS in 1989 and then revised it in 1995 (e.g., deleting or adding codes). Thus, the start date is set to be January 1996. The end date of December 2018 was the most recent date when the data were downloaded.

The choices of customs districts and destination countries are based on the trading value. The United States has exported softwood logs from multiple ports on the eastern, southern, and western coasts. Only those with a substantial trading value over time are included; otherwise, constructing a continuous price series between a customs district and a destination would become difficult. As a result, a total of five customs districts in the United States are covered in the study: Anchorage (abbreviated as Anc), Seattle (Sea), Columbia-Snake (Col), San Francisco (San), and Los Angeles (Los). Each customs district has multiple ports that are usually within one state, i.e., Anc in Alaska, Sea in Washington, and San and Los in California. Col is an exception, with most ports in Oregon and some in Washington. A total of three destination countries are included: Japan (JA), South Korea (SO), and mainland China (CH). Only China has substantial imports from the districts of San and Los. Thus, a total of 11 pairs of districts and destinations are formed. Each pair has a value series (v) and a price series (p). For instance, vSeaJA and pSeaJA denote, respectively, the value and price of softwood log export from Seattle to Japan.

For the proposed time series analyses, the price data are transformed into a real logarithmic series, following the treatment in the literature (e.g., González-Rivera and Helfand 2001; Hänninen et al. 1997). The Producer Price Index for all commodities from the Bureau of Labor Statistics is used to deflate the data (https://fred.stlouisfed.org), and 1996 serves as the base year. Nominal data without any transformation are used to compute descriptive statistics and facilitate comparisons.

3.2. Average export values, prices, and market shares

In Table 1, the summary statistics of nominal trade values and prices are reported by customs district and destination country pairs. The total export value of softwood logs by the United States over the period of 1996 to 2018 for the selected product codes is US$25.2 billion, and US$19.5 billion (78%) is between the selected five customs districts in the United States and three destination countries. Thus, the chosen customs districts and destination countries cover most of the softwood log exports by the United States. Among the 11-value series, the largest one is US$6.9 billion from Columbia-Snake to Japan (vColJA; 28% of all softwood log exports), followed by that from Seattle to Japan (vSeaJA; 14%) and Columbia-Snake to China (vColCH; 9%).

The mean prices and their standard deviations by pair are reported in Table 1. For example, the mean price is US$184·m⁻³ for pColJA and US$173·m⁻³ for pColCH; the corresponding standard deviation is US$25·m⁻³ and US$49·m⁻³. By destination country, the prices of Japan's imports are generally higher than those of China and South Korea for the three major customs districts (i.e., Col, Sea, and Anc). Across all the five customs districts, the prices related to Seattle and Columbia-Snake are higher than those in others; the exception is the price in Los Angeles. Exports from Los Angeles to China have a low trading value (1% of the total export) and a high mean price (US$369·m⁻³).

The major products in the exports by district–destination pair and their market shares are also reported. For example, the trade of vColJA is mainly composed of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (HTS 4403200040; 97%) and Douglas-fir with a larger dimension (HTS 4403250040, cross-sectional dimension of 15 cm; 1%). In contrast, softwood log exports from Anchorage Customs District are mainly spruce and hemlock products. Overall, Douglas-fir, hemlock, and spruce are the leading species, and the product shares in the export mix vary by customs district and destination.

To reveal the variation over time, the 11 monthly export values and prices are plotted in Figs. 1 and 2. By trading value, Japan had dominated the market during the first few years after 1996. Exports to China mainly occurred after the 2008 recession and when Russia began to impose more restrictions on its log exports. The import values by South Korea have been smaller and more stable in comparison with those by Japan and China. Imports by China are not only more recent, but also the most volatile. By trading price, it is the most stable for Japan and the least stable for China. In particular, the export price between Los Angeles and China has both the largest average and swings among all. Overall, there is some inverse relationship between values and prices over time: the larger a value series is, the more stable its price series is.

Fig. 1. Monthly values of softwood log exports (US$ million) between five customs districts in the United States and three destination countries from January 1996 to December 2018. The five customs districts in the United States are Anchorage (Anc), Seattle (Sea), Columbia-Snake (Col), San Francisco (San), and Los Angeles (Los). The three importing countries are Japan (JA), South Korea (SO), and China (CH). For instance, vColJA denotes the export value between Col and JA.
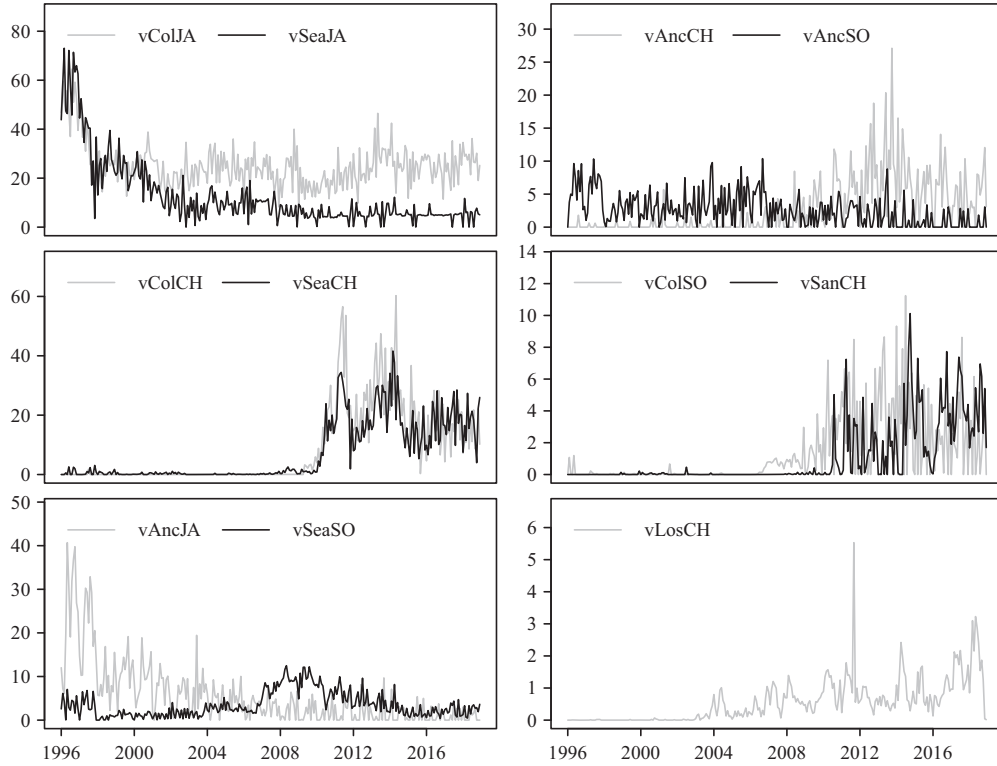
Fig. 2. Monthly prices of softwood log exports (US$·m⁻³) from January 1996 to December 2018. Note, for instance, that pColJA denotes the export price between Col and JA. See Fig. 1 for other definitions.

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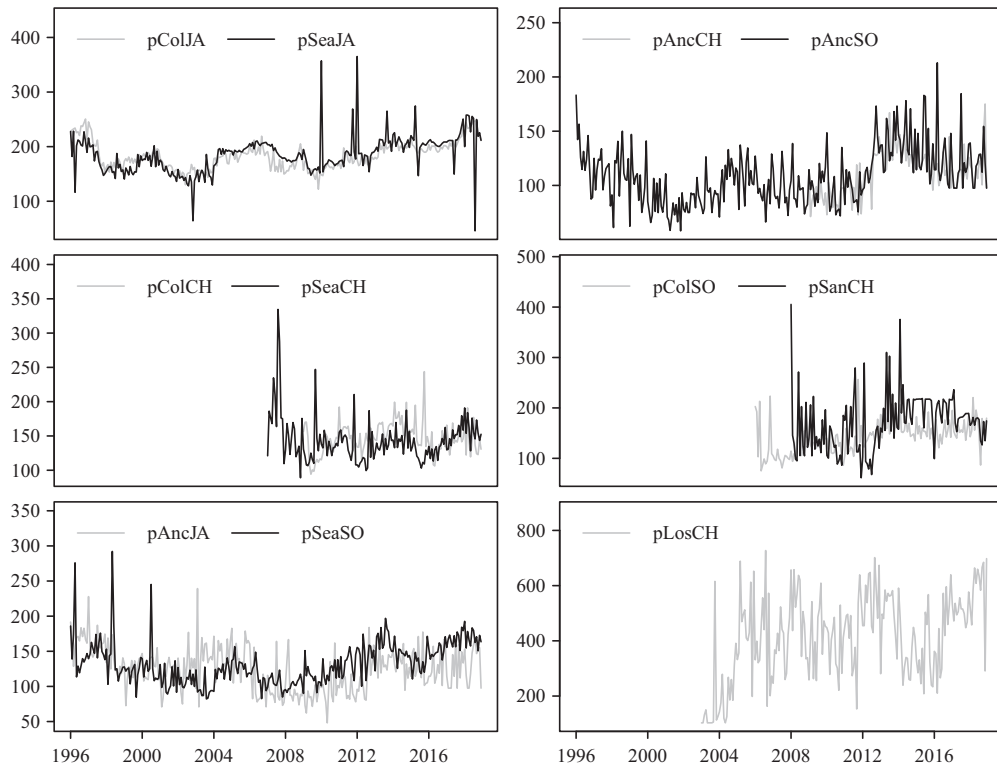
Table 2. Trace test statistics from co-integration analyses and the number of co-integrating vectors.

Variables	Start	Obs.	$r = 0$	$r \leq 1$	$r \leq 2$	$r \leq 3$	$r \leq 4$	$r \leq 5$	$N-r = s$
Time									
A0 = 11 series	2009	120	368.44***	292.08***	232.75***	175.17**	129.31	88.86	11–4 = 7
A1 = 5 series	1996	276	161.02***	95.06***	63.38***	32.19***	6.95		5–4 = 1
A2 = A1 + pLosCH	2003	192	135.40***	85.54***	54.83**	31.32	13.36	3.27	6–3 = 3
A3 = A1 + pSeaCH	2007	144	127.18***	79.18**	51.10*	31.53	15.16	3.19	6–3 = 3
A4 = A1 + pColSO	2007	144	150.29***	91.07***	57.83**	30.69	14.41	2.81	6–3 = 3
A5 = A1 + pColCH	2009	120	145.65***	93.70***	53.90**	33.71*	14.86	1.72	6–4 = 2
A6 = A1 + pAncCH	2009	120	144.70***	98.33***	59.35***	32.87*	11.44	1.61	6–4 = 2
A7 = A1 + pSanCH	2009	120	129.39***	83.76***	54.80**	31.74	13.83	1.58	6–3 = 3
District									
B1 = Col	2009	120	53.52***	23.62***	2.31				3–2 = 1
B2 = Sea	2007	144	55.37***	20.18**	5.78				3–2 = 1
B3 = Anc	2009	120	61.74***	25.21***	5.36				3–2 = 1
Destination									
C1 = JA	1996	276	87.47***	34.98***	6.20				3–2 = 1
C2 = SO	2007	144	66.35***	20.78**	3.48				3–2 = 1
C3 = CH (3)	2009	120	48.24***	19.58*	6.17				3–2 = 1
C4 = CH (5)	2009	120	95.05***	55.76**	25.94	13.13	5.03		5–2 = 3

Note: Obs., number of observations. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. There are 11 price series in total. A1 = pColJA + pSeaJA + pAncJA + pSeaSO + PAncSO; B1 = pColJA + pColCH + pColSO; B2 = pSeaJA + pSeaCH + pSeaSO; B3 = pAncJA + pAncCH + pAncSO; C1 = pColJA + pSeaJA + pAncJA; C2 = pColSO + pSeaSO + pAncSO; C3 = pColCH + pSeaCH + pSanCH; C4 = five Chinese prices. The statistics from $r \leq 6$ to $r \leq 10$ for A0 are not reported to save space.

4. Empirical results

Time series analyses are conducted on the real logarithmic price series. The unit root test reveals that all the price series are nonstationary and integrated at the order of one. Thus, a co-integration analysis can be conducted on these price series. In addition, the lag order for the vector autoregressive model is selected at four through the Akaike information criterion.

4.1. Boundaries of the export market

The analysis is first conducted for all the 11-price series as an initial trial to test for co-integration. The results are labeled as the scenario of A0 in Table 2. While the whole study period from 1996 to 2018 contains a total of 276 monthly observations, there are only 120 observations in the A0 scenario because of China's late entry into the market. The trace statistics reveal that the number of co-integrating vectors (r) is four, and there are seven common integrating factors among the 11-price series (i.e., $s = N - r = 11 - 4 = 7$). Therefore, the 11 pairs of log exports do not belong to the same economic market (Gonzalo and Granger 1995; González-Rivera and Helfand 2001).

To search for the boundary of an integrated economic market, three dimensions are explored: time, customs district, and destination. First, the five-price series covering the entire study period with 276 monthly observations are included in one co-integration analysis (i.e., the A1 scenario). These series are pColJA, pSeaJA, vAncJA, vSeaSO, and vAncSO. The trace test statistics reveal that there are four co-integrating vectors and one common integrating factor among these five prices. Thus, they belong to the same economic market. The market is then expanded by adding one of the other six prices. It turns out that each of the other combinations (i.e., the scenarios from A2 to A7) has more than one common integrating factor. Thus, the original five-price series are the most extensive set that comprises the same economic market.

The boundary search is also conducted by the customs district (i.e., Col, Sea, and Anc). The results are reported as scenarios B1 through B3 in Table 2. The trace test statistics support that the three prices within each of the three central customs districts comprise an integrated market. By destination, the three prices for Japan and South Korea (i.e., the C1 and C2 scenarios) also each form a separate integrated market. In contrast, the five prices for China do not show the same integration. The maximum number of China's prices for an integrated economic market is three, i.e., pColCH, pSeaCH, and pSanCH (scenario C3).

Given that the exports to China started around 2009 and became stable around 2012, a natural question is whether China's entry into the market has any impact on the degree of integration among the prices of Japan and South Korea. To address that concern, a rolling window is used to conduct the co-integration analysis on the five prices with complete coverage repeatedly. Two types of windows are defined: an expanding window versus a fixed window. For the expanding window, the first co-integration regression is conducted between January 1996 and January 2012, and then for each new regression, the end of the window is expanded by one month. The fixed window is a revision of the expanding one, with one month being dropped at the beginning of the price data to maintain the same width of the window.

The p values of trace test statistics for two key hypotheses on the number of co-integrating vectors are plotted in Fig. 3. As expected, the p values for $r \leq 4$ are larger than 0.10 for all the trials, and the p values for $r \leq 3$ are less than 0.10 and significant for most co-integration analyses. The difference between the results for the two types of window definitions is that the p values for the expanding window decline as more observations are added, indicating a more integrated market among the imports by Japan and South Korea over time. With the fixed window, the p values are relatively stable for most of the trials, but the p values increase and become larger than 0.10 after 2017. Overall, the integration relationship among the five prices of Japan and South Korea has been maintained after China's entry, and based on the results from the expanded window, it has even been strengthened over time.

### 4.2. Price decomposition and the driving force

Given that the five prices for Japan and South Korea with full-time coverage are integrated into the same economic market, detailed analyses are conducted on this group of prices and the market from this point on. Following Gonzalo and Granger (1995), the common integrating factor of f_t in this market is estimated as

$$(4) \qquad f_t = 0.048p\text{SeaJA} + 0.110p\text{AncJA} + 0.070p\text{SeaSO} \\ + 0.058p\text{AncSO} + 0.830p\text{ColJA}$$

where pSeaJA denotes the export price between the Seattle Customs District and Japan, and other price series are similarly defined.

The weights for pSeaJA, pSeaSo, and pAncSO are relatively small. To examine whether these three numbers can be restricted

Fig. 3. The *p* values of the trace test statistics from co-integration analyses with a rolling window on the five prices of Japan and South Korea from January 2012 to December 2018. In the left panel, the sample is expanded with one more monthly observation each time. In the right panel, the sample window is fixed by dropping the first observation and adding one more in the end. r3 refers to the *p* values associated with the trace test statistic on the hypothesis of $r \leq 3$, and r4 refers to $r \leq 4$.
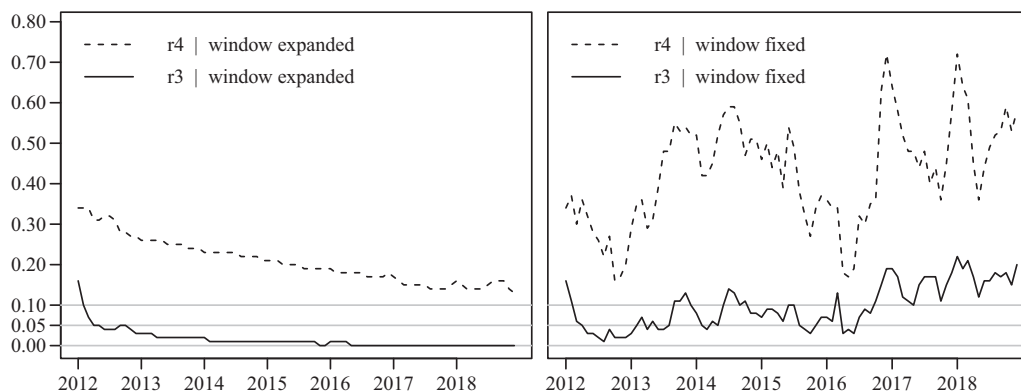
to zero, a likelihood ratio test is employed. The *p* value from the test is 0.09. Therefore, they are only marginally significant at the 10% level. If the three coefficients are restricted to zero, the weights become 0.120 for pAncJA and 0.870 for pColJA, which does not change much from 0.110 and 0.830. Overall, it can be concluded that the price between the Columbia-Snake Customs District and Japan explains most of the variation in the price evolution, and thus it can be perceived as the driving force in the whole system.

With the above estimate of the common integrating factor, each of the five prices for Japan and South Korea can be decomposed into permanent and transitory components. In Fig. 4, the original prices and their decomposition are shown, which allows a detailed demonstration of the changes over time. As shown in eq. 2, the value of the original price at a specific month is equal to the sum of the permanent component and transitory component. To better reveal the tracing relationship between the original price and the permanent component, the mean value of the transitory component over the whole period is added to that of the permanent component. Thus, the value of the permanent component shown in Fig. 4 is the adjusted value of the actual permanent component.

For the price of pColJA, the decomposition reveals that most of its original variation has been explained by the permanent component. The transitory component in pColJA has a minimal variation, and its mean value is close to zero. In comparison, the other prices have considerably more variation in the transitory component, and the permanent components do not trace the original prices as closely as in the case of pColJA. The pattern revealed through the decomposition is consistent with the above estimate of weights in the common integrating factor. In sum, the price pair between the Columbia-Snake Customs District and Japan has served as the driving force in the integrated economic market.

4.3. Interdependence and degree of market integration

The above sequential search by the co-integration analysis reveals that the five prices for Japan and South Korea with full-time coverage are co-integrated and form an economic market. Thus, a vector error correction model can be estimated for them. In Table 3, the normalized co-integration vectors are reported. The relationship is normalized on the price from the Columbia-Snake Customs District to Japan (pColJA). The four co-integrating vectors reveal the relationships among the five price variables.

In Table 4, the adjustment coefficients in the vector error correction model are reported. This demonstrates the adjustment in the short run. The magnitude of the estimates reveals the response of each price to the shock. With these estimates, the im-

pulse response rates can be computed and plotted to better illustrate the short-run adjustment in the market.

The persistence profile for the five prices of Japan and South Korea is reported in Fig. 5. Note that there is a total of four co-integrating vectors, and each of them corresponds to one price, with the exception of the price of pColJA, which is used in the normalization. The shock is measured and scaled to one and reported on the vertical axis, e.g., 0.10 for 10% of the initial shock. A logarithmic scale is used to better reveal the differences between the lines. A total of 12 months is reported on the horizontal axis.

The persistence profile clearly reveals the response of these prices to market disturbance. For the four prices (pSeaJA, pAncJA, pSeaSO, and pAncSO), the shares of the shock absorbed in the market adjustment are 99%, 85%, 93%, and 94% by the end of the first month and 99%, 97%, 96%, and 95% by the end of the fourth month. Thus, most of the shocks disappear within four months. The price of pSeaJA has the fastest response as it takes only about one month to make most of the adjustments. In contrast, pAncJA is relatively slower in the adjustment process.

In Fig. 6, the generalized impulse responses to the shock in the price of pColJA are shown. The price of pColJA is chosen as the source of the disturbance because pColJA has been identified as the driving force in the system. The shock is measured as one standard error of pColJA. The findings are similar to those from analyzing the persistence profile. The price of pSeaJA has the fastest response, the price of pAncJA has the slowest response, and the overall response rate across all price pairs is rapid.

5. Summary and discussion

The exportation of softwood logs has been an essential component of forest products trade for the United States. Most of the log exports have originated from the Pacific Northwest region, where timber harvesting and log supply are deeply influenced by government interventions and restrictions. On the demand side, Japan has been the major importer for decades, while China has emerged as the leading participant in the market since 2009. In this study, time series econometric methods have been employed to assess the extent and degree of market integration of softwood logs exported from Pacific Northwest customs districts over 1996–2018. Several outcomes are generated from the analyses, and they have implications for stakeholders involved in the softwood log trade market.

Firstly, softwood log exports to Japan and South Korea are found to be highly integrated. In contrast, while exports to China have been substantial since 2009, both the values and prices have

Fig. 4. Decomposition of the five price series for Japan and South Korea into permanent and transitory components from January 1996 to December 2018. The prices are real monthly logarithmic series, in US$·m⁻³. The average of the transitory component is added to the permanent component to facilitate the comparison. Note, for instance, that pSeaJA denotes the export price between Sea and JA. See Fig. 1 for other definitions.
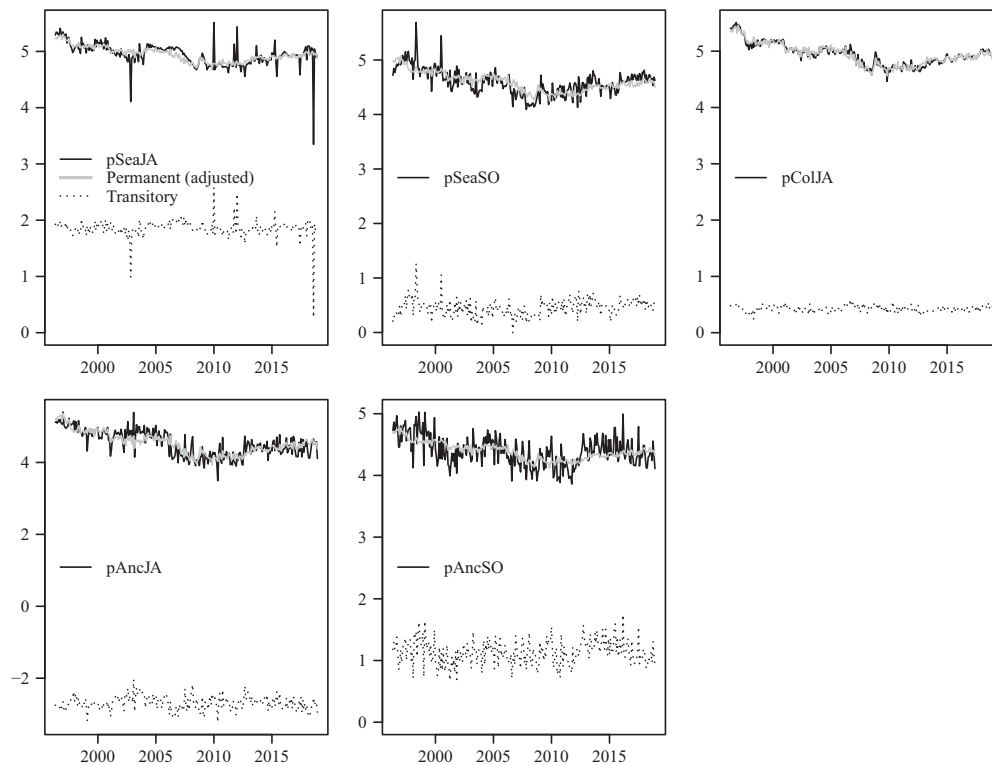
Table 3. Normalized co-integration vectors for the five prices of Japan and South Korea from January 1996 to December 2018.

Variable	CV1	CV2	CV3	CV4
pSeaJA	1.00	0.00	−0.00	0.00
pAncJA	0.00	1.00	0.00	−0.00
pSeaSO	0.00	0.00	1.00	−0.00
pAncSO	−0.00	0.00	0.00	1.00
pColJA	−0.68	−1.60	−0.92	−0.72
Constant	−1.57	3.38	−0.07	−0.83

Note: CV1 to CV4 refer to the four co-integrating vectors from the co-integration analysis on the five price series with full-time coverage.

been volatile. The trade between the United States and China has evolved more independently, and it does not become an integrated part of the existing market between the United States and Japan and South Korea. Therefore, softwood log exporters in the United States have faced declining demand from Japan and, at the same time, a rising but more volatile and independent import market of China. This finding confirms some of the justifications behind the trade war between China and the United States that occurred in 2018. The current market structure has brought challenges to all stakeholders, including forest landowners or businesses, in maintaining a stable and predictable relationship across the softwood log export destinations. Identifying the cause of volatility observed in China's log imports is a research topic worthy of further study. To gain a deep understanding of China's log import market, future studies will need to examine the structure of relevant industries in China with detailed information.

The five price variables for Japan and South Korea with full-time coverage are determined to be in the same economic market. One common integrating factor is identified, and the price of export from the Columbia-Snake Customs District to Japan has served as

the driving force in the whole system. This is consistent with the fact that the export value related to this district–destination pair is the largest one across all the pairs over 1996–2018. Apparently, the finding is conditional on the selected study period. State-level inferences from these findings are confounded by the fact that the Columbia-Snake Customs District includes ports in both Washington (notably the Longview Port) and Oregon, and softwood logs exported from a port can come from multiple states. Additional research would be beneficial to observe and assess whether the trade between a customs district and China will drive the market in the future, given China's increasing dominance over the export of softwood logs from the United States and the ongoing trade war between the two countries.

Overall, the response of prices to a market disturbance is fast. A shock on the whole system or the leading price variable is usually absorbed within four months, and for some price pairs (e.g., the export between the Seattle Customs District and Japan), the shock can be absorbed as quickly as within one month. This is consistent with the finding of fast responses in the lumber market (e.g., Shahi and Kant 2009) but differs from the much slower response rate in agricultural commodity markets (e.g., González-Rivera and Helfand 2001). Quick responses to market shocks suggest that information across the softwood log market has been disseminated relatively fast, and market participants need to act promptly when demand and supply conditions in this region vary.

In recent decades, international forest products markets have become increasingly globalized. Roundwood is bulky, and it is usually inefficient to transport it over a long distance. Nevertheless, decreasing shipping costs and China's booming economy have fueled the constant growth of global roundwood trade. The Pacific Northwest region of the United States has benefited from these changes and subsequent increases in trade. As the softwood log market has been continually evolving, the relationships between major suppliers and consumers are likely nonlinear and

Table 4. Coefficient estimates from the error correction model for the five prices of Japan and South Korean from January 1996 to December 2018.

Variable	pSeaJA		pAncJA		pSeaSO		pAncSO		pColJA	
	Estimates	t statistics	Estimates	t statistics	Estimates	t statistics	Estimates	t statistics	Estimates	t statistics
Ecm_1	−0.80***	−7.10	−0.08	−0.48	0.11	1.05	0.14	1.02	0.08*	1.72
Ecm_2	−0.04	−0.63	−0.32***	−3.85	0.10*	1.83	0.13*	1.84	0.07***	3.02
Ecm_3	−0.08	−0.96	0.08	0.71	−0.35***	−4.57	0.22**	2.18	0.05	1.45
Ecm_4	0.13	1.66	0.08	0.72	−0.04	−0.58	−0.59***	−5.93	−0.02	−0.53
$\Delta pSeaJA_{t-1}$	−0.96***	−15.71	−0.06	−0.72	0.09	1.52	0.03	0.34	0.03	1.10
$\Delta pAncJA_{t-1}$	−0.05	−1.05	−0.78***	−12.16	0.03	0.73	0.04	0.72	0.01	0.29
$\Delta pSeaSO_{t-1}$	0.03	0.45	−0.06	−0.69	−0.72***	−11.78	−0.05	−0.67	0.05*	1.79
$\Delta pAncSO_{t-1}$	0.01	0.06	0.24***	3.36	0.06	1.27	−0.77***	−12.13	0.01	0.13
$\Delta pColJA_{t-1}$	0.47***	2.90	−0.07	−0.32	0.25	1.63	0.08	0.42	−0.50***	−7.89
$\Delta pSeaJA_{t-2}$	−0.93***	−11.04	0.01	0.09	0.15*	1.84	0.02	0.21	0.06	1.67
$\Delta pAncJA_{t-2}$	−0.05	−0.81	−0.60***	−7.59	0.07	1.35	0.17**	2.43	0.04**	1.99
$\Delta pSeaSO_{t-2}$	−0.09	−1.19	0.01	0.08	−0.56***	−7.69	0.07	0.69	0.01	0.24
$\Delta pAncSO_{t-2}$	0.04	0.65	0.20**	2.12	0.08	1.25	−0.72***	−8.67	−0.01	−0.05
$\Delta pColJA_{t-2}$	0.38**	2.13	0.33	1.33	0.40**	2.40	0.07	0.30	−0.34***	−4.79
$\Delta pSeaJA_{t-3}$	−0.83***	−8.13	−0.14	−0.95	0.10	1.04	0.08	0.62	0.08**	1.94
$\Delta pAncJA_{t-3}$	−0.07	−1.22	−0.43***	−5.07	0.14**	2.42	0.11	1.42	0.07***	2.91
$\Delta pSeaSO_{t-3}$	−0.08	−0.90	0.01	0.01	−0.47***	−5.83	0.10	0.90	0.04	1.11
$\Delta pAncSO_{t-3}$	0.05	0.63	0.12	1.16	0.05	0.75	−0.69***	−7.32	−0.03	−1.02
$\Delta pColJA_{t-3}$	0.53***	2.91	0.22	0.86	0.06	0.32	0.22	0.95	−0.20***	−2.81

Note: Ecm_1 to Ecm_4 are the four error correction terms. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Fig. 5. The persistence profile from the error correction model of five prices for Japan and South Korea over 12 months. Note that there are four co-integrating vectors among the five price series. For instance, CV1 refers to the first co-integrating vector and is related to the export price between Sea and JA (pSeaJA). See Fig. 1 for other definitions.
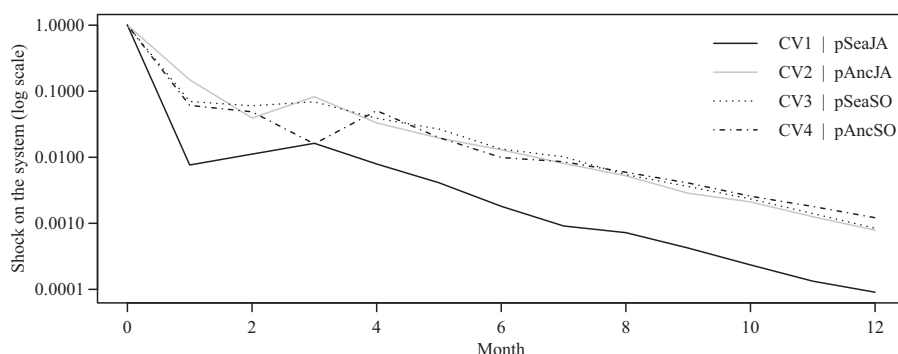
Fig. 6. Generalized impulse responses from the error correction model of five prices for Japan and South Korea for a one standard error shock on the price variable of pColJA over 18 months. See Fig. 5 for the definition of co-integrating vectors. Note that pColJA denotes the export price between Col and JA. See Fig. 1 for other definitions.
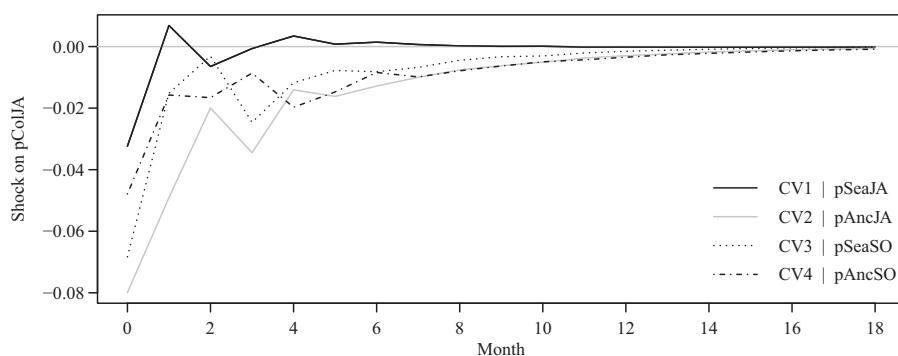
will vary over time. Therefore, there will be a constant need to regularly monitor the interaction among market participants. In addition, international trade of other forest products (e.g., hardwood logs and lumber) are also worthy of more analyses, as each of them has a market with unique features and challenges. Finally, all forest products exports are different from the trade of other commodities in that forests have many environmental functions (e.g., biodiversity protection). Thus, the effect of fluctuating trade on forest management and environmental services in the region also deserves more attention and analyses.

Acknowledgements

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