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# GLOBAL PULPWOOD MARKETS AND THE LAW OF ONE PRICE

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Abstract. Many models of international trade assume that perfect competition exists and externalities do not distort market behavior. The Law of One Price (LOP) is said to hold when the price of a similar product is the same in different markets when expressed in common currency. Considering pulpwood markets, it has been suggested that long-term relationships exist among various markets, but the LOP does not necessarily hold. Most of this research has been performed for the most developed forest sectors in the world, such as the United States and Scandinavia. With the progressing globalization of forest production, we expected that pulpwood prices in various countries would follow similar trends. The objective of this research was to study the global pulpwood market and relationships among the most important producers. Using Johansen cointegration method, the LOP was tested for pulpwood prices in the United States, Canada, Germany, Sweden, Finland, Norway, France, Spain, Chile, Brazil, New Zealand, and Australia from 1988 to 2012. The results suggested that while several long-term price relationships have been discovered, the LOP generally did not hold. The exception were Germany and Norway, where the LOP was close to holding for coniferous prices.

**Keywords:** Pulpwood prices, wood markets, cointegration, Law of One Price

## 1 Introduction

The progressing globalization of forest markets and changes in international trade may influence how industrial roundwood marktes operate around the world (Mäki-Hakola 2002; Toivonen et al. 2002). In analyzing international commodity markets, several authors have claimed that the price of a product should be the same in competitive markets when adjusted for exchange rates (Ardeni 1989; Goodwin 1992). This relationship is called the Law of One Price (LOP). Perfect competition assumes that (1) the actors behave in a rational way, (2) the firms are price takers, (3) products are homogeneous, (4) there is perfect information, (5) the transactions costs are small, and (6) there are no barriers to entry or exit (Wetzstein 2005, pages 258-259). For example, it has been argued that agricultural products are homogeneous, and producing them in different countries should not lead to differences in prices (Ardeni 1989; Goodwin 1992; Knetter 1989; Miljkovic 1999). Others, however, have claimed that LOP does not hold in the majority of cases, despite the fact that many models have assumed perfectly competitive markets worldwide (Miljkovic 1999). Tests of the LOP have been widely performed in agricultural commodity markets and in many instances the law was not satisfied (Miljkovic 1999). Different reasons have been provided for this outcome. Among others, they include transportation costs, pricing to market, exchange risks, institutional factors, and non-tradable production inputs (Miljkovic 1999).

In forestry, Buongiorno and Uusivuori (1992) tested the pulp and paper export prices from the United States (US) to six European countries and Japan between 1978 and 1988 for the LOP. The results showed that the LOP could not be rejected in 52 of the 56 pairs of price series analyzed. The LOP was also tested for hardwood pulpwood, mixed hardwood sawtimber, and oak sawtimber markets in six states of the US –Alabama, Arkansas, Louisiana, Mississippi, Tennessee, and Texas– from 1977 to 1997 (Nagubadi et al. 2001). The authors found that while the LOP did not hold these markets were partially integrated, meaning that they can be grouped according to their long-term price trends. Furthermore, thirteen stumpage pine sawtimber and eleven pine pulpwood markets in eight southern states –Texas, Louisiana, Alabama, Florida, Georgia, South Carolina, Mississippi, and Arkansas– were tested for cointegration between 1977 and 1996 (Yin et al. 2002). The results showed that southern pine sawtimber and pulpwood markets were partially integrated. These markets could have been grouped in different ways, and the distance was not always a major criterion in their groupings.

In Scandinavia, Finnish roundwood markets were tested for the LOP after structural changes that occurred in the 1980s and 1990s (Toppinen 1998). It was found that the LOP between the four major geographic regions in Finland held only for pine sawtimber prices. Norway spruce pulpwood prices were tested for the LOP using quarterly domestic, import and export price series for 1988-2000 (Nyrud 2002). The results indicated that the LOP held for the domestic and imported prices. Størdal and Nyrud (2003) tested the LOP for Norwegian roundwood markets and found that the LOP held for pine pulpwood prices only when transportation costs were included in the analysis. The LOP was tested for roundwood markets in Austria, Finland, and Sweden between 1980 and 1997 (Toivonen et al. 2002). Annual delivered sawtimber and pulpwood prices for pine and spruce were used. The LOP held for roundwood markets in Finland and Sweden, but not between Finland and Austria, or Sweden and Austria. In addition, it was found that shocks in Finnish roundwood markets impacted markets in Sweden. Toppinen et al. (2005) studied nominal delivered prices for pine, spruce, and birch from 1996 to 2004 and found that pulpwood prices were not cointegrated in the long run. Mäki-Hakola (2002) tested a similar group of markets for cointegration, including roundwood markets in Finland, Estonia, Germany, and Lithuania between 1994 and 2001. The author found that pine pulpwood markets in those countries were cointegrated and that birch and spruce pulpwood markets were partially integrated.

While several studies analyzed the LOP for roundwood markets in a country or a region, there has been no study analyzing the most important global pulpwood markets. Moreover, most of the existing studies did not estimate the adjustment dynamics of the roundwood prices. The objective of this study was to test the LOP in global pulpwood markets and to analyze the relationships among prices in the most important pulpwood markets. Markets selected for this study included the US Southeast, the US Northwest, Canada East, Canada West, Germany, Sweden, Finland, Norway, France, Spain, Chile, Brazil, New Zealand, and Australia. These markets were selected according to their share in the total world production by volume and as dictated by data availability. Price data were divided into coniferous and non-coniferous products and then these markets were grouped according to three criteria: (1) region, (2) trade volume and direction, and (3) production volume. The next section provides background information for the selected pulpwood producers, including the information about their forest resources, wood production and trade, and pulpwood markets. The description of methods and data used comes next. The last sections provide a detailed description and discussion of the results.

## 2 Forest resources

**2.1 Forest cover** While several of the analyzed countries have large forest area, only a small fraction of that area is typically devoted to plantations (Table 1). For example, in South America Brazil has a total of 519.5 million hectares (ha) of forests, of which 1 % are planted forests. Chile has 16.2 million ha, of which 15% are planted forests. The US has the largest area of planted forests among the analyzed countries with 25.3 million ha. In Oceania, Australia has a total of 149.3 million ha of forest, which represents 19% of its landmass, but only 1.9 million ha are planted forests. Similarly, New Zealand has a total of 8.2 million, of which 22% are planted forest. In Europe, Sweden has 69% of the land area covered with forests, including 3.6 million ha of plantations. Finland has around 73% of its area covered with forests, from which 16.2 million ha are natural forests. Germany has a similar planted area to Finland, 5.3 million ha, and 5.8 million ha of natural forests. Finally, Spain, Norway, and France have around 30-35% of their land area covered with forests, from which 15% are planted in Spain and Norway, and 10% in France.

The ownership of the forest resources differs among the selected countries. In Australia, Brazil, and Canada the majority of the land is publicly owned. In Chile, Finland, France, Norway, Spain and Sweden, the majority of the land is privately owned. Germany and the US have the ownership of forest resources nearly evenly distributed between public and private ownership. For example, in Norway 80% of the forests are owned by private landowners such as individuals and families, 12% is owned by the state and local governments, 4% by industries, and 4 % is common land; while in Sweden 50% of the forestland is owned by private landowners and the rest is divided equally between public forestlands and industrial forestlands (Nordic Family Forestry 2013a, b). Another example is Chile, where the majority of the privately owned forestland is owned by to vertically integrated companies, CMPC and Arauco (Lignum 2012).

**2.2 Production and trade** Industrial roundwood is defined by the Food and Agriculture Organization (FAO) as the production of all roundwood excluding wood fuel (FAO 2013a, page 4). It includes sawtimber and veneer logs, pulpwood, and other industrial roundwood but excludes telephone poles. The wood volume is reported under bark. Overall, industrial roundwood

Table 1: Forest area by country

| **Country** | **Total forest area (000 ha)** | **Natural forest area (000 ha)** | **Planted forest area (000 ha)** | **Percent natural forest area** | **Percent planted forest area** | **Percent private forestland** | **Percent public forestland** |
|---|---|---|---|---|---|---|---|
| Australia | 149,301 | 147,398 | 1,903 | 99 | 1 | 25 | 75 |
| Brazil | 519,523 | 512,105 | 7,418 | 99 | 1 | 19 | 81 |
| Canada | 310,134 | 301,171 | 8,963 | 97 | 3 | 8 | 92 |
| Chile | 16,231 | 13,847 | 2,384 | 85 | 15 | 75 | 25 |
| Finland | 22,156 | 16,252 | 5,904 | 73 | 27 | 68 | 32 |
| France | 15,954 | 14,321 | 1,633 | 90 | 10 | 74 | 26 |
| Germany | 11,076 | 5,793 | 5,283 | 52 | 48 | 45 | 55 |
| New Zealand | 8,269 | 6,457 | 1,812 | 78 | 22 | 36 | 64 |
| Norway | 10,065 | 8,590 | 1,475 | 85 | 15 | 86 | 14 |
| Spain | 18,173 | 15,493 | 2,680 | 85 | 15 | 69 | 31 |
| Sweden | 28,203 | 24,590 | 3,613 | 87 | 13 | 76 | 24 |
| US | 304,022 | 278,659 | 25,363 | 92 | 8 | 57 | 43 |

* Source: FAO (2010)

is produced and consumed primarily within a country in which it is produced; the share of exports in the total production of roundwood worldwide was 7% as of 2012 (FAO 2013). Industrial roundwood production worldwide was 1,657 million cubic meters ($m^3$) as of 2012 (FAO 2013).

Pulpwood is defined by FAO as the roundwood and wood chips made directly from the roundwood that is used to produce wood pulp, particleboard, and fiberboard (FAO 2013a, page 4). World pulpwood production reached 586.9 million $m^3$ in 2012. Four countries accounted for 50% of pulpwood output, with the US producing 23.4 % of the total volume. Brazil ranked second as a pulpwood producer.

Wood pulp is the most important product derived from pulpwood. It is defined by FAO as the product prepared by mechanical or chemical process from pulpwood, wood chips, particles or residues and used to produce paper, paperboard, fiberboard and other cellulose products (FAO 2013a, page 8). The US, Brazil, Canada, Sweden, and Finland account for 61% of wood pulp production in the world. The leading producer is the US with 29% of the market, followed by Canada and Brazil, with 11% and 8%, respectively. Canada is the leading exporter of wood pulp in US dollars (USD) followed by the US and Brazil. The other important South American country is Chile, with 8% of the market.

Regarding coniferous pulpwood, the US alone produced 74.8 million $m^3$ of coniferous pulpwood in 2012 (Table 2). Chile produced 10.4 million $m^3$ of coniferous industrial roundwood. Except for Spain, the European countries produce mainly coniferous pulpwood. The exports were directed to countries in the region. In addition, the Scandinavian countries imported roundwood from Russia. Brazil is the leading producer of non-coniferous pulpwood among the selected countries; with 64.2 million of $m^3$ of production by 2012. The second largest producer in the world is the US.

Global pulpwood production by volume was less concentrated in 2011 than in 2000. In 2000, top five largest producers accounted for 62% of the worldwide production. In 2011, these top five producers accounted for 50% of the output. The five second tier producers increased their market share from 15% to 17% between 2000 and 2011, and the five third tier countries had a similar share throughout the period. The largest change among the top five pulpwood producers has been the rising market share of Brazil, increasing from 9% to 12% from 2000 to 2011. As a result, Brazil has become the second pulpwood producer in the world by volume.

**2.3 Pulpwood Markets** Pulpwood prices in the selected countries are currently determined in open markets. In the past, however, some countries had set their prices through different mechanisms, including price negotiations. For example, pulpwood prices in Norway had been determined by central negotiations after the World War II. Pulpwood price negotiations were abandoned in 1992. Similarly to Norwegian markets, pulpwood prices in Finland were negotiated at a national level from the 1960s (Toppinen 1988). These price agreements were abandoned between 1991 and 1994. Finnish wood pulp industry is highly concentrated in terms of production (Toppinen 1988). Wood purchases are conducted di-

Table 2: Pulpwood production

| Country | Coniferous (000 $m^3$) | Non-coniferous (000 $m^3$) | Percent coniferous world production | Percent non-coniferous world production |
|---|---|---|---|---|
| Australia | 5,283 | 7,199 | 1.9% | 2.3% |
| Brazil | 9,865 | 64,238 | 3.6% | 20.5% |
| Canada | 9,964 | 16,308 | 3.6% | 5.2% |
| Chile | 10,412 | 12,310 | 3.8% | 3.9% |
| Finland | 19,415 | 5,877 | 7.1% | 1.9% |
| France | 7,180 | 3,511 | 2.6% | 1.1% |
| Germany | 8,900 | 4,310 | 3.2% | 1.4% |
| New Zealand | 3,312 | 358 | 1.2% | 0.1% |
| Norway | 4,246 | 74 | 1.5% | 0.0% |
| Spain | 2,625 | 5,552 | 1.0% | 1.8% |
| Sweden | 26,796 | 3,404 | 9.8% | 1.1% |
| US | 74,785 | 54,275 | 27.3% | 17.3% |
| World total | 274,075 | 312,870 | 66.7% | 56.7% |

* Source: FAO (2013b)

rectly by the wood pulp industry, so consequently the pulpwood buyers are highly concentrated and may exert a degree of market power. Likewise, Sweden had relied on agreements to set pulpwood prices, which before 1995 were negotiated by the forest owners associations (Lundmark and Shahrammehr 2011). In Germany forests owned by federated states supplied 44% of the total roundwood as of 2002; however, pulpwood prices have been determined by open markets with the presence of some intermediaries (Mäki-Hakola 2002). Among the selected European countries, Spain is the one with the highest share of industrial roundwood imports and prices are determined in open markets (Ortuño Pérez 2012). In France, 66% of roundwood from privately owned sales are conducted by direct sales, 25% by supply agreements, and 9% by auctions (Elyakime and Cabanettes 2009). In the case of publicly owned forestland, around 50% of the roundwood is sold in auctions, 40% is sold through direct sales, and 10% through supply agreements.

The US is the world's leading pulpwood producer. The majority of the pulpwood comes from privately owned forestland and prices are set in an open market. In the Southeast, 70% of the production came from non-industrial forestlands and 26% came from forestlands owned by private corporate groups (Johnson et al. 2011). In Canada, the government established an annual allowable cut (AAC) for the public lands in order to harvest in a sustainable fashion (Canadian Forest Service 2012). Even though pulpwood prices are not being set through negotiations, the high concentration in the pulp industry may result in uncompetitive markets and pricing powers. In Brazil, pulpwood prices are determined in an increasingly open market as the firms increasingly rely on "fomento" programs for their wood supply rather than their own forestland (Soares et al 2010 in Marques 2012, page 50). In the "fomento" program landowners produce wood for the firm on their own land following the management regime established by the firm and the wood is sold at market prices.

In New Zealand, pulpwood is destined either for export or local markets (Niquidet and Manley 2007), and prices are determined in an open market (Gorman 2002). In Australia, most of the non-coniferous pulpwood comes from native forest owned by the state government (Neilson and Flynn 2004). As of 2011, the total pulpwood harvested came 17% from native non-coniferous, 41% from planted non-coniferous, and 42% from coniferous (Department of Agriculture Fisheries and Forestry 2014). Pulpwood prices were set by the local governments in long-term harvest contracts with the goal of securing roundwood volumes for the industry (Department of Agriculture Fisheries and Forestry 2013, page 24). In the 2000s, the government started to encourage the use of open market mechanisms.

## 3 Data and methods

**3.1 Data** Delivered pulpwood prices were obtained from the Wood Resources International, Inc. (WRI). The data represent delivered to the mill coniferous and non-coniferous pulpwood prices expressed in USD per $m^3$ (USD/$m^3$). The period of analysis was from the first quarter of 1988 to the third quarter of 2012. The coniferous pulpwood price series were obtained for the following markets: the US Southeast, the US Northwest, Canada East, Canada West, Germany, Sweden, Finland, Norway, France, Spain, Chile, Brazil, New Zealand, and Australia. The non-coniferous pulpwood prices were obtained for the following markets: the US Southeast, the US Northwest, Canada East, Canada West, Germany, Sweden, Finland, France, Spain, Chile, Brazil, and Australia.

Exchange rates were obtained from the Organization for Economic Co-operation and Development (OECD) website for Australia, Canada, Chile, New Zealand, Norway, and Sweden (OECD 2013). For Germany, Spain, France, and Finland, exchange rates were obtained from the German Central Bank (Deutsche Bundesbank 2013a). For Brazil, exchange rates were obtained from the Central Bank of Brazil (Central Bank of Brazil 2013b). CPIs were obtained from the Office of Statistics of each country, except as following: for the United States, the St. Louis Federal Reserve; for Brazil, the Central Bank of Brazil; and for Germany, the Central Bank of Germany (Australian Bureau of Statistics 2013; Central Bank of Brazil 2013a; Central Bank of Chile 2013; Deutsche Bundesbank 2013b; Instituto Nacional de Estadstica 2013; National Institute of Statistics and Economic Studies 2013; St. Louis Federal Reserve 2013; Statistics Canada 2013; Statistics Finland 2013; Statistics New Zealand 2013; Statistics Norway 2013; Statistics Sweden 2013). All the CPIs were converted to 2009 base year.

Whenever the analysis included Brazil, the time period investigated started in the third quarter of 1994 when the Plan Real was executed (Alves et al. 2001). This price series is noted as $\text{Brazil}_{94}$. Brazil changed its currency and experienced hyperinflation since 1988 until 1994 when it introduced the Real (BRL). The BRL was fixed to the USD one to one, so the government would intervene when the BRL was valued at one USD, but would not intervene when it was worth more than one USD (Frenkel and Rapetti 2010). In 1999, the government allowed the BRL to float freely.

Average delivered coniferous pulpwood nominal prices for the period ranged from 22 to 55 USD/$m^3$ depending on the country and on the region (Table 3). For the period 1988-2012, Chile had the lowest average price, while Germany had the highest,similar to Norway and Finland. Brazilian prices had the highest variation of the period, 54%, while the US Southeast had the lowest variation, 11%.

The 2008 world financial crisis is reflected in pulpwood prices of all the countries analyzed with a marked decrease in pulpwood prices that year (Figure 1). Prices in the US Northwest and in Canada West showed increases in the mid-90s.

Prices in Norway, Finland, Germany, and Sweden showed similar trends. The European storms in 1999, 2004, and 2006 led to an increase in harvest levels to recover the downed wood. This increase in harvest might have lowered price levels in the region as well.

In the Southern hemisphere, Brazil showed the largest increase in pulpwood prices since the second half of the 2000s. Coniferous roundwood prices in New Zealand showed similar trends to prices in Australia since the end of the 1990s. While in New Zealand prices have been set in open markets, in Australia the government started encouraging open market mechanisms since 2000. Therefore, the roundwood prices of New Zealand might have adjusted to the prices in Australia when open market mechanisms were set. Finally, France and Spain showed similar trends until 2003.

Non-coniferous pulpwood delivered prices ranged from an average of 28 to 61 USD/ $m^3$ (Table 4). The non-coniferous group has fewer countries than the coniferous group because there are fewer non-coniferous pulpwood producers of significance worldwide meeting the 5% threshold. Brazilian prices had the highest variation in the period, 54%, while prices in the US had the lowest variation, 14%.

Non-coniferous price series contained more variability than coniferous price series (Figure 2). In North America, the changes in prices were less dramatic than in Europe, while in the Southern hemisphere prices started to increase in the 2000s. In South America, the most important producer is Brazil which historically had had low roundwood prices. However, from 2004 prices have been increasing. It is important to note that prices also increased in local currencies; therefore, the exchange rate was not necessarily a factor for the increase. In Europe, Spain, another important producer of non-coniferous pulpwood, showed peaks in 1995 and again in the 2006 when prices in Euros also increased.

**3.2 Methods** Several authors relied on the Johansen's cointegration method to test the long-term price relationships (Mäki-Hakola 2002; Nagubadi et al. 2001; Størdal and Nyrud 2003; Toppinen 1988; Yin et al. 2002). Others used pairwise regression analysis because of data limitations (Toivonen et al. 2002), or because the products were not homogeneous (Buongiorno 1992). This study relied on the cointegration analysis to capture the long-term relationships and the adjustment dynamics of the prices in different markets. The concept of cointegration was developed in the benchmark of vector autorregression (VARs) models with the work by Johansen (1988) and by Johansen and Juselius (Johansen 1988; Johansen and Juselius 1990). The VAR approach considers all variables as endogenous, and the model's equations reflect all the relationships among them. The

Table 3: Delivered coniferous pulpwood nominal price statistics, in USD/$m^3$

| **Pulpwood Market** | **Number of observations** | **Mean** | **Standard deviation** | **Coefficient of variation** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|---|
| US Southeast | 99 | 35 | 4 | 11% | 25 | 45 |
| US Northwest | 99 | 33 | 8 | 24% | 22 | 55 |
| Canada East | 99 | 47 | 10 | 21% | 33 | 68 |
| Canada West | 99 | 31 | 8 | 26% | 19 | 59 |
| Norway | 99 | 55 | 9 | 16% | 38 | 76 |
| Sweden | 99 | 51 | 12 | 24% | 31 | 75 |
| Finland | 99 | 54 | 12 | 22% | 35 | 83 |
| France | 99 | 52 | 10 | 19% | 34 | 76 |
| Germany | 99 | 56 | 9 | 16% | 36 | 76 |
| Spain | 99 | 35 | 8 | 23% | 24 | 53 |
| Brazil | 99 | 26 | 14 | 54% | 11 | 58 |
| Chile | 99 | 22 | 7 | 32% | 9 | 38 |
| New Zealand | 99 | 26 | 6 | 23% | 18 | 43 |
| Australia | 99 | 29 | 6 | 21% | 17 | 44 |

Table 4: Non-coniferous pulpwood delivered nominal price statistics, in USD/$m^3$

| **Pulpwood Market** | **Number of observations** | **Mean** | **Standard deviation** | **Coefficient of variation** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|---|
| US Southeast | 99 | 33 | 5 | 15% | 23 | 42 |
| US Northwest | 99 | 26 | 4 | 15% | 18 | 36 |
| Canada East | 99 | 33 | 8 | 24% | 24 | 48 |
| Sweden | 99 | 52 | 11 | 21% | 31 | 74 |
| Finland | 99 | 54 | 12 | 22% | 35 | 81 |
| France | 99 | 44 | 10 | 23% | 29 | 67 |
| Germany | 99 | 53 | 17 | 32% | 23 | 89 |
| Spain | 99 | 61 | 14 | 23% | 42 | 94 |
| Brazil | 99 | 28 | 15 | 54% | 10 | 64 |
| Chile | 99 | 35 | 8 | 23% | 18 | 53 |
| Australia | 99 | 41 | 14 | 34% | 24 | 77 |

vector error correction models (VECMs) are a type of VAR model whereby the restriction is imposed that a long-run equilibrium relationship exists among the non-stationary variables of the system. In this case, the variables are said to be cointegrated.

The first step in conducting a cointegration analysis is to test for the stationarity of each price series. The first one is the Augmented Dickey-Fuller (ADF) test used to test whether a series is non-stationary (i.e., it has a unit root) (Enders 1995, page 225). The null hypothesis under this test is that the series has a unit root. This test assumes that there is no correlation among the residuals of the model.

To account for serial autocorrelation, Phillips and Perron proposed another test that relaxes this assumption and incorporates non-parametric adjustment to the ADF statistics (Hamilton 1994, pages 506-512). One limitation of the Phillips-Perron (PP) test is that it has been shown to frequently reject the null hypothesis of a unit root when this hypothesis is true (Enders 1995, page 242).

The third test considered was the GLS version of the ADF test termed the ADF General Least Squares (ADF-GLS) test (Elliott et al. 1996). This test is very similar to the ADF test, but the data are detrended and the coefficients are estimated using GLS instead of Ordinary Least Squares (OLS). The null hypothesis in the ADF-GLS test is that the time series is non-stationary. Two alternative specifications can be tested, (1) the series is stationary about a linear time trend, and (2) the series is stationary with no linear time trend.

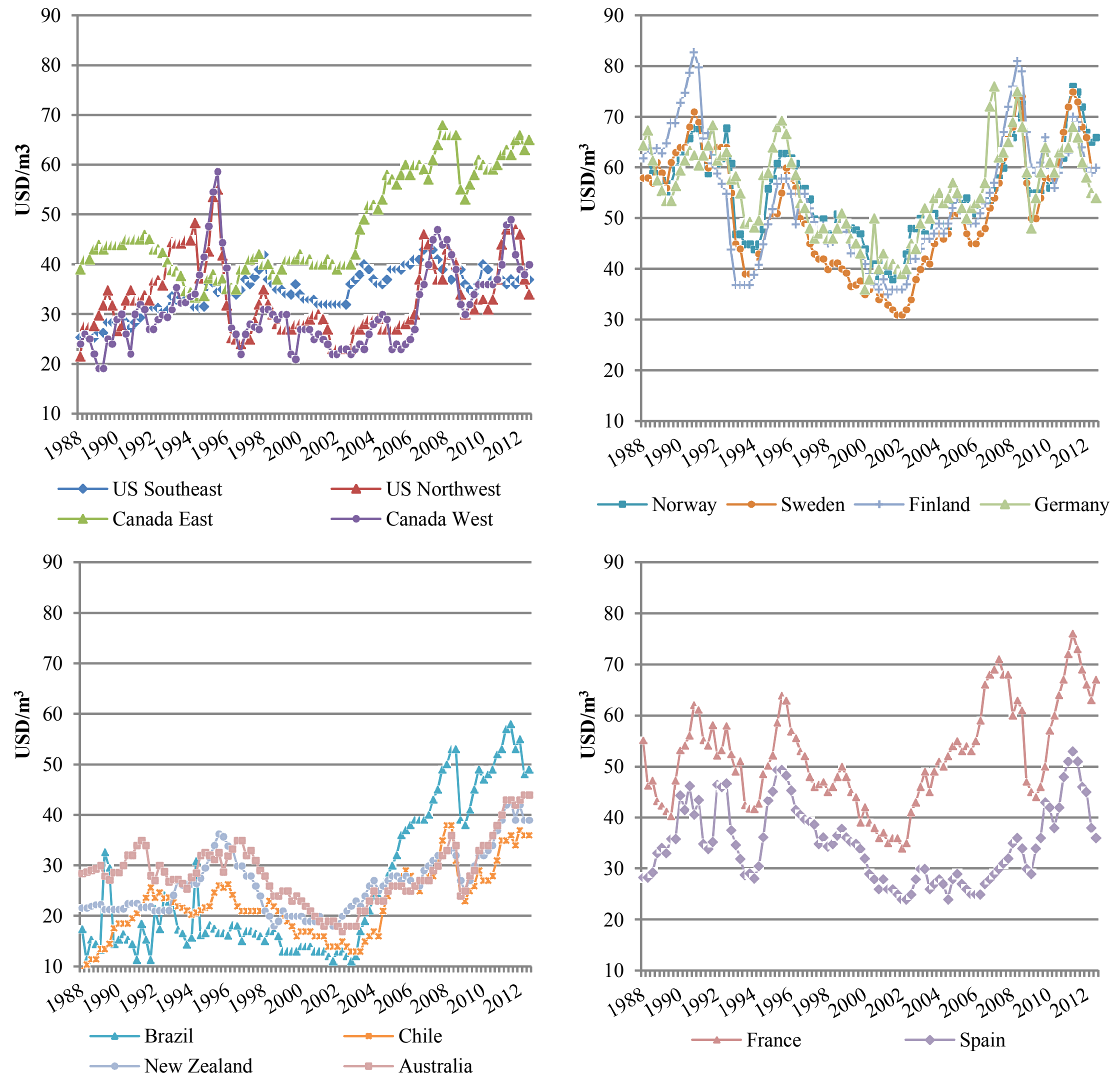


Figure 1: Coniferous pulpwood delivered nominal prices 1988 Q1-2012 Q3, in USD/$m^3$

Given the data used in this research, the most appropriate approach appears to be the ADF-GLS test because this test corrects the ADF test for possible correlation in the residuals. Furthermore, the ADF-GLS test performs better than the PP test in large samples (Hayashi 2007, page 603). The data set used in this research is considered large, because it includes 99 quarterly observations. For these reasons, we selected the ADF-GLS test in this analysis.

The Akaike Information Criterium (AIC) and Schwartz, or Bayesian Information Criterium (SBIC), were used to select the number of lags to include in the ADF and PP tests, and SBIC was used to select the lags to include in ADF-GLS tests. The SBIC was preferred to the AIC when results differed, as it has better asymptotic properties than the AIC (Hayashi 2007, page 603). Prices were converted to logarithms to eliminate large variations in the price series. First, the series were tested for stationarity using ADF, PP, and ADF-GLS tests. The series were tested assuming a trend and a constant, and only a constant. The results are reported for nominal prices in USD without a trend and a constant. The results for real prices in USD are mentioned in the text when these results differed from the ones obtained for nominal price series. Real prices are relevant because some of the analyzed countries have experienced high inflation during the period of the analysis, which may have distorted price trends.

In order to estimate a VECM, Johansen's approach maximizes the likelihood function of the system of equations subject to the restrictions that there are $r$ cointegration vectors, with $r$ denoting any natural number. The restriction is implemented by using the fact that the order of cointegration is the rank of $\pi{=}\alpha\beta$', where $\alpha$ and $\beta$ are ($p$ $x$ $r$) matrices, with $p$ the number of variables. If there are $r$ cointegrating vectors, a VAR model

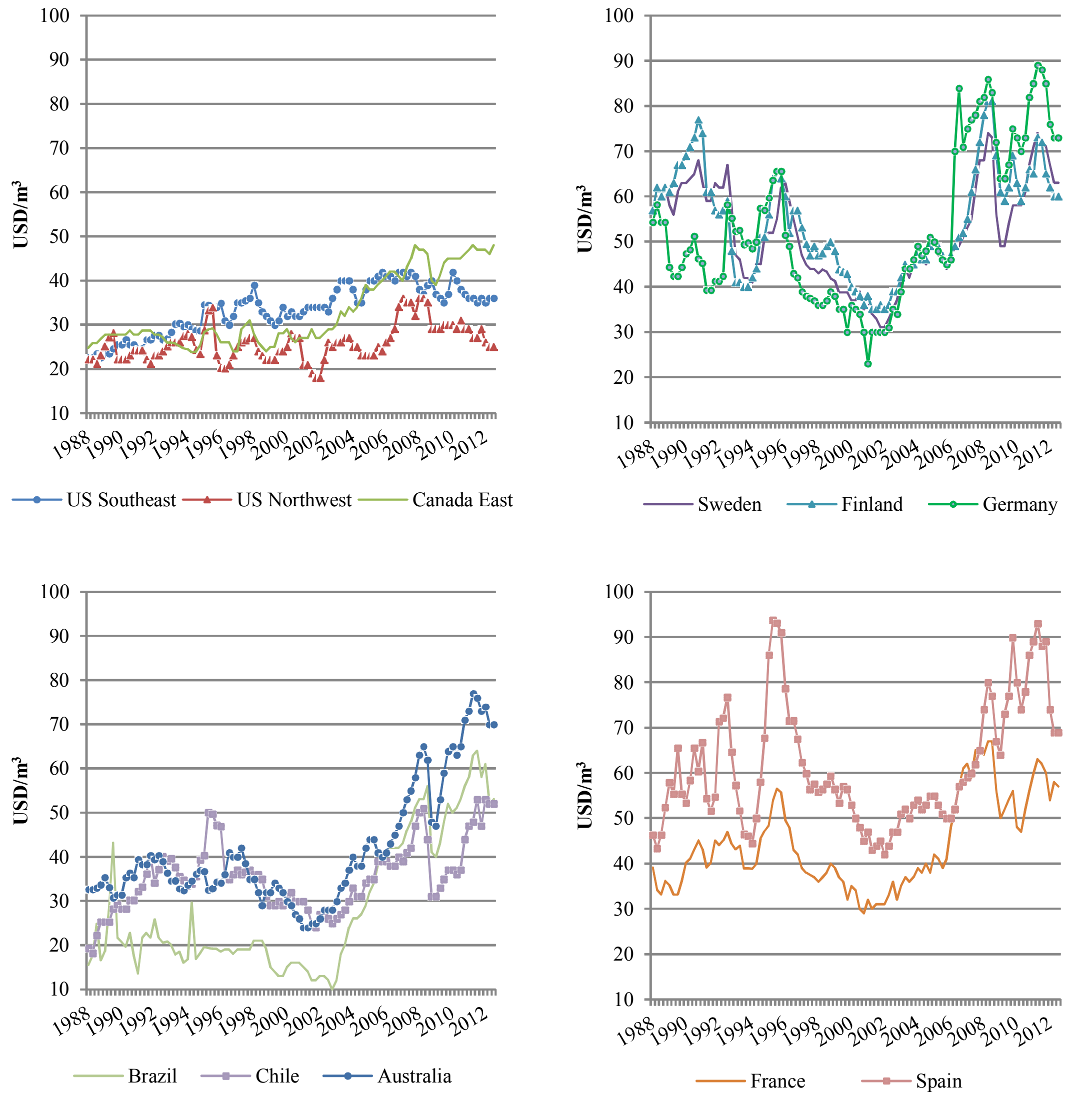


Figure 2: Augmented Dickey Fuller General Least Squares (ADF-GLS) unit root tests for coniferous pulpwood nominal prices, in USD

can be estimated as the following VECM (adapted from Juselius 2006, page 116):

$$\begin{aligned}\Delta y_t \;=\; & \alpha\beta' y_{t-1} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \\ & + \ldots + \Gamma_{k-1}\Delta y_{t-k+1} + C + D_t + \varepsilon_t\end{aligned}$$

where:
$t = 1, \ldots T$ is the time period
$k$ is the lag length
$y_t$ is a ($p$ x *1*) vector of variables
$\beta$ is the ($p$ x $r$) cointegration vector
$\alpha$ is the ($p$ x $r$) loading matrix, which measures how $y_t$ changes to "correct" the error, or the deviation from the long-run relation
$\Gamma_i$ is a ($p$ x $p$) matrix of parameters
$C$ is a ($p$ x *1*) vector of constants
$D_t$ is a ($p$ x *1*) vector of seasonal dummies
$\varepsilon_t$ is a ($p$ x *1*) vector of white noise errors

Johansen proposed five alternative model specifications to test for cointegration: (1) a model with no deterministic trend; (2) a model with no linear trend and with an intercept; (3) a model with no linear trend and with an unrestricted constant; (4) a model with a linear trend but without constant; and (5) a model with unrestricted constant and a unrestricted trend (Juselius 2006, pages 136-138).

The LOP holds if in a system of p prices there exist p-1 cointegrating vectors meaning that the p markets follow one common trend. If there are fewer than *p-1* cointegrating vectors, the markets are considered to be partially integrated (Yang et al. 2000). Therefore, for the LOP to hold, three conditions must be met. First, the $p$ series are cointegrated, second they are cointegrated in $p$-$1$ vectors, meaning that there is a long-term relationship among them, third, that the $\beta$ vector could be normalized in order to have two variables with equal magnitude and opposite sign, implying that the prices move together in the long-term.

There are two cointegration tests to choose from: the trace test and the maximum eigenvalue test (Johansen 1988; Johansen and Juselius 1990). The difference between these two tests is the alternative hypothesis used. The trace test can be written as follows:

$$H_0 : r = \overline{r}, \ \ \overline{r} < p \ , \ H_A : r = p$$

where:
$H_0$ is the null hypothesis
$H_A$ is the alternative hypothesis
$r$ is the number of cointegrating vectors that under the null hypothesis is equal to $\overline{r}$

The trace test statistics is defined as follows (adapted from Enders 1995, page 391):

$$-T \sum_{i=\overline{r}+1}^{n} \log \left(1 - \widehat{\lambda}_i\right)$$

where T was previously defined. The $\widehat{\lambda}_i$ are the eigenvalues of the matrix $\pi$ and are indicators of the relationship between the long-term part of the equation and the stationary part (Juselius 2006, page 132).The maximum eigenvalue test has the following null and alternative hypothesis:

$$H_0 : r = \overline{r}, \ \overline{r} < p, \ H_A : r = \overline{r} + 1$$

where terms are defined as in Equation (2).

The maximum eigenvalue statistics is defined as follows (adapted from Enders 1995, page 391):

$$-T\log \left(1 - \widehat{\lambda}_{r+1}\right)$$

where terms are defined as in Equation (2).

The adjustment and cointegrating coefficients can be normalized by setting them to one in order to interpret the system of cointegrating equations. A likelihood test is conducted to test the validity of the restrictions imposed. This $\chi^2$ test has $r$ degrees of freedom and compares the restricted and the unrestricted models and distributions.

In order to conduct the cointegration analysis of the pulpwood prices, the data were grouped according to three criteria: (1) region, (2) trade volume and direction, and (3) production volume. Regional groupings were defined by the continent to which they belong: Europe, North America, South America, and Oceania. For Europe, two groups were defined, the first one included all the European countries in the database–Germany, Spain, France, Sweden, Norway, and Finland– while the second included only Germany, Sweden, Norway, and Finland. The groups were called Europe I and Europe II, respectively. The roundwood prices in Scandinavian countries –Sweden, Norway, and Finland– and Germany have been previously analyzed (Mäki-Hakola 2002; Toivonen et al. 2002). Therefore, the Europe II group was created to compare the results from the current research with the previous ones.

The trade groupings were defined by the share of each market in the global pulpwood exports in USD from 1997 to 2010 by country of origin. A market had to have at least a 5 % share in global trade to be included in this group. Only coniferous producers fulfilled this criterion. The countries that export to China, Japan and Korea were Australia, Canada, New Zealand, the US and Chile. Brazil was not considered in the analysis because it has experienced the instances of hyperinflation and currency changes which might have altered the results. The production groupings were defined by the share of each country in coniferous and non-coniferous global production.

Finally, based on the results of these cointegration tests, pairwise cointegration was tested for selected countries. In the regional groupings, a dummy variable was included to analyze the effects of the introduction of the Euro (EUR) in 2002. The variable to account for the introduction of the EUR was defined as follows:

$$D_{Euro} = \begin{cases} 1, & time > 2001 \ Q4 \\ 0, & otherwise \end{cases}$$

## 4 Results and discussion

**4.1 Unit root tests** For coniferous pulpwood nominal prices, the ADF-GLS test could not reject the null hypothesis of a unit root for all the series, except for the US Northwest prices were the hypothesis was rejected at 5% (Table 5). The series were differentiated and tested for unit root, including the US Northwest series. All the series were stationary in first differences at 5%, meaning that they are integrated of order one, hereafter referred as I(1). The null hypothesis of a unit root could not be rejected for coniferous pulpwood real prices.

Subsequently, the unit root tests were conducted for non-coniferous pulpwood prices. The null hypothesis of a unit root could not be rejected for all the series in nominal USD, except for the US Northwest (Table 6). Pulpwood prices from the US Northwest were included in the cointegration analysis as the ADF-GLS rejected

Table 5: Augmented Dickey Fuller General Least Squares (ADF-GLS) unit root tests for coniferous pulpwood nominal prices, in USD

| **Pulpwood Market** | **SBIC** | **Levels** | **First differences** |
|---|---|---|---|
| US Southeast | 1 | -0.62 | -7.23* |
| US Northwest | 1 | -2.14** | -2.43** |
| Canada East | 1 | -0.18 | -4.20* |
| Canada West | 2 | -2.06 | -4.82* |
| France | 1 | -1.89 | -2.18** |
| Germany | 1 | -1.98 | -6.26* |
| Spain | 4 | -2.20 | -5.27* |
| Sweden | 2 | -2.01 | -5.17* |
| Finland | 2 | -2.13 | -4.92* |
| Norway | 2 | -1.90 | -6.19* |
| New Zealand | 2 | -0.78 | -5.24* |
| Australia | 1 | -1.18 | -7.06* |
| $\text{Brazil}_{94}$ | 1 | -0.12 | -5.13* |
| Chile | 2 | -0.14 | -3.55* |

Notes: (1) SBIC= Schwartz-Bayesian Criteria, (2) *significant at 1%, **significant at 5%, ***significant at 10%

Table 6: Augmented Dickey Fuller General Least Squares (ADF-GLS) unit root tests for non-coniferous pulpwood nominal prices, in USD

| **Pulpwood Market** | **SBIC** | **Levels** | **First differences** |
|---|---|---|---|
| US Southeast | 1 | -0.50 | -7.70* |
| US Northwest | 2 | -2.83*** | -6.39* |
| Canada East | 1 | -0.02 | -5.16* |
| France | 1 | -1.29 | -2.83* |
| Germany | 1 | -1.42 | -5.57* |
| Spain | 2 | -1.93 | -4.35* |
| Sweden | 2 | -1.99 | -5.71* |
| Finland | 2 | -2.24 | -3.88* |
| Australia | 2 | -0.35 | -6.31* |
| Chile | 1 | -0.39 | -5.24* |
| $\text{Brazil}_{94}$ | 2 | -0.37 | -4.30* |

Notes: (1) SBIC= Schwartz-Bayesian Criteria, (2) *significant at 1%, **significant at 5%, ***significant at 10%

the unit root at 10% but the results have to be taken cautiously.

Furthermore, non-coniferous pulpwood real prices expressed in USD were tested for unit root. Results were similar to the results in nominal prices. The series were differentiated, and the unit root tests results showed that the null hypothesis of a unit root was rejected for all series. Therefore, non-coniferous prices series are I(1), both for nominal and real prices in USD.

**4.2 Cointegration analyses** Since the analyses were inconclusive as to whether there was a linear trend in the model, a model with a constant and without a trend and a model with a constant and a trend were specified. Only results for a model with a constant and without a trend are presented as the results for both specifications were similar.

**Regional groupings** For the coniferous dataset the countries were grouped by region. Europe I grouping included the following countries: Germany, Spain, France, Sweden, Finland, and Norway. The results of the trace test for coniferous pulpwood nominal prices in USD including the variable $D_{Euro}$ indicated that the hypothesis of one cointegrating vector could not be rejected at 1%, and the maximum eigenvalue tests yielded the same result (Table 7). The results were similar when using real prices in USD. When the variable $D_{Euro}$ was not included, the hypothesis of one cointegrating vector was rejected at 1% under the trace test and under the maximum eigenvalue test. This result suggests that the introduction of the EUR had an effect on the long-term dynamics of pulpwood prices. The LOP did not hold for coniferous pulpwood prices of the group Europe I because a necessary condition of four cointegrating vectors for the five series was not met. Therefore, in Europe there is not a single pulpwood market.

Subsequently, the coniferous pulpwood prices of Norway, Sweden, Finland, and Germany (Europe II) were tested for cointegration. The null hypothesis of one cointegrating vector could not be rejected at 1% under the maximum eigenvalue and the trace tests. The LOP did not hold because the first necessary condition was to find three cointegrating vectors for the four series. In real price terms, results also showed that the series were cointegrated in one cointegrating vector. A previous study had suggested that Finnish and German pulpwood markets were cointegrated for the period 1994-2001 (Mäki-Hakola 2002). Another study had shown that Finnish and Swedish pulpwood markets analysis yielded different results depending on the species analyzed. While the LOP held for spruce pulpwood prices, for pine pulpwood prices only held when Finnish prices were regressed on Swedish prices. These results should be taken cautiously because the study was conducted using only 18 annual observations (Toivonen et al. 2002).

The third region analyzed was North America, which included the US Southeast, the US Northwest, Canada East, and Canada West. The null hypothesis of one cointegrating vector among the nominal prices in USD could not be rejected. The LOP did not hold because

Table 7: Cointegration tests for coniferous pulpwood nominal prices regional groupings, in USD

| **Maximum rank** | **Trace statistic** | **Critical value** | | **Maximum eigen-value statistic** | **Critical value** | |
|---|---|---|---|---|---|---|
| | | **5%** | **1%** | | **5%** | **1%** |
| *Europe I: Germany, Spain, France, Sweden, Finland, Norway (1)* | | | | | | |
| 0 | 119.59 | 94.15 | 103.18 | 45.14 | 39.37 | 45.10 |
| 1 | 74.45* | 68.52 | 76.07 | 28.74 | 33.46 | 38.77 |
| 2 | 45.71** | 47.21 | 54.46 | 20.30 | 27.07 | 32.24 |
| 3 | 25.41 | 29.68 | 35.65 | 12.32 | 20.97 | 25.52 |
| 4 | 13.10 | 15.41 | 20.04 | 7.31 | 14.07 | 18.63 |
| 5 | 5.79 | 3.76 | 6.65 | 5.79 | 3.76 | 6.65 |
| *Europe II: Norway, Sweden, Finland, Germany (1)* | | | | | | |
| 0 | 65.90 | 47.21 | 54.46 | 33.38 | 27.07 | 32.24 |
| 1 | 32.51* | 29.68 | 35.65 | 18.65 | 20.97 | 25.52 |
| 2 | 13.86** | 15.41 | 20.04 | 9.38 | 14.07 | 18.63 |
| 3 | 4.48 | 3.76 | 6.65 | 4.48 | 3.76 | 6.65 |
| *North America: US, Canada (1)* | | | | | | |
| 0 | 59.00 | 47.21 | 54.46 | 41.38 | 27.07 | 32.24 |
| 1 | 17.62* | 29.68 | 35.65 | 10.43 | 20.97 | 25.52 |
| 2 | 7.18 | 15.41 | 20.04 | 6.29 | 14.07 | 18.63 |
| 3 | 0.90 | 3.76 | 6.65 | 0.90 | 3.76 | 6.65 |
| *South America: Chile, $Brazil_{94}$(1)* | | | | | | |
| 0 | 10.29* | 15.41 | 20.04 | 9.07 | 14.07 | 18.63 |
| 1 | 1.22 | 3.76 | 6.65 | 1.22 | 3.76 | 6.65 |
| *Oceania: Australia, New Zealand (2)* | | | | | | |
| 0 | 12.36* | 15.41 | 20.04 | 8.76 | 14.07 | 18.63 |
| 1 | 3.60 | 3.76 | 6.65 | 3.60 | 3.76 | 6.65 |

(1) The number of lags used is in parenthesis, (2)*significant at 1%, **significant at 5%, ***significant at 10%

the necessary condition of three cointegrating vectors did not hold.

The fourth region analyzed was South America which included the two most important producers, Brazil and Chile. In this group, from the first quarter of 1994 to the third quarter of 2012, coniferous pulpwood prices in nominal and real USD were not cointegrated. Therefore, the LOP did not hold.

The fifth group analyzed was Oceania, which included New Zealand and Australia. Like prices in South America, coniferous pulpwood nominal prices in Oceania were not cointegrated, and similar results held for real prices. The LOP did not hold. However, while in New Zealand pulpwood prices have been traded in open markets, in Australia they have been set in long-term contracts until recently. This difference might have contributed to the different trend in pulpwood prices.

The estimates of the VECM were restricted to include only the significant long-term parameters, $\beta$, while the adjustments parameters, $\alpha$, were not restricted (Table 8). For all the models, the test of overidentifying restrictions did not reject the null hypothesis that the restrictions imposed were valid. The results for the group Europe I suggested that coniferous pulpwood nominal prices in Sweden, Finland, Germany, Spain, and Norway shared a long-term relationship in the period 1988-2012. All the prices move in the same direction in the long-term except for prices in Norway. French prices were not significant in explaining the model; therefore, a restriction was added to the cointegrating coefficient by setting it to zero. The estimated adjustment parameters, $\alpha$, indicated that the prices in Spain responded more than the other prices to changes in the system.

For the Europe II group, the estimated VECM suggested that coniferous pulpwood nominal prices of Germany, Norway, and Finland shared a long-run relationship. The results suggested that coniferous pulpwood nominal prices of Germany and Norway moved in the same direction in the long-term while Finnish prices did not. The estimated adjustment parameters, $\alpha$, were not significant, except for the coefficient for Sweden.

In North America, the VECM estimates indicated that there was a long-term relationship among coniferous pulpwood nominal prices of US Southeast, US

Table 9: Cointegration tests for coniferous pulpwood nominal prices trade grouping, in USD

| **Maximum rank** | **Trace statistic** | **Critical value** | | **Maximum eigen-value statistic** | **Critical value** | |
|---|---|---|---|---|---|---|
| | | **5%** | **1%** | | **5%** | **1%** |
| *Exporting to China, Korea and Japan: US, Canada, New Zealand, Australia, Chile (1)* | | | | | | |
| 0 | 153.45 | 124.24 | 133.57 | 51.22 | 45.28 | 51.57 |
| 1 | 102.23* | 94.15 | 103.18 | 41.74 | 39.37 | 45.1 |
| 2 | 60.48** | 68.52 | 76.07 | 26.85 | 33.46 | 38.77 |
| 3 | 33.63 | 47.21 | 54.46 | 19.79 | 27.07 | 32.24 |
| 4 | 13.84 | 29.68 | 35.65 | 9.13 | 20.97 | 25.52 |
| 5 | 4.71 | 15.41 | 20.04 | 3.01 | 14.07 | 18.63 |
| 6 | 1.70 | 3.76 | 6.65 | 1.70 | 3.76 | 6.65 |

(1) The number of lags used is in parenthesis, (2)*significant at 1%, **significant at 5%, ***significant at 10%

Table 8: VECM estimates for coniferous pulpwood nominal prices regional groupings, in USD

| **Region** | $\beta$ | $\alpha$ | $\chi$**2** |
|---|---|---|---|
| *Europe I (1)* | | | |
| Sweden | 1.000 | -0.138 | 2.033 |
| Finland | -1.251 | -0.074** | *0.154* |
| Germany | -1.911 | 0.051** | |
| France | - | -0.073*** | |
| Spain | -0.332 | -0.110* | |
| Norway | 2.165 | -0.136 | |
| C | 1.224 | | |
| *Europe II (1)* | | | |
| Germany | 1.000 | -0.055*** | |
| Norway | -1.573 | 0.240*** | 3.181 |
| Sweden | - | 0.216 | *0.075* |
| Finland | 0.501 | 0.158*** | |
| C | 0.286 | | |
| *North America (1)* | | | |
| US Southeast | 1.000 | -0.009*** | |
| US Northwest | 2.395 | -0.050*** | 0.028 |
| Canada East | - | -0.037 | *0.867* |
| Canada West | -1.970 | 0.134 | |
| C | 5.153 | | |

Notes: (1) The number of lags used is in parenthesis, (2)*significant at 1%, **significant at 5%, ***significant at 10%, (3) the p-value is in italics, (4) C=constant

Northwest, and Canada West. Furthermore, coniferous pulpwood nominal prices of the US Southeast and Canada West have a positive relation in the long-term. The adjustment coefficients were not significant for the US Southeast and the US Northwest prices. On the other hand, the Canada West adjustment coefficient was significant and indicated a response to changes in the system of prices. The results have to be considered cautiously because the prices of US Northwest were non stationary in levels only at 5%.

Finally, in the regional grouping for non-coniferous pulpwood prices, the null hypothesis of non-cointegration could not be rejected for nominal prices in the groups analyzed, except for North America. Results are not reported here but are available upon request.

**Trade grouping** Coniferous pulpwood nominal prices in trade grouping were cointegrated in one vector at 5% and in two vectors at 1%, using the trace test and the maximum eigenvalue test (Table 9). Real prices were cointegrated at 1%. Therefore, the US Southeast, New Zealand, Chile, and Australia coniferous pulpwood nominal prices had a long-term relationship, but the LOP did not hold because the necessary condition of three cointegration vectors was not met.

The estimates of the VECM of the trade grouping was restricted to include only the significant $\beta$ parameters, while parameters $\alpha$ were not restricted (Table 10). Our results indicated that the nominal prices of the US Southeast, New Zealand and Chile moved in same direction in the long-term.

**Production grouping** Finally we run a cointegration analysis for a production group including. The production group included the US Southeast, US Northwest, Sweden, and Finland but the results were not substantially different from the previous results.

**Pairwise cointegration** Our previous results indicated that the coniferous pulpwood nominal prices from the US Southeast and Chile were cointegrated when the countries were grouped by trade. In addition, coniferous prices from Chile and New Zealand were cointegrated when grouped by trade. Finally, German coniferous

Table 11: Cointegration tests for coniferous pulpwood nominal prices pairwise grouping, in USD

| **Maximum rank** | **Trace statistic** | **Critical value** | | **Maximum eigen-value statistic** | **Critical value** | |
|---|---|---|---|---|---|---|
| | | **5%** | **1%** | | **5%** | **1%** |
| *Chile, New Zealand (1)* | | | | | | |
| 0 | 15.02* | 15.41 | 20.04 | 13.54 | 14.07 | 18.63 |
| 1 | 1.48 | 3.76 | 6.65 | 1.48 | 3.76 | 6.65 |
| *Chile, US Southeast (2)* | | | | | | |
| 0 | 13.43* | 15.41 | 20.04 | 7.83 | 14.07 | 18.63 |
| 1 | 5.60 | 3.76 | 6.65 | 5.6 | 3.76 | 6.65 |
| *Germany, Sweden (2)* | | | | | | |
| 0 | 26.80 | 15.41 | 20.04 | 21.72 | 14.07 | 18.63 |
| 1 | 5.07* | 3.76 | 6.65 | 5.07 | 3.76 | 6.65 |
| *Germany, Norway (1)* | | | | | | |
| 0 | 25.59 | 15.41 | 20.04 | 21.28 | 14.07 | 18.63 |
| 1 | 4.31* | 3.76 | 6.65 | 4.31 | 3.76 | 6.65 |

(1) The number of lags used is in parenthesis, (2)*significant at 1%, **significant at 5%, ***significant at 10%

Table 10: VECM estimates for coniferous pulpwood nominal prices trade grouping, in USD

| **Region** | $\beta$ | $\alpha$ | $\chi$**2** |
|---|---|---|---|
| *To China, Japan and Korea (1)* | | | |
| US Southeast | 1.000 | -0.032*** | 3.988 |
| New Zealand | -0.502 | -0.033*** | *0.263* |
| Chile | -0.580 | 0.251 | |
| US Northwest | - | 0.255 | |
| Canada East | - | 0.079** | |
| Canada West | - | 0.186* | |
| Australia | 0.946 | -0.134** | |
| C | -3.303 | | |

Notes: (1) The number of lags used is in parenthesis, (2)*significant at 1%, **significant at 5%, ***significant at 10%, (3) the p-value is in italics, (4) C=constant

pulpwood prices were cointegrated with prices in Sweden and Norway.

Based on these results, pulpwood prices in these countries were tested for pairwise cointegration. First, results indicated that coniferous pulpwood nominal prices of the US Southeast and Chile were not cointegrated (Table 11). Second, coniferous pulpwood prices in Chile and New Zealand were tested for cointegration because these two countries are important radiata pine pulpwood producers, so the prices could share a long-term relationship. However, the prices were not cointegrated in nominal or in real terms. One of the factors that might explain these results are that pulpwood is consumed domestically, primarily in Chile. Third, coniferous pulpwood nominal prices in Germany and Sweden were cointegrated in one vector. Fourth, Germany and Norway coniferous pulpwood nominal prices were cointegrated in one vector.

The estimated VECMs showed that the LOP was close to holding between the prices in Germany and Norway because one cointegrating vector between the two series was found and also the long-term coefficients, $\beta$, were 1 and -0.896 (Table 12). Moreover, coniferous pulpwood prices in Sweden did not adjust fast to changes in prices in Germany. On the other hand, prices in Norway adjusted to changes in prices in Germany.

To summarize, the LOP did not hold for any of the groups analyzed except for the coniferous pulpwood nominal prices of Germany and Norway. However, in some cases, long-term relationships were identified. Comparing different results, in the majority of the cases, the markets that were found to be cointegrated had the same long-term trend for different groups. Coniferous pulpwood nominal prices in Finland and Sweden had a moved in opposite direction between 1988 and 2012 in all the groups in which they were included; this also held true for coniferous pulpwood nominal prices in Finland and Germany and the US Southeast and the US Northwest. Consequently, we identified a pattern in the long-term relations among pulpwood prices between Finland and Sweden, Finland and Germany, and the US Southeast and the US Northwest. These differences could be explained by different inflation trends and different trends in the exchange rates in these countries.

Table 12: VECM estimates for coniferous pulpwood nominal prices pairwise groupings, in USD

| **Pairwise** | B | $\alpha$ |
|---|---|---|
| | *Germany, Sweden (3)* | |
| Germany | 1.000 | -0.367 |
| Sweden | -0.570 | *0.072**** |
| C | -1.769 | |
| | *Germany, Norway (1)* | |
| Germany | 1.000 | -0.160** |
| Norway | -0.896 | *0.210* |
| C | -0.421 | |

Notes: (1) The number of lags used is in parenthesis, (2)*significant at 1%, **significant at 5%, ***significant at 10%, (3) the p-value is in italics, (4) C=constant

## 5 Conclusions

The results showed that the LOP did not hold for the pulpwood nominal prices when grouped by region, by level of production, or by direction of trade. For some selected pairs of countries results also indicated that the LOP did not hold with the exception of coniferous pulpwood nominal prices in Germany and Norway. These results also hold for real prices. The implication of these results is that there appears to be no single worldwide pulpwood market.

However, results differed when coniferous pulpwood and non-coniferous pulpwood prices were considered. In the coniferous pulpwood groupings, countries that are located in the same region seemed to adjust their pulpwood prices to the neighbors in the long-term while the short-term adjustments depend on the region analyzed. For example, in the group Europe II –Germany, Norway, Sweden, and Finland– coniferous pulpwood nominal prices adjusted in the short term as well as in the long term to a long-term trend. Furthermore, countries that exported the majority of their coniferous pulpwood to common markets did not adjust their prices in the long term. Finally, the coniferous pulpwood producers shared a long-term common trend in the period of the analysis but only the prices of the US Northwest adjusted in the short-term to changes in the system of prices. In the non-coniferous pulpwood groupings, only one long-term relationship was identified. Prices of the largest producers of non-coniferous worldwide –the US Southeast and Brazil– shared a long-term relationship.

These results can be potentially explained by pulpwood market characteristics and economic changes that had occurred in the period 1988-2012. Regarding pulpwood market characteristics, these markets turned to be not as competitive as initially thought. Pulpwood is mostly consumed within the country of production, and these prices might be influenced more by local factors than by external factors. First, it appears that some markets are dominated by few firms which may enjoy a degree of market power. For example, in Chile the pulpwood industry is dominated by two companies. Furthermore, in the period 1988-2012, some countries had set their prices either through negotiations, such as Norway, Finland, and Sweden until the early 1990s, or through long-term contracts with the government such as in Australia. Regarding economic changes that occurred in the period, the most important events identified were the emergence of the common European currency, the EUR, in 2002, the change of currency in Brazil in 1994, and the hyperinflation in Brazil between 1990 and 1994. These changes might not have allowed the prices to return to a long-run equilibrium, if one existed.

For conducting the unit root tests, it appeared that the ADF-GLS was the most appropriate because of a large number of observations covering a longer time span. In testing for the LOP it appeared that the Johansen method was the most appropriate as it captures the long-term as well as the short-term relationships. However, this method can be quite restrictive and it was rather difficult to confirm the three necessary conditions for the LOP to hold: (1) the prices to be cointegrated, (2) to find $p-1$ cointegrating vectors among $p$ variables, and (3) the long-term coefficients have to equal 1 and -1. Further, the analysis was conducted with delivered prices. It is possible that the LOP could have held for stumpage prices. But if stumpage prices followed similar trends but harvest and hauling costs did not, the LOP would not hold for delivered prices.

The limitations of this study are related to the high level of data aggregation. Typically, one price series is representative entire countries or large wood supply regions. We recognize that this high level of aggregation may be a limiting factor for the study as there are likely to specific trends among regions in the same country. However, these results can be considered as the first step in studying worldwide pulpwood markets.

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