PRICE DYNAMICS OF THE WOODY FEEDSTOCKS USED FOR WOOD PELLET PRODUCTION IN THE US SOUTH

by

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(Under the Direction of Jacek Siry)

ABSTRACT

The US South has recently experienced a rapid expansion in wood pellet production. The growth of this industry within the context of international export markets and the existing US fiber markets is examined. As raw material inputs represent the highest variable cost component of wood pellet production, flexibility in the strategic sourcing of woody feedstocks can hedge against volatility in the fiber markets and allow for the cost minimization of raw material inputs. Time series modeling tools were employed to explore the various price relationships among four common woody feedstocks used in the production of wood pellets. The feedstocks were found to be cointegrated. A Vector Error Correction Model (VECM) was used to provide the structure through which impulse response functions and forecast error variance decompositions were analyzed. The results of these price dynamics indicate a production preference of residuals over pulpwood.

INDEX WORDS: Time series, Cointegration, Wood pellets, Bioenergy

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DEDICATION

Molly, thank you for all the support and encouragement along the way.

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CHAPTER 1

INTRODUCTION

There is increasing demand for woody biomass for the purpose of energy production. This demand is currently policy driven, reflecting an effort to reduce fossil fuel consumption and greenhouse gas emissions. The main policy driving wood pellet demand is the European Union's implementation of its 2020 climate and energy package. The package is a legally binding set of targets that include a 20% reduction of greenhouse gas emissions from 1990 levels, 20% contribution of renewables in energy consumption, and a 20% increase in energy efficiency by 2020. This mandate, along with individual member states' incentives, represents the largest market force in wood pellet demand (European Commission, 2014b).

With continued year-over-year growth, wood pellets represent the largest segment of the wood biomass portfolio for energy as it relates to the US South. The United States has been exporting wood pellets to Europe since 2008, initially shipping approximately 85,000 tons (Newes et al., 2012). In 2012, the US exports had increased to over 1.45 million metric tons before doubling to 2.9 million metric tons by 2013. Of these US exports of wood pellets to Europe, 99% originated from the US South (U.S. Energy Information Administration, 2014). The USDA Foreign Agriculture Service estimates that the value of exported wood pellets from the US could represent $600 million in 2015 and over $1 billion by 2020 (USDA Foreign Agriculture Service, 2014).

The supply chain of industrial wood pellets is complex, multifaceted, and geographically unique. The main objectives of the supply chain are to minimize costs while ensuring a consistent and continuous supply. This must be done within the confines of environmental constraints imposed by the policy driving the demand for wood pellets (Gold & Seuring, 2011). Continued growth is dependent upon US producers meeting these increasingly stringent environmental policy demands for emissions. The United Kingdom, the largest importer of US wood pellets by volume, requires certain wood pellet emissions criteria. The dynamic nature of the supply chain for industrial wood pellets in the US South necessitates allocation of a variety of woody resources for pellet production. Increased variability in allocation impacts not only costs but also greenhouse gas emissions (Shabani, Akhtari, & Sowlati, 2013).

The objective of this thesis is to address two questions:

1. How have wood pellet markets, as related to the US South, developed from 2009 through 2014?
2. Within these markets, what are the price relationships among four woody feedstocks used in the production of wood pellets in the US South?

Regarding the first question, a market analysis is developed. It is organized into four sections. Wood pellet demand is addressed first. This section frames the policies that are driving wood pellet markets–both energy and sustainability–and provides a quantitative overview of the developments within the markets. It begins with Europe, the largest importer of wood pellets globally, and is followed by the United Kingdom, the largest importer of wood pellets within the EU. This section concludes with "Other Markets," which provides overviews of the world's largest importers of wood pellets–Denmark, Italy, Belgium, the Republic of Korea, and the Netherlands ("FAOSTAT," 2015).

The second and third sections of the market analysis address supply, both wood pellet and wood fiber respectively. A quantitative overview of US wood pellet production, specifically export markets, is developed within the context of global production. Availability of the US wood fiber resources to meet production demand is then addressed.

The final section of the market analysis is wood fiber demand. Though wood pellet markets are policy driven, pellet producers in the US South operate and compete in existing wood fiber markets. This section looks at the different types of woody feedstocks used in the production of wood pellets, the prices of this wood fiber, and the framework in which pellet producers compete with other users of woody feedstocks.

With regard to the second question, the price dynamics of four common woody feedstocks used in the production of wood pellets in the US South are analyzed. Raw material inputs represent the highest variable cost component of production. Price informs a firm’s decision to buy and determines woody feedstock allocation in production. These various price relationships are explored using multivariate time series analysis. This thesis seeks to establish if these feedstocks are cointegrated. Further, a Vector Error Correction Model (VECM) provides the structure through which impulse response functions and forecast error variance decompositions are analyzed, giving insight into the dynamic interactions between feedstock prices. Such information will aid pellet production in two ways. First, understanding the dynamic price relationships will provide insight into optimization, thereby helping to minimize fiber costs. Secondly, these various cost relationships of woody feedstocks provide inference to the underlying carbon relationships that pellet production is based upon.

The remainder of this thesis is organized as follows: a review of the literature, methodologies and data for the previously stated objectives, presentation of the results, and a discussion of these results with the conclusion. References are provided at the end. Within this construct, the two thesis questions are individually addressed under the headings market analysis and price dynamics, respectively.

CHAPTER 2

LITERATURE REVIEW

The development of bioenergy markets, both bioliquids and solid biomass, has been periodically addressed through scientific research. Heinimö et al., (2009) provided a comprehensive overview of the global biofuels market through 2006 (Heinimö & Junginger, 2009). Lamars et al., (2012) presented the quantification of the direct trade of solid biofuel commodities, including wood pellets, through 2009 (Lamers, Junginger, Hamelinck, & Faaij, 2012). Goh et al., (2013) developed an overview of the international wood pellet market through 2010. This global perspective was built by examining regional changes in wood pellet production, trade, and policy (Goh et al., 2013). Sikkema et al., (2011) examined the European wood pellet market in detail, covering traded volumes, prices, and policies through 2010 (Sikkema et al., 2011). Though the global market and the US wood pellet market are clearly intertwined, a specific focus on the development of US wood pellet markets from 2009 through 2014 has yet to be examined.

Wood bioenergy demands on markets have also been previously addressed through scientific research. The majority of this research focuses on policy effects in regards to potential bioenergy demand (Ince, Kramp, Skog, Yoo, & Sample, 2011). Galik et al., (2009) examined the regional aggregate bioenergy potential in three southern states and modeled the interaction of logging residues and roundwood supply. Supply was found to be a function of harvesting levels, prices, and price elasticity–with variability within region and over time. Wood bioenergy potential would be inherently limited if it were solely dependent on residues of the existing traditional industry (Galik, Abt, & Wu, 2009). Abt et al., (2012) modeled potential impacts of increasing wood bioenergy demand in regards to supply response, carbon, and land use. Through simulation of timber markets, it was concluded that wood bioenergy would impact existing market participants, most notably users of pulpwood–pulp, paper, and oriented strand board (Abt, Abt, & Galik, 2012).

Other studies have examined the allocation of biomass as a resource for different forms of energy in effort to minimize greenhouse gas emissions (Bentsen, Jack, Felby, & Thorsen, 2014). Additionally, environmental risks from extraction of specific feedstocks have been studied for varying raw material inputs into bioenergy (Lamers, Thiffault, Paré, & Junginger, 2013). There are also studies regarding carbon mitigation with various feedstocks. Dwivedi et al., (2014) examined the carbon efficiencies of multiple wood biomass feedstocks–both economic and environmental–with the same assumptions and using the same model. In doing so, a platform for comparison was provided. The study found logging residues preferable to pulpwood in reducing production costs and decreasing greenhouse gas emissions in the production of bioenergy (Dwivedi & Khanna, 2014).

Production costs of wood pellets are influenced by a variety of factors, with woody feedstocks identified as one of the leading costs components in the production of wood pellets (Uasuf & Becker, 2011) . Thek et al., (2004) examined wood pellet production costs through different framework conditions, specifically those of Austria and Sweden. Raw material feedstocks, sawdust in both cases, were found to be the main component of production cost (Thek & Obernberger, 2004). Mani et al., (2006) also found raw material costs to be the highest cost in regards to overall production, representing approximately 40% of production costs with sawdust again being the feedstock (Mani, Sokhansanj, Bi, & Turhollow, 2006). All of these studies took place outside the U.S. and used only residuals as a feedstock option. Similar results were found by Ning et al., (2011), however, with 76% of surveyed US pellet manufacturers citing raw materials as the dominant cost in production. This study represented production from pellet mills throughout the US and was not exclusive to southern production (Ning & Rice, 2011).

Econometric analysis within the context of international trade of forest products have also been investigated (Cheng, Mei, & Wan, 2013). Spatial integration in forest product markets–such as OSB (Goodwin, Holt, & Prestemon, 2011), roundwood (Luppold & Prestemon, 2003), and lumber (Shahi & Kant, 2009)–as well as integration in the stumpage markets have also been examined (Yin, Newman, & Siry, 2002). Price relationships among woody feedstocks used in the production of wood pellets have not been performed.

CHAPTER 3

METHODOLOGY AND DATA

3.1 Market Analysis

For the purpose of developing a market analysis, a survey of statistical sources of information and policy regulations was assessed. Trade statistics data was drawn from Eurostat, the statistical office of the European Union; HM Revenue & Customs, United Kingdom; US Census Bureau, United States; and Korean Customs Service, Republic of Korea.

The harmonized system (HS)–a two, four, or six-digit number that is used to numerically classify internationally traded products–provides the code 440131 for wood pellets. Prior to 2012, there was no specific HS code for wood pellets (World Customs Organization, 2012). Each individual country within the system boundary of this analysis, however, attaches additional identifying numbers to the HS code.

The EU classification system for trade statistics is the Combined Nomenclature (CN). The CN is an eight-digit identifier that integrates the six-digit HS code and adds two digits. In 2009, the EU created CN 44013020–"Sawdust and wood waste and scrap, agglomerated in pellets" – from the more generalized HS 440130–"Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms"–to better identify the growing wood pellet trade flows. With the creation of HS 440131 in 2012, the CN code for wood pellets became 44013100 (European Commission, 2015). For the purpose of this thesis, EU trade statistics from 2009 through 2011 are represented by CN 44013020, and statistics from 2012 through 2014 are represented by CN 44013100.

Additionally, Eurostat makes the distinction between external and internal EU wood pellet imports. As the EU consists of 28 countries, the total number of EU wood pellet imports will include both external, which are imports into the EU from outside, and also internal, the traded wood pellet volumes from the 28 countries within the EU. The distinction applies to individual EU countries as well.

This thesis presents EU wood pellet imports in regards to external imports only. This is done in an effort to prevent double counting the volumes that are imported into the EU and subsequently traded. It also provides granularity in assessing the external EU wood pellet market in which the US operates. On a specific country basis, however, both the total wood pellet imports and the external wood pellet imports are provided.

In the UK, HM Revenue & Customs provides two classification systems, the CN–and subsequently the HS–and the Standard International Trade Classification (SITC). SITC is based on the statistical division of the United Nations. In this thesis, UK wood pellet imports, as classified by HM Revenue & Customs, are provided from 2012 through 2014 using the CN classification of wood pellets ("UKtradeinfo," 2015).

The Korean Customs Service implements a classification system similar to the EU but with ten-digit commodity codes based on the harmonized system. Referred to as the HSK, the classification for imported wood pellets is 4401310000. Korean wood pellet imports are provided from 2012 through 2014.

The US integrates the two, four, and six-digit HS codes into a ten-digit commodity classification system. The export classification system, which differs from the imports, is referred to as "Schedule B" and is defined by the US Census Bureau as the "Statistical Classification of Domestic and Foreign Commodities Exported from the United States" ("U.S.

Census Bureau, Common Trade Definitions - Foreign Trade," 2015). The Schedule B classification for exported wood pellets is 4401310000. Unlike the EU, the US did not have a specific identification code for wood pellets prior to the implementation of HS code 440131 in 2012. Therefore, US wood pellet exports are presented from 2012 through 2014.

All international trade statistics from the above stated sources were retrieved as monthly wood pellet trade statistics. The statistics were annualized from the retrieved monthly data when needed. All trade volumes were converted to metric tons.

Statistics relating to US fiber supply are available by technical publications of the US Forest Service. Timber Mart-South provided south-wide market price data from 2004 through the first quarter of 2015 for woody feedstocks that are commonly used in the production of wood pellets. The nominal price data was converted to real price data using the Producers Price Index, PPI ("Bureau of Labor Statistics," 2015). Statistics were computed following this transformation. Additional statistics on wood fiber product production and capacity were derived from the statistics division of the Food and Agricultural Organization of the United Nations (FAO) and by industry trade associations. US energy statistics for biomass were developed based on information from the US Energy Information Administration (EIA) and the Federal Energy Regulatory Commission (FERC).

3.2 Price Dynamics

3.2.1 Data

The data employed was the delivered prices, in dollars per short ton, of four common woody feedstocks used in the production of wood pellets. As the data is proprietary, the feedstocks have been coded–Fpw, Fr1, Fr2 and Fr3. Aside from pulpwood, which is Fpw, the remaining residuals–not respective to order–are chipped residues, sawdust, and shavings. The data set is composed of 156 weekly observations per feedstock, which is approximately three years of data. The time series begins the second week of 2011 and ends the last week of 2013 (Figure 1). Nominal prices were converted to real prices using the Producer Price Index, PPI ("Bureau of Labor Statistics," 2015).

Price movements of the woody feedstocks appear to be correlated, and after an initial downward trend, all exhibit an upward trend. The structure of the data is provided by the summary statistics (Table 1). The Jarque-Bera test statistic indicates that the series are not normally distributed at the 5% significance level. The positive skewness showed that all feedstocks are skewed to the right. The coefficient of variation showed that Fpw and Fr2 have very similar levels of dispersion, with Fr3 having the highest level of dispersion and Fr1 the least amount of dispersion. Feedstocks Fpw, Fr2 , and Fr3 show a platykurtic distribution with negative excess kurtosis, while Fr1 appears to have a more peaked distribution.

3.2.2 Cointegration

Cointegration addresses equilibrium relationships between variables. Nonstationary time series may be driven by a stochastic trend. A linear combination of the variables, however, may in fact be stationary (Engle & Granger, 1987). To determine unit-root stationarity, the augmented Dickey-Fuller (ADF) test and the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test were performed. The Akaike (AIC), Schwarz Bayesian (SBC), and Hannan and Quinn (HQ) information criterion were applied to specify order. The error-correction model used for the Johansen cointegration test is as follows,

$$\Delta z_t = \Pi z_{t-1} + \sum_{i-1}^{p-1} \Phi_i^* \Delta z_{t-i} + \mathrm{c(t)} + \Theta(B) a_t \qquad (1)$$

The cointegration test is based on likelihood ratio tests and was used to determine the rank of the Π matrix as Π is related to the covariance matrix between z_{t-1} and Δz_t. If the variables are I(1), integrated to the first order, the matrix Π has a rank 0≤m<k, representing non-stationarity but cointegration among the variables. If there is cointegration among the variables, the rank of Π is m >0, then Π may be expressed as $\Pi = \alpha\beta'$. The vector $w_t = \beta' z_t$ would be an I(0) process and represents the cointegrated series.

Both the trace statistic, as defined by equation 2, and the maximum eigenvalue, equation 3, were used to test cointegration with the Johansen procedure (Johansen, 1988), (Johansen & Joselius, 1990).

$$L_{tr}\,(m_0) = -(T - kp)\sum_{i=m_0+1}^{k} \ln(1 - \lambda_i) \tag{2}$$

$$L_{max}\,(m_0) = -(T - kp)\ln(1 - \lambda_{m_0+1}) \tag{3}$$

3.2.3 Vector Error Correction Model

As previously established, the cointegrating matrix β is known. As such, the cointegrating process $w_t = \beta' z_t$ is available. The vector autoregression model, VAR (p), reduces to

$$\Delta z_t = \alpha w_{t-1} + c(t) + \sum_{i=1}^{p-1} \Phi_i^* \Delta z_{t-i} + a_t \tag{4}$$

where the remaining parameters can be estimated using ordinary least-squares method.
To ensure the vector error correction model, VECM, is adequately specified, the residuals were analyzed. The cross-covariance matrix of the residuals is defined as

$$\hat{C}_\ell = \frac{1}{T-p} \sum_{t=p+\ell+1}^{T} \hat{a}_t \hat{a}'_{t-\ell} \tag{5}$$

The lag residual cross-correlation matrix is defined as

$$\hat{R}_\ell = \hat{D}^{-1} \hat{C}_\ell \hat{D}^{-1} \tag{6}$$

where $\hat{D}$ is the diagonal matrix of the square roots of the diagonal elements of $\hat{C}_0$. The multivariate Portmanteau test using the mulitvariate Ljung-Box test statistic,

$$Q_k(m) = T^2 \sum_{\ell-=1}^{m} \frac{1}{T-\ell} tr(\hat{C}_\ell' \hat{C}_0^{-1} \hat{C}_\ell \hat{C}_0^{-1}) \tag{7}$$

was also used to check the residual cross-correlations.

3.2.4 Impulse Response Function

The impulse response function (IRF) provides insight into the dynamic interactions between variables of a VECM process, specifically the effects of a standard deviation change in one woody feedstock to another within the system. In this case, innovations were orthogonalized using the Cholesky decomposition of Σ_a, where P is a lower triangular matrix and $\Sigma_a = PP'$. The orthogonalized shocks are provided by $w_t = P^{-1}a_t$. The process follows a moving average (MA) representation of a VAR (p) model,

$$z_t = \sum_{i=0}^{\infty} \Theta_i w_{t-i} \tag{8}$$

where $\Theta_i = \Phi_i P$ and the components of $w_t = (w_{1t}, \ldots, w_{Kt})'$ are not correlated with a variance of $\Sigma_w = I_K$. $\Theta_i$can be interpreted as the responses to innovations in the system.

It is important to note that a cointegrated VAR (p) model will not have a valid MA representation, as shown above, as it is unstable. The $\Theta_i$matrices can still be computed, but the responses do not necessarily have to revert to zero as $i \rightarrow \infty$. As such, an innovation may not die out asymptotically (Lütkepohl, 2007).

3.2.5 Forecast Error Variance Decomposition

The forecast error variance decomposition (FEVD) provides the percentage of the variance of the errors of a woody feedstock forecast as a result of a specific innovation on itself or another feedstock. Based on the same MA representation with orthogonal innovations, equation 8, the percentage contribution from a given shock can be written as (Lütkepohl, 2007),

$$w_{jk,h} = \frac{\sum_{i=0}^{h-1} (e_j' \Theta_i e_k)^2}{\sum_{i=0}^{h-1} \sum_{k=1}^{K} \theta_{jk,i}^2} \tag{9}$$

Table 1. Summary statistics for weekly real price series

	Fpw	Fr1	Fr2	Fr3
Standard Deviation	2.0289	0.9257	2.4280	1.9509
Skewness	0.4138	0.3227	0.8858	0.4836
Kurtosis	-0.9570	1.6226	-0.4281	-0.4804
Jarque-Bera	10.1665	21.1592	21.8137	7.5015
Coefficent of Variation	0.0861	0.0495	0.0822	0.1378

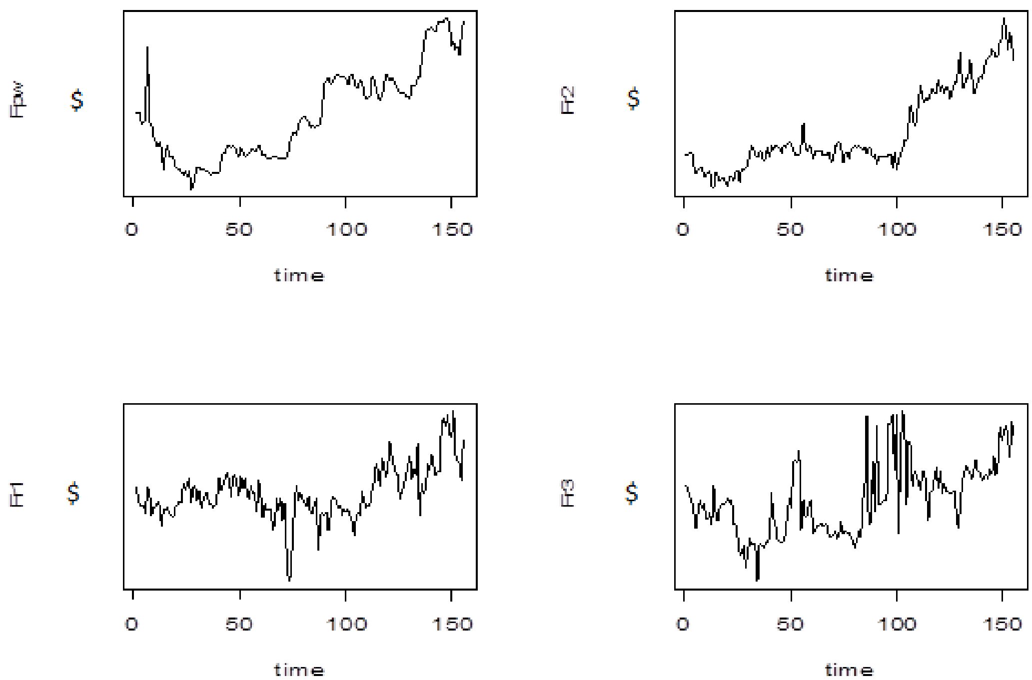


Figure 1. Time Series Plots of Four Woody Feedstocks used in the Production of Wood Pellets.

CHAPTER 4

RESULTS

4.1 Market Analysis

4.1.1 Wood Pellet Demand

There is increasing demand for woody biomass for the purpose of energy production. In 2014, worldwide wood pellet production exceeded 26 million metric tons. This represents an increase of approximately 18% over 2013 production (“FAOSTAT,” 2015). This demand is currently policy driven, reflecting an effort to reduce fossil fuel consumption and greenhouse gas emissions.

4.1.1.1 EU Policy

The main policy driving wood pellet demand is the European Union’s implementation of its 2020 climate and energy package. According to FAO data, Europe consumption accounted for 77% of worldwide pellet production in 2013 (“FAOSTAT,” 2015). The 2020 package, which is a set of targets that include a 20% reduction of greenhouse gas emissions from 1990 levels, a 20% contribution of renewables in energy consumption, and a 20% increase in energy efficiency by 2020, is legally binding (European Commission, 2014b). The European Commission estimates bioenergy will account for approximately 60% of the EU’s renewable energy contribution. Solid biomass is projected to account for the majority of this contribution, approximately 79% (USDA Foreign Agriculture Service, 2014). This mandate, along with individual member states’ incentives, represents the largest market force in wood pellet consumption.

The 2009 EU Renewable Energy Directive (RED), which is part of the energy and climate package, sets binding renewable energy targets for each of the EU's member states. As the 20% contribution of renewable energy is for the EU, each member state has a different contribution target, which varies from 10% for Malta to 49% for Sweden. Each member state submitted a National Renewable Energy Action Plan (NREAP) in 2010. The NREAPs provide the framework by which each member state will reach its legally binding 2020 target. The only parameter set forth in the allocation of renewables by the EU is a 10% minimum target for biofuels in transportation. The share of renewables in other sectors, such as electricity generation and heating, is unconstrained ("Renewable Energy Directive," 2015).

4.1.1.2 EU Sustainability

Biofuels and bioliquids must comply with the sustainability criteria in Article 17 of the RED; this article provides for a minimum greenhouse gas emission reduction in conjunction with a land-use change criterion. Solid and gaseous biomass, such as wood pellets, are excluded from these requirements (European Commission, 2014a). In accordance with the parameters set forth in the RED, the European Commission in 2010 published sustainability criteria for solid and gaseous biomass. The report, EC COM(2010) 11 final, recommended similar sustainability criteria previously set out in Article 17 of the RED for bioliquids, including minimum greenhouse gas savings for biomass set at 35%, rising to 50% in 2017, and 60% in 2018, when compared to the EU's fossil fuel mix. The land criteria of the RED, which states that biomass should not be sourced from the conversion of high carbon stock areas, was also recommended. Due to the nature of solid biomass, the commission diverged from the RED and recommended that the calculations of GHG emissions include the conversion efficiency of biomass in its capacity for electricity, heating, or cooling. The commission, however, decided to make these non-binding sustainability recommendations for member states. These guidelines, and the RED itself, do not include any greenhouse gas accounting for the combustion of biogenic carbon or indirect land use change (European Commission, 2010).

4.1.1.3 EU Market

As a result of the RED, Europe has become the largest importer of wood pellets globally. The policy framework instituted determines the profit margins of wood pellets sold within EU markets. With the viability of trade linked to these margins, sourcing of wood pellets is based on the cost-competitiveness of market participants. Dominant exporting countries have characteristically had low feedstock costs and an existing infrastructure due to a developed forest industry. As a result, these countries have been able to provide price competitive wood pellets to the EU market (Lamers et al., 2012).

The EU imported 6.546 million metric tons of wood pellets from outside the European Union in 2014 ("Eurostat," 2015). Since the implementation of the RED in 2009, this represents a 285% increase in imported wood pellets (Figure 2). Figure 2 also informs that the growth of these volumes has slowed and only a few countries are importing sizable external volumes. Imported external volumes in 2014 only represented 7% growth, year- over- year from 2013 volumes. Annually, from 2009 through 2014, six countries–United Kingdom, Netherlands, Italy, Denmark, Sweden, and Belgium–represent approximately 90% or more of that year's imported external volumes into the EU.

In 2014, the majority of imported volumes were from North America, with the US and Canada comprising of 79% of total EU wood pellet imports from outside the union. The US alone was 59% of external EU imports by volume in 2014 (Figure 3). This represents a 40% increase in EU imports of wood pellets from the US year-over-year. In contrast, 2014 EU imported Canadian wood pellet volumes were down 36% year-over-year at 1.259 million metric tons ("Eurostat," 2015).

4.1.1.4 UK Policy

The RED set a target of 15% energy consumption from renewables by 2020 for the UK. In 2009 when the RED was released, approximately 3% of the energy consumed in the UK came from renewable sources ("National Renewable Energy Action Plan for the United Kingdom," 2010). In 2013, renewables composed 5.2% of energy consumption in the UK (Department of Energy & Climate Change, 2014). Further, it has been estimated that 11% of the UK's total energy needs will be sourced from biomass by 2020 ("Renewables Obligation: Sustainability Criteria," 2014).

The Renewable Obligation (RO) is currently the main support mechanism for renewable electricity in the UK. First implemented in 2002, the RO creates an obligation to suppliers to source an increasing percentage of their supply from renewable sources. The obligation, which increases annually, is set by the UK's Department of Energy & Climate Change (DECC) six months prior to the preceding obligation period. RO eligible renewable generators are given Renewable Obligation Certificates (ROCs), which are banded by renewable technology type and issued by the Office of Gas and Electricity Markets (Ofgem). Suppliers redeem ROCs to meet their obligation. When suppliers do not have enough certificates, they must pay into a buy-out fund. The buy-out fund is then proportionally returned to suppliers based on the number of ROCs redeemed. Thus, the value for ROCs is based on two elements: the avoided payout into the buy-out fund and the payment from the buy-out fund ("Renewable Obligation: Guidance for Generators 2015," 2015). In 2014/2015 the buyout per ROC is £43.30; however, ROCs themselves do not have a fixed price and are tradable commodities based on supply and demand between generators and suppliers ("The Renewables Obligation (RO) - Low carbon technologies," 2015). Dedicated biomass generators receive 1.5 ROCs per MWh. In 2016 this will be reduced to 1.4 ROCs. The scheme will close to new generators in 2017 and will cease to support biomass in 2027 ("Renewable Obligation: Guidance for Generators 2015," 2015).

The UK has recently introduced a new support mechanism for large scale renewable electricity generation, the Contracts for Difference (CfD). CfDs are essentially a feed-in tariff, where payments are made to a producer for electricity generated from a renewable source. Generators sell electricity to the wholesale market and, based on a strike price and a defined market reference price, either receive or make a payment. Currently, the previously mentioned RO scheme is operating parallel to the CfD scheme until the RO closes in 2017. Generators can choose between the two mechanisms until 2017, at which point CfDs will be the only support scheme available to new generators ("Electricity Market Reform-Contract for Difference: Contract and Allocation Overview," 2013).

4.1.1.5 UK Sustainability

Though the RED does not have binding sustainability criteria for solid biomass, the UK has implemented such criteria. The national sustainability requirements in the UK generally follow the recommendations of the EU. Since 2011, electricity generators over 50 kW have reported to Ofgem on the RO sustainability criteria. The criteria consist of two components: a greenhouse gas lifecycle analysis and a land criterion. A framework is provided for the GHG lifecycle criterion; operators must be below the threshold of 285 kgCO_2e per MWh. This represents a reduction target of approximately 60% from fossil fuel alternatives. The land criteria places restrictions on sourcing feedstocks from land with high carbon stocks or high biodiversity value ("Renewables Obligation: Sustainability Criteria," 2014).

In 2014, the Department of Energy and Climate Change introduced a new sustainability criteria, the "Timber Standard for Heat & Electricity: Woodfuel used under the Renewable Heat Incentive and Renewables Obligation." The Timber Standard, which covers a range of social and environmental concerns, can be met by proving wood sourced for the production of wood pellets is legal and sustainable. A legal source is that which is harvested in accordance with the EU Timber Regulation, which is a binding framework requiring due diligence prior to the importation of a wood product. A sustainable source is defined by 10 criteria within the Timber Standard ("Timber Standard for Heat and Electricity: Woodfuel used under the Renewable Heat Incentive and Renewables Obligation," 2014).

4.1.1.6 UK Market

Within the EU, the UK has quickly become the largest importer of wood pellets by volume. In 2014, the UK imported 4,757,135 million metric tons of wood pellets. From 2012 through 2014, imported wood pellet volumes into the UK increased 220% (Figure 4).

The majority of these pellets, 80%, are being sourced from North America (Figure 5). Over this same two-year period, there has been a dramatic change in market share of UK import volumes between North American exporters (Figure 6). In 2014, the UK imported 2.759 million metric tons from the US, an increase of 64% year-over-year. During this same year, the UK imported 1.024 million metric tons from Canada, a decrease of 24% year-over-year. The US wood pellets represented 58% of market share by volume of UK imports in 2014 ("UKtradeinfo," 2015).

4.1.1.7 Other Markets

Aside from the UK–Denmark, Italy, Belgium, the Republic of Korea, and the Netherlands represent the world's largest importers of wood pellets, based on average imports between 2012 and 2014 ("FAOSTAT," 2015). There is slight variation in this order when only considering pellets imported from outside the EU.

Market share of EU imported wood pellet volumes has changed markedly from 2009 through 2014 (Figure 7). In 2009, the UK represented less than 1% of external EU wood pellet imports. By 2014, over 57% of wood pellets imported from outside the EU were done so by the UK. The Netherlands has decreased their market share of external EU imports significantly over this time horizon. In 2009, approximately 47% of wood pellets imported into the EU were done so by the Netherlands. By 2014, less than 5% of external EU wood pellet imports were attributed to the Netherlands.

Denmark was the world's second largest importer of wood pellets in 2014, importing a total, which includes both internal and external EU imports, of 2,128,564 metric tons. This is an 8% decline from total 2013 volumes but a 142% increase from total 2009 import volumes of 878,510 metric tons. The majority of Denmark's wood pellet imports are sourced from within the EU, accounting for 77% of all Denmark's total wood pellet imports in 2014. Latvia, which has been the largest exporter into Denmark since 2011, represented 29% of the total market share in 2014. The top three exporters into Denmark's wood pellet market–Latvia, Estonia, and Russia–accounted for 82% of total imported volumes in 2014. The US provided 4% of the total market in 2014, exporting 86,313 metric tons (Figure 8).

Denmark imported 492,605 metric tons from outside the EU in 2014, approximately 23% of total imports. This represented a 2% decrease from external 2013 levels. The fourth largest importer of wood pellets from outside the EU in 2014, Denmark accounted for close to 8% of all external EU imports. Russia was the dominant external EU exporter into Denmark markets with 79% of the market share (Figure 9). North American pellet exports into Denmark were down markedly in 2014, with US wood pellet imports into Denmark down 29% year-over-year and Canadian imports down 65% over the same time frame (Figure 10) ("Eurostat," 2015).

In 2014, Italy was the third largest importer of wood pellets globally, importing a total of 1,935,964 metric tons. This represents a 10% increase from total 2013 volumes and a 310% increase from total 2009 volumes, when Italy imported 472,243 metric tons ("Eurostat," 2015). Austria has been the leading exporter into the Italian market every year since 2009. In 2014, Austria represented 20% of market share of total imported Italian wood pellets. In contrast, the US had 9% of the total market share in 2014. The top five exporting countries into the Italian market in 2014–Austria, Canada, US, Bosnia and Herzegovina, and Germany–represented 53% of total import volumes (Figure 11).

Italy accounted for approximately 11% of wood pellet imports from outside the EU in 2014, second only to the UK. Italy imported 718,444 metric tons from outside the EU in 2014, approximately 37% of its total wood pellet imports (Figure 12). This represented a 26% increase in external volumes over the previous year. The US was 25% of the external EU 2014 market by volume with 179,965 metric tons, a 50% year-over-year increase (Figure 13) ("Eurostat," 2015).

Korea was the world's fourth largest importer of wood pellets in 2014, importing a total of 1,849,571 metric tons. This is a 282% increase from 2013 volumes of 484,668 metric tons (Figure 14). The US exported 61,977 metric tons to Korea in 2014, which was 3% of market share by volume (Figure 15). This was, however, a 94% increase over the previous year. Producers from Southeast Asia represented 58% of imported volume for 2014 ("Korea Customs Service. Import/export By Commodity - 영문사이트," 2015).

Belgium was the fifth largest importer of wood pellets in the world in 2014, importing a total of 657,377 metric tons. This represents a decline of approximately 27% from the 896,188 metric tons imported in 2013. Furthermore, total 2014 import volumes were down 32 % from a 2012 high of 970,470 metric tons. The total import volumes in 2014 were, however, 46% above 2009 levels. Imports from within the EU represented approximately 19% of total imports with the Netherlands being the dominant trading partner (Figure 16). The Netherlands represented 60%, which was 73,662 metric tons, of wood pellets imported by Belgium from within the EU.

In 2014, external EU wood pellet imports into Belgium accounted for approximately 8% of all external EU wood pellet imports. Belgium gets the majority of its imported wood pellets from outside the EU; external EU wood pellet imports represented 81 % of the country's imported market share in 2014. Belgium was the third largest importer of wood pellets from outside the EU with 534,570 metric tons in 2014. This represents a 29% decrease from external 2013 volumes and a 32% decrease from a record high of 780,471 metric tons of external wood pellet imports in 2012. North America was the dominant source for Belgium wood pellets, representing 99% of external EU imports in 2014 (Figure 17). US exports represented 79% of this external market share ("Eurostat," 2015).

In 2014, the Netherlands was the world's seventh largest importer of wood pellets, importing a total of 451,200 metric tons. This represents a decline of approximately 17% from total 2013 volumes. Further, total import volumes were down 57% from a high of 1,055,218 metric tons in 2011. The majority of total import volumes came from outside the EU. Import volumes from within the EU accounted for approximately 32% of total imported wood pellets. The US had the dominant market share of total imported wood pellets, accounting for 60% in 2014 (Figure 18).

The Netherlands represents approximately 5% of external EU wood pellet imports into Europe. In 2014, the Netherlands imported 307,804 metric tons of wood pellets from outside the

EU, a 38% decrease from 2013. External EU wood pellet imports into the Netherlands are down close to 70% from their highs in 2010 (Figure 19). North America was the dominant source of external wood pellets in 2014, accounting for 96%. The US alone was 88% of external market share in 2014 (“Eurostat,” 2015).

4.1.2 Wood Pellet Supply

The five largest producers of wood pellets in 2014, in order of volume, were the US, Germany, Canada, Sweden, and Latvia. These countries represented 53% of total worldwide production. Of these countries the US, Canada, and Latvia were the top three largest exporters of wood pellets for 2014 as well (“FAOSTAT,” 2015).

4.1.2.1 US

The US produced approximately 6.9 million metric tons of pellets in 2014 of which 58%, or 4.005 million metric tons were exported (“FAOSTAT,” 2015). With continued year-over-year growth, wood pellets represent the largest segment of the wood biomass portfolio for energy as it relates to the US South. The US has been exporting wood pellets to Europe since 2008, initially shipping approximately 85,000 tons (Figure 20) (Newes et al., 2012). In 2012, the US had increased to over 1.898 million metric tons of wood pellet exports before more than doubling to 4.005 million metric tons by 2014 (Figure 21). Wood pellet exports in 2014 represent a 39% increase in volume from the 2.882 million metric tons exported in 2013. Additionally, exports in January 2015 represent a 29% increase over exports in January of the previous year (“U.S. Census Bureau, Foreign Trade Division. Trade by Commodity. USA Trade [Online Database],” 2015).

Since 2012, the majority of exported wood pellets from the US have been to the EU. The market share of exported US volumes, however, has changed significantly (Figure 22). The UK, Belgium, and the Netherlands made up approximately 88% of exported US volumes in 2012; by 2014 the UK represented 73% of exported US volumes. ("U.S. Census Bureau, Foreign Trade Division. Trade by Commodity. USA Trade [Online Database]," 2015).

Of these US exports of wood pellets, the overwhelming majority originated from the US South (Figure 23 and Figure 24). Between 2012 and 2014, exports of wood pellets from southern ports represented 99% of all exported volumes ("U.S. Census Bureau, Foreign Trade Division. Port-level Exports. USA Trade [Online Database]," 2015).

The value of US wood pellet exports, reported as FAS (Free Alongside Ship), represented $519,399,498 in 2014 ("U.S. Census Bureau, Foreign Trade Division. Trade by Commodity. USA Trade [Online Database]," 2015). Assuming trade flows continue at current growth rates, the value of exported wood pellets from the US could represent $600 million in 2015 and over $1 billion by 2020 (USDA Foreign Agriculture Service, 2014).

Within the context of US exports, despite increased growth, wood pellets represent a small fraction of fiber products exported in regard to value. Examining major forest product exports, the approximately 4 million metric tons of wood pellets exported in 2014 represented less than 2% of the value of US wood fiber exports. In the South, the percentage is higher but still less than 4% of southern fiber exports (Figure 25). The volume of wood pellets exported in 2014, however, represented 9% of wood fiber exports. For the South, nearly 14% of 2014 fiber export volumes were wood pellets (Figure 26) ("U.S. Census Bureau, Foreign Trade Division. Port-level Exports. USA Trade [Online Database]," 2015).

4.1.3 Wood Fiber Supply

Available potential supply of the forest resource in the US has been examined (U.S. Department of Energy, 2011). Levels of both forest and timberland have increased since 2006. In

2012, there were approximately 766 million acres of forest land in the US, 514 million acres of which were in timberland. Specifically, the US South had approximately 245 million acres of total forest, 210 million acres of which were in timberland. These numbers represent an increase of 4% in forest and 2% in timberland since 2007 (Oswalt, Smith, Miles, & Pugh, 2014).

In 2011, the US South produced approximately 166 million green tons of pulpwood, which represented 81.5% of total US pulpwood production. This production had been relatively stable but with a downward trend, having declined approximately 5% between 2000 and 2011. Of the 166 million tons in 2011, 82% was roundwood with the remaining 18% classified as residuals. This dynamic has changed markedly as residuals represented about 30% of produced pulpwood in the early part of the decade (Bentley & Steppleton, 2013).

The US Forest Service estimated that during 2011 approximately 59.3 million dry tons of wood residues were produced. Over 99% of these residuals were utilized with 40% or 23.5 million tons being used in fiber products. The majority of wood residues, 26 million dry tons in 2011, were used as commercial fuel (Oswalt et al., 2014).

4.1.4 Wood Fiber Demand

Despite recent gains in production volumes, fiber used for the production of wood pellets in the US South constitutes a rather small percentage of regional fiber demand (Figure 27). Traditional end users of pulpwood–paper, pulp and OSB production–currently consume about 140 million tons of pulpwood and chips in the US South (Mendell & Lang, 2013). In comparison, the total volume of roundwood pulpwood consumed through the biomass sector was estimated to be around 3.1 million tons in 2012. This amount represents 3% of the total pulpwood demand in the US South (Washburn, Balter, Aronow, & Newcomb, 2013).

4.1.4.1 Feedstocks

Traditionally, the feedstock of wood pellet production was considered logging residues and other low-cost by-product residues (Spelter & Toth, 2009). As a result, many existing studies focusing on sustainability of wood bioenergy have also generally limited their research to the use of residues, both from logging and manufacturing (Perlack et al., 2005)(Energy Information Administration, 2007) (Energy Information Administration, 2009a).

With increasing demand, however, traditional avenues of sourcing have been expanded. Wood bioenergy production from pulpwood has impacted the industrial roundwood market in the US South (Abt et al., 2012). Most notably throughout the South, an estimated 71% of pine pulpwood stumpage price increases can be attributed to increased demand for wood bioenergy (Lang, 2014).

This has two main effects. The first is that it dramatically increases the potential feedstock of wood pellets. If wood pellets are solely dependent on residues, they are inherently limited in production by the industries from which they are sourced (Galik et al., 2009). An additional consideration associated with residue dependence relates to strategic location. By locating near abundant residue supply, one would have to locate within the woodbasket of traditional market participants, areas that generally have higher roundwood prices. Furthermore, logging residues are not always the best economic feedstock option. They provide approximately 20% of the volume that a roundwood harvest could produce. Given the costs associated with transportation, this means logging residues are not always a low cost supply for pellet manufacturers (Abt et al., 2012). The second effect is that as residual supply is exhausted, wood bioenergy demand is met with pulpwood and competes directly with traditional pulpwood market participants, mainly pulp and oriented strand board or OSB (Galik et al., 2009).

4.1.4.2 Current Fiber Markets

Delivered prices for the main woody feedstocks used in the production of wood pellets in the US South have remained fairly stable over the last ten years (Figure 28). In terms of real delivered prices in first quarter 2015 dollars, the aggregate of these feedstocks were down approximately 4% from the first quarter of 2004 with whole tree chips–pine and hardwood–process residuals, and pine sawmill chips leading the decline. This represents an average compound annual growth rate of -0.23% for the feedstocks (Timber Mart-South, 2015).

Real delivered pulpwood prices were down approximately 1% from the first quarter of 2004 through the first quarter of 2015. Real delivered pine pulpwood prices, however, were still down 2.16% from first quarter 2010 highs, -0.42 % compound annual growth rate. Furthermore, they were down 31.18% from the first quarter of 1998, which provided a compound annual growth rate of -6.87%. This coincided with the high point of pulp capacity in the US South. Real delivered hardwood pulpwood prices were down approximately 1% from first quarter highs, -0.17% compound annual growth rate. Hardwood pulpwood was also down 14.21% from first quarter of 1998 highs, which resulted in a compound annual growth rate of -2.88% (Timber Mart-South, 2015).

With the exception of process residuals, which include sawdust, trimmings and bark, real prices for all the other feedstocks were down from their pre-recession highs. In real prices, pine process residuals were up close to 12% from their second quarter 2008 highs, a compound annual growth rate of 1.63%. Hardwood process residuals were up 26.19% from first quarter of 2009 highs, a compound annual growth rate of 3.64%. To note, both products were still markedly below their highs in fourth quarter of 2014, -3.54% for pine process residuals and -

7.33% for hardwood process residuals. The majority of the price growth was contributed to the most recent quarter (Timber Mart-South, 2015).

4.1.4.3 Other Major Market Participants

4.1.4.3.1 Pulp & Paper

Pulp and paper facilities compete directly for the same woody feedstocks–namely pulpwood roundwood and residuals–as pellet mills. In 2014, the US produced 47.803 million metric tons of wood pulp ("FAOSTAT," 2015). Timber Mart-South estimates there are 73 pulp mills currently operating in their 11 state southern region, with approximately 37.194 million metric tons of capacity (Figure 29) (Timber Mart-South, 2015).

The American Forest and Paper Association stated the US capacity for paper and paperboard products was 77,903,582 metric tons in 2014, a decrease of 5.68% since 2010. The majority of this decrease in capacity was attributable to paper production, down 15.29%. Paperboard capacity actually increased during this period from 45.782 million metric tons to 46.720 million metric tons, approximately 2% ("55th Annual Survey of Paper, Paperboard, and Pulp Capacity," 2015).

Actual production, according to FAO, came in slightly below capacity with 71,766,966 metric tons of paper and paperboard produced in 2014. This was down approximately 19% from a high in 1997 of 88.511 million metric tons ("FAOSTAT," 2015).

4.1.4.3.2 OSB

The recession and subsequent housing decline had a devastating impact on OSB production. Housing starts dropped from 2.07 million units in 2005 to .55 million units in 2009, resulting in a 27% reduction in the consumption of pulpwood by southern OSB mills (Washburn et al., 2013). Production has since improved markedly, however. In 2014, the US produced

11.512 million cubic meters of OSB; the US South accounted for approximately 81% of this production with 9.274 million cubic meters. From 2010 through 2014, US OSB production increased more than 26% (“Engineered Wood Statistics-First Quarter 2015,” 2015).

4.1.4.3.3 Wood for Energy

US electricity generation in 2014 was approximately 4.093 billion MWh. The majority of this, 67%, came from fossil fuels–coal, natural gas, and petroleum. Renewables, however, accounted for 13% of electric generation in 2014; biomass accounted for 1.7% of total electricity generated in 2014 (EIA, 2015). The US installed 254 MW of capacity in 2014 that used biomass as the primary fuel. This represented 1.65% of total installed capacity for the year. From 2010 through 2014, the US averaged 500 MW of annual capacity from biomass (“Energy Infrastructure Update December 2014,” 2015).

Forest products companies have long used process residuals for electricity and energy production. In the US, net generation of electric power in 2014 from wood and wood-derived fuels was 43,050 thousand MWh (“Electric Power Monthly,” 2015).

4.2 Price Dynamics

4.2.1 Cointegration

All series failed to reject the null hypothesis, the existence of a unit-root, with the ADF test (Dickey & Fuller, 1979). These results were validated through the KPSS test (Kwiatkowski, Phillips, Schmidt, & Shin, 1992). The test statistics for all series were above the critical value of 0.738; thus, the null hypothesis of stationarity for the KPSS test was rejected by all series (Table 2).

As all four series are unit-root nonstationary, a VAR model was employed to test cointegration of the series using the Johansen methodology. A VAR (7) model was selected using the AIC. Since the real prices of the series exhibit upward drift, the constant vector of the differenced data is not zero, as such $c(t) = c_0$.

The cointegration tests provided eigenvalues of 0.2741669, 0.1129268, 0.03527143, and 0.02532277. In both tests, the null hypothesis of m=1 could not be rejected (Table 3). The eigenvector was normalized; the first element of the vector is 1. The cointegrated series is $w_t = (1.0000, 1.3481971, -0.8447341, -0.6033167)z_t$. The adjustment coefficients, α, are -0.205, -0.049, 0.0079, and 0.389.

The ADF test of w_t confirms that the series is unit-root stationary. The Dickey-Fuller test statistic, based on the univariate AR (7) model, is -4.392 and has a p-value < 0.01. The unit-root null hypothesis was rejected. The time plot, along with the autocorrelation function of w_t, shows the characteristics of a stationary time series (Figure 30).

Analysis of the residuals shows that the model provides a reasonable approximation of the dynamic dependence of the data. The significance plot of the cross-correlation matrices (CCM) demonstrates that the residuals do not possess significant serial or cross-correlations, with the exception of lag 21 (Figure 31).

The Ljung-Box statistic failed to reject the null hypothesis of no cross-correlation. The p-value for the first lag, however, was 0.33. This p-value is worth noting as it corresponds with the first lag of the cross correlation matrix. Though the statistic still fails to reject the null hypothesis, it suggest structure in the first lag of the residuals (Tsay, 2014).

4.2.2 Impulse Response Function

As the model is sufficiently specified, the impulse response functions provide insight into the interactions of the woody feedstocks within the system. As previously established, in the US South roundwood pulpwood is the most dominant feedstock available to pellet producers. As such, a shock to pulpwood prices provides valuable information as to how it, and other residual feedstock prices, will react (Figure 32).

A shock in Fpw leads to a subdued initial increase, albeit a permanent one for pulpwood itself. Following an initial rise, prices decline before stabilizing after approximately ten weeks. The impact on the same shock on Fr3 is more pronounced. Fr3 shows a slight increase before declining, followed by an increase from week five through week 12 at which point it stabilizes at a permanently higher level. Such a reaction between Fpw and Fr3, suggests that the prices of the two feedstocks are correlated. Fr1 responds to the shock with an increase in price through week five before declining until approximately week 12. Residual Fr2 remains, generally, unaffected by the shock to Fpw.

An impulse to Fr1 prices decays quickly and stabilizes after approximately seven weeks; minor volatility persists through the 20 week period (Figure 33). Unexpectedly, a shock to Fr1 elicits a decrease in Fpw prices that does not fully stabilize until approximately week 12. The feedstock Fr2 increases in price for the first six weeks before stabilizing at an elevated level. Fr2 appears to follow the inverse of Fr1. Fr3 responds to the impulse to Fr1 with an initial increase before declining and stabilizing after 10 weeks.

A shock to Fr2, similar to Fr1, decays quickly before approaching stabilization around week seven, though a permanent increase remains (Figure 34). The impulse on Fr2 has a positive, though negligible, impact on Fpw prices. Fr1 shows increases through week four prior to declining and stabilizing in week eleven. Fr3 responds to an Fr2 shock with a decrease in price that stabilizes around week 11.

An innovation to the residual Fr3 decays rather quickly, with price volatility related to the impulse stabilizing in week seven, albeit at a higher price (Figure 35). Fpw prices respond to a shock in Fr2 with an increase for the first six weeks before a gradual decline and leveling at approximately week 15. This impact, however, is minimal. Fr1 increases slightly through week seven, before stabilizing slightly higher. Fr2 is, generally, unaffected by an impulse in Fr3.

4.2.3 Forecast Error Variance Decomposition

The FEVD of the four woody feedstocks after 12 weeks indicated that the variability of Fpw, pulpwood prices, contributed 4%, 1%, and 36% of the variance for Fr1, Fr2, and Fr3 (Table 4). Feedstock Fr1 also had a degree of influence on the variance of Fpw, Fr2, and Fr3, contributing 16%, 10%, and 3% respectively. Feedstock Fr3 contributed 12% of the variance in Fpw. Less than 1% of the variance of Fpw was attributable to the variability of Fr2 prices. The price relationship between Fr1 and Fr2 is of interest, as each feedstock price contributes a similar percentage to the variance of the other (Figure 36).

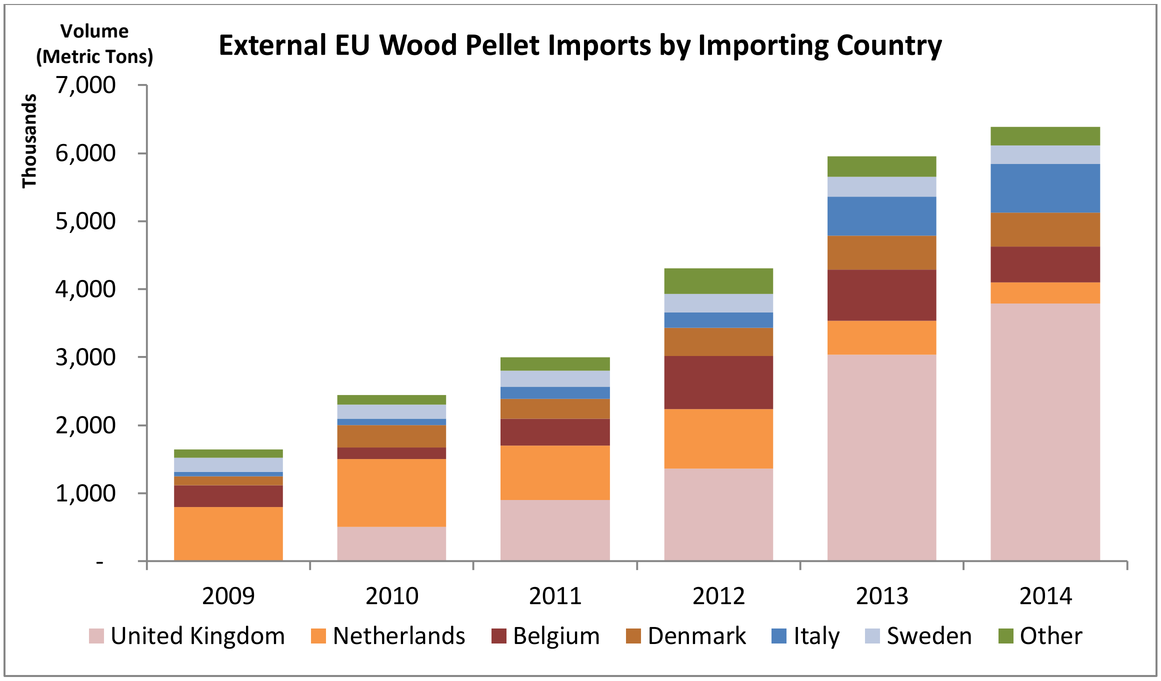


Figure 2. EU Wood Pellet Imports from outside the EU by Importing Country 2009-2014. Source: Eurostat

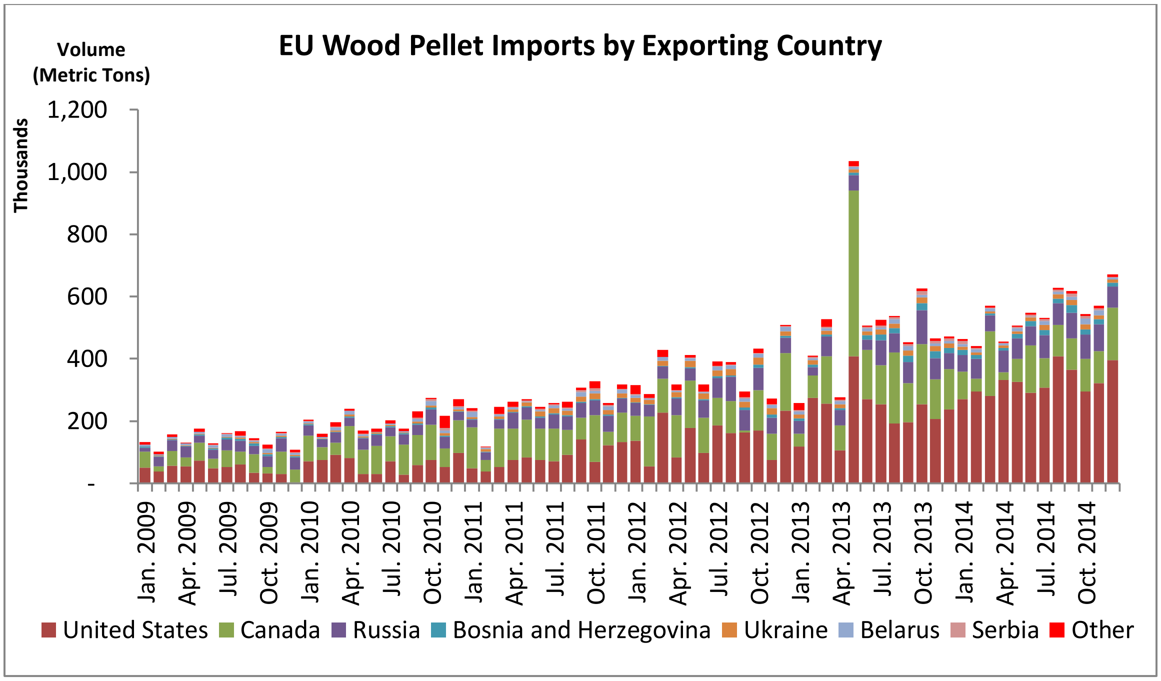


Figure 3. External EU Wood Pellet Imports by Exporting Country. Source: Eurostat

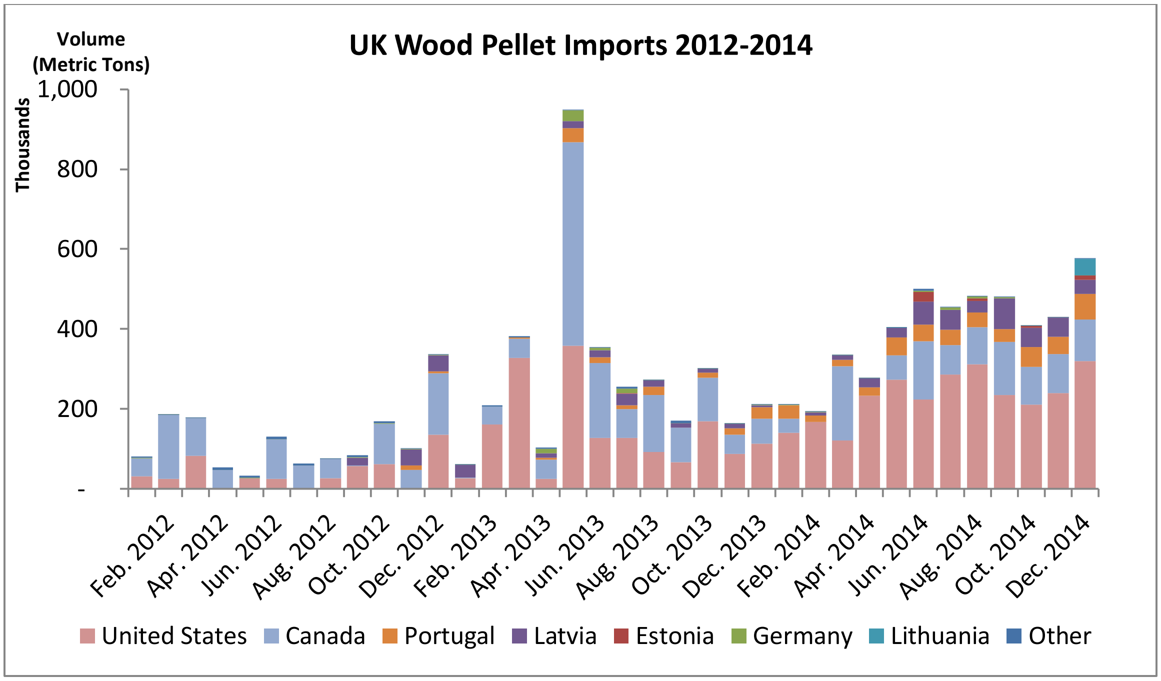


Figure 4.Total UK Wood Pellet Imports 2012-2014. Source: UK HM Revenue & Customs

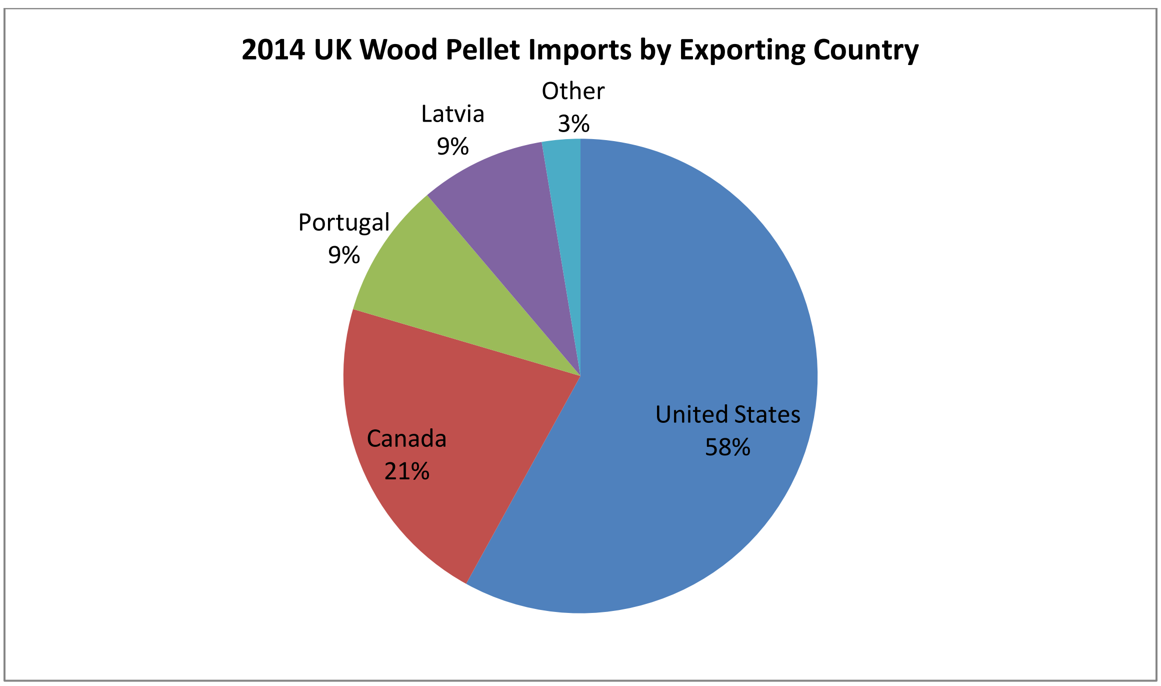


Figure 5. UK Wood Pellet Imports in 2014 by Exporting Country Market Share. Source: UK HM Revenue & Customs

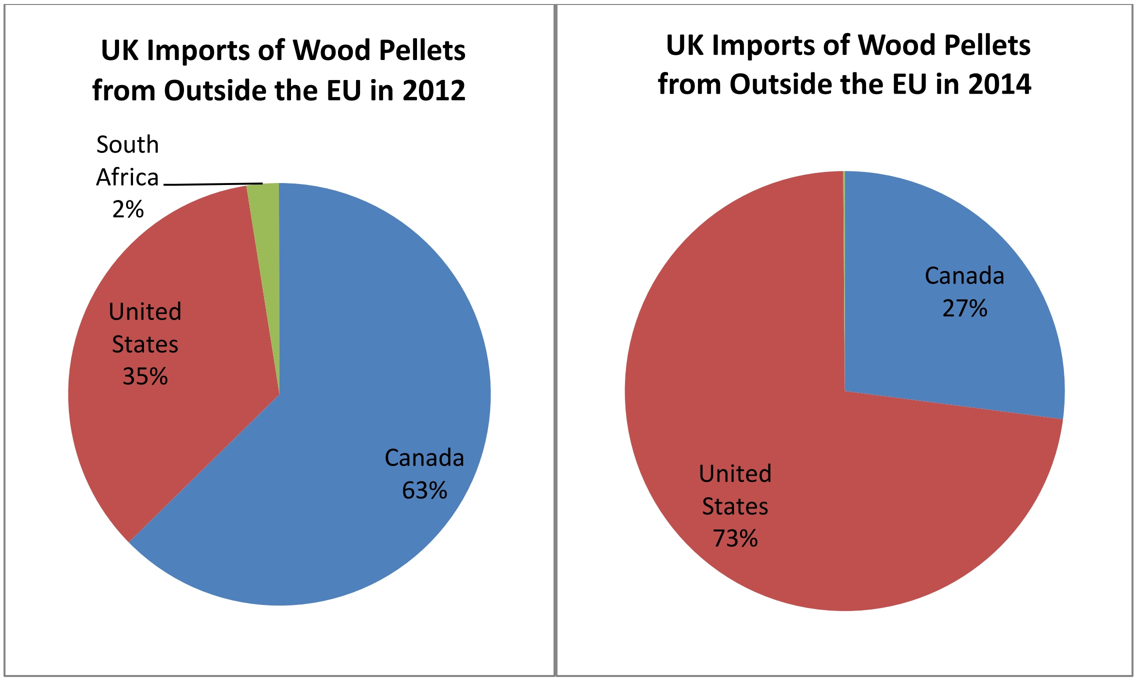
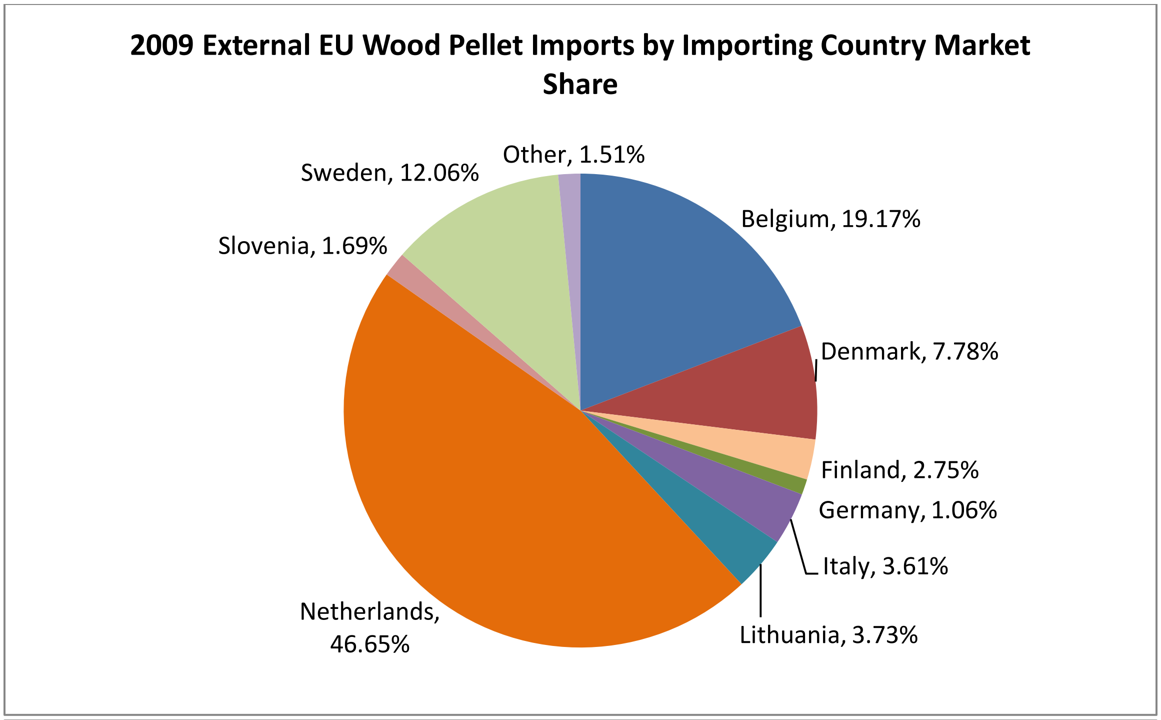


Figure 6. Changing Dynamics of UK Wood Pellet Imports by Volume. Source: UK HM Revenue & Customs



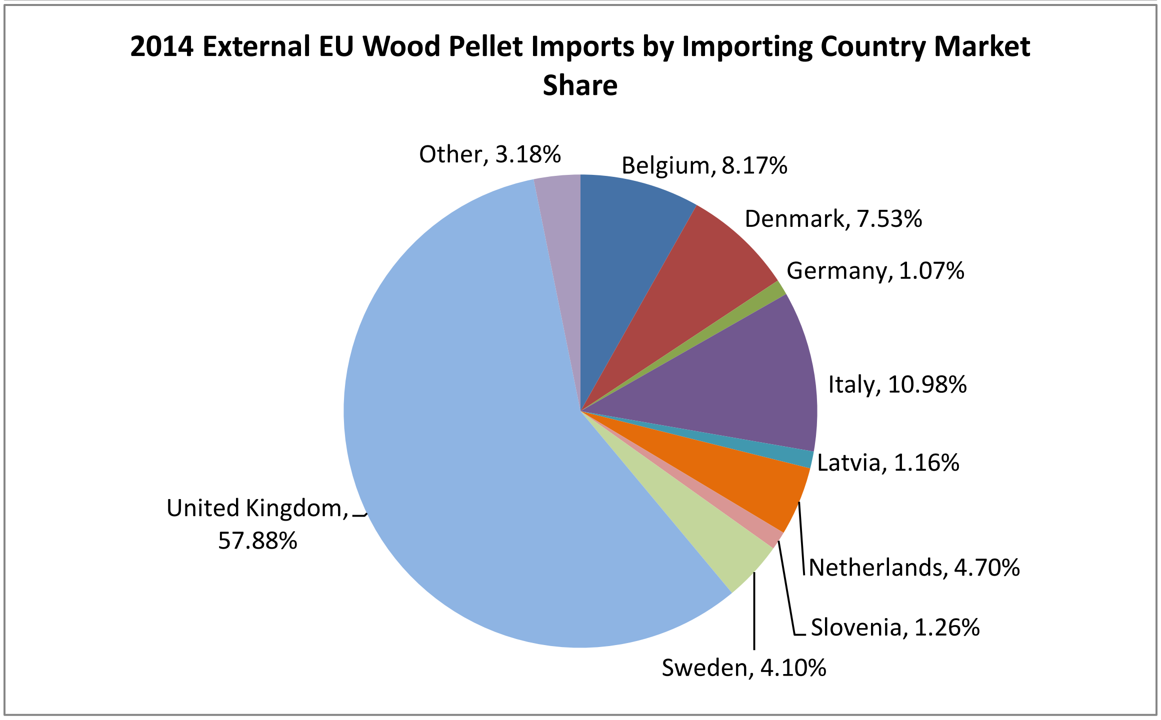


Figure 7. External EU Wood Pellet Imports by Percentage of Importing Country. Source: Eurostat

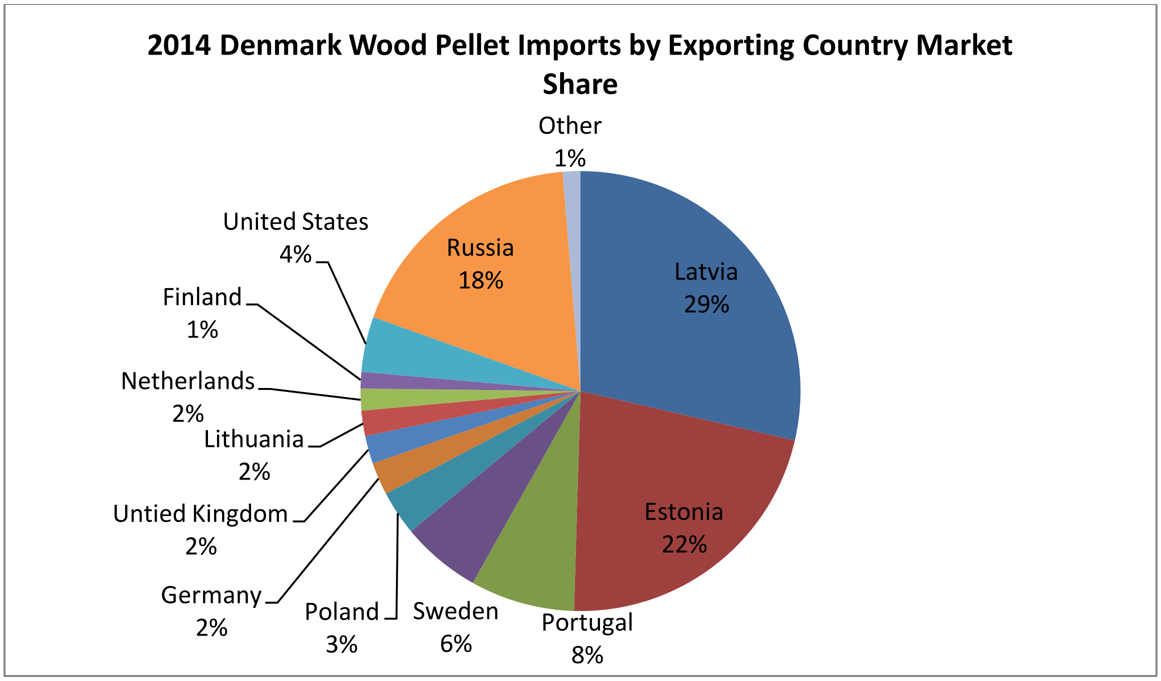


Figure 8. Denmark Wood Pellet Imports in 2014 by Exporting Country Market Share. Source: Eurostat

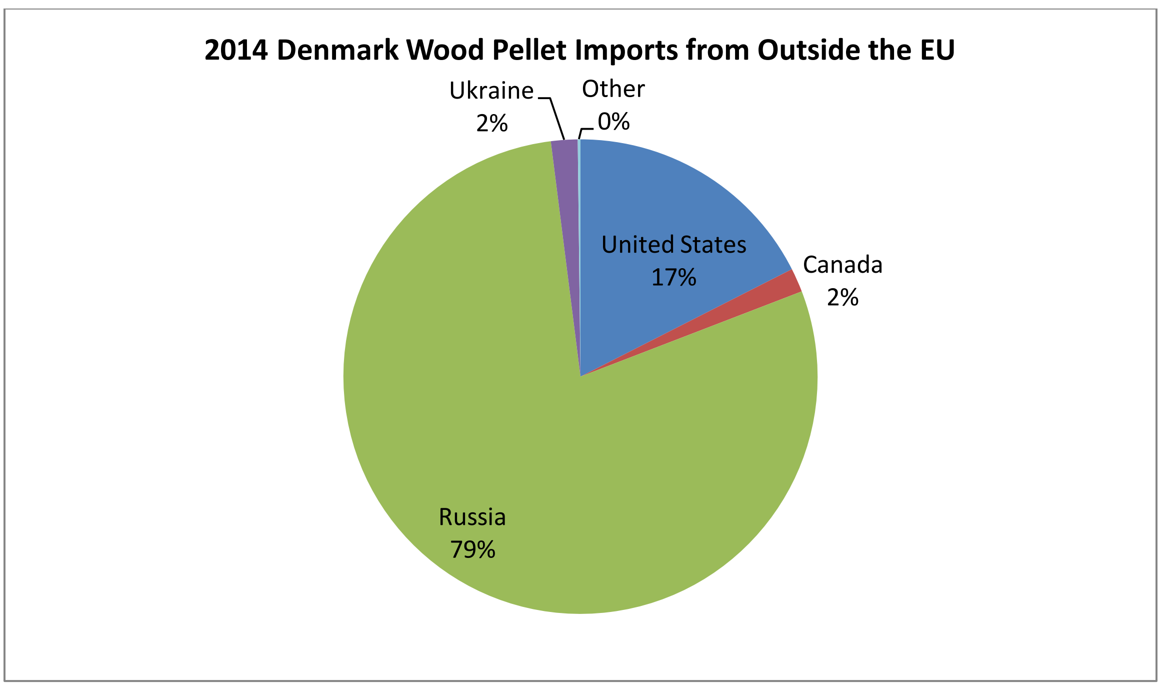


Figure 9. Denmark Wood Pellet Imports from Outside the EU by Exporting Country Market Share. Source: Eurostat

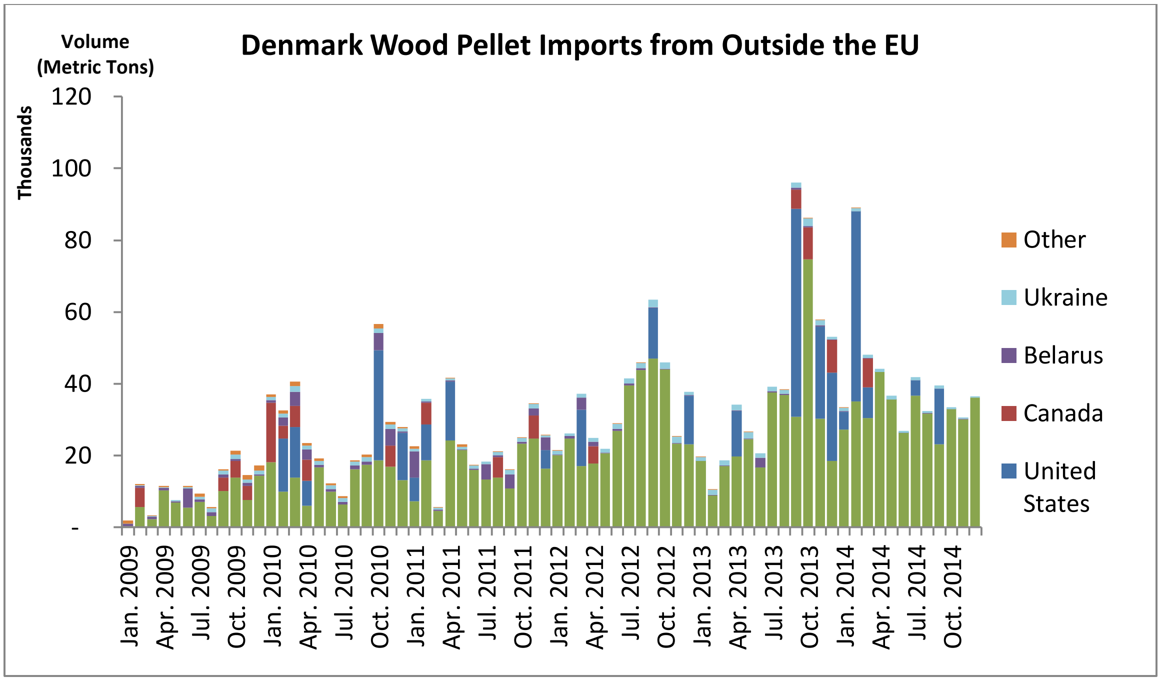


Figure 10. Denmark Wood Pellet Imports from Outside the EU. Source: Eurostat

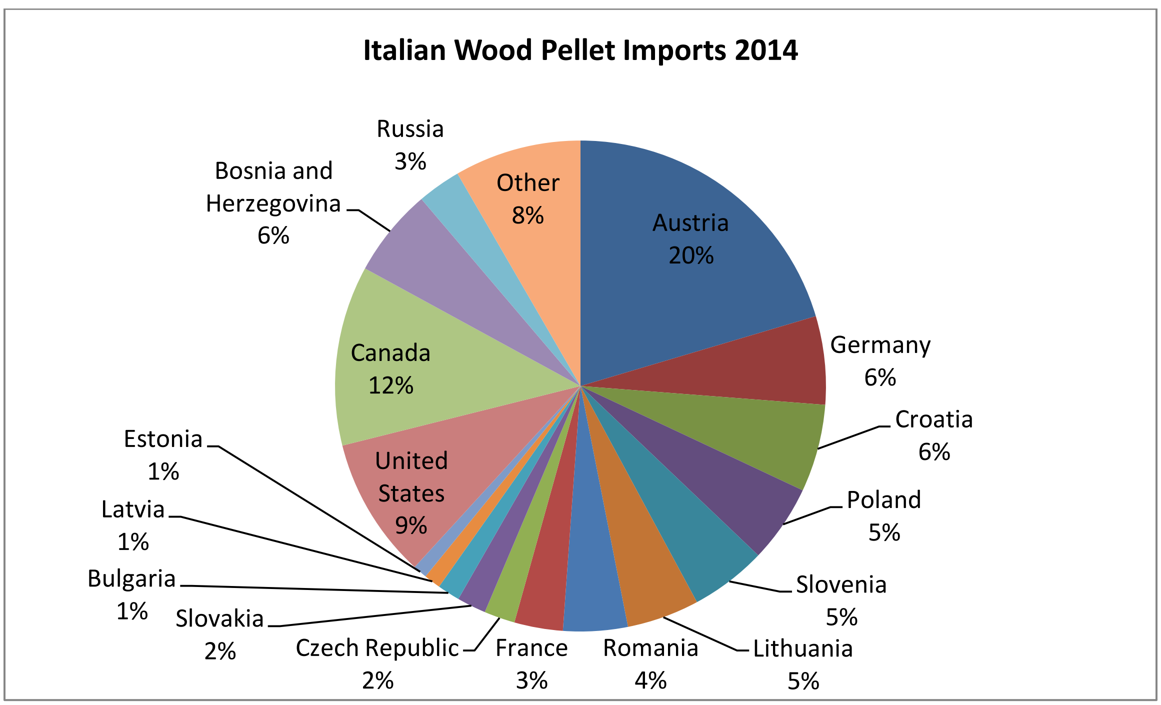


Figure 11. Italian Wood Pellet Imports in 2014 by Exporting Country Market Share. Source: Eurostat

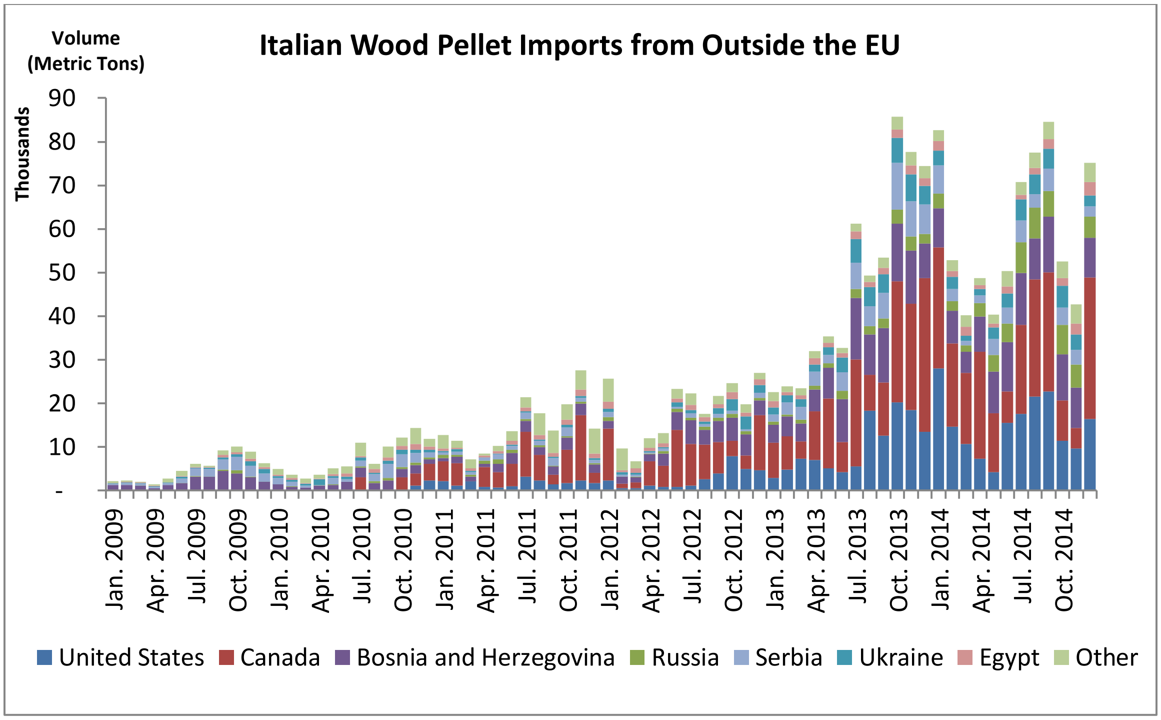


Figure 12. Italian Wood Pellet Imports from Outside the EU. Source: Eurostat

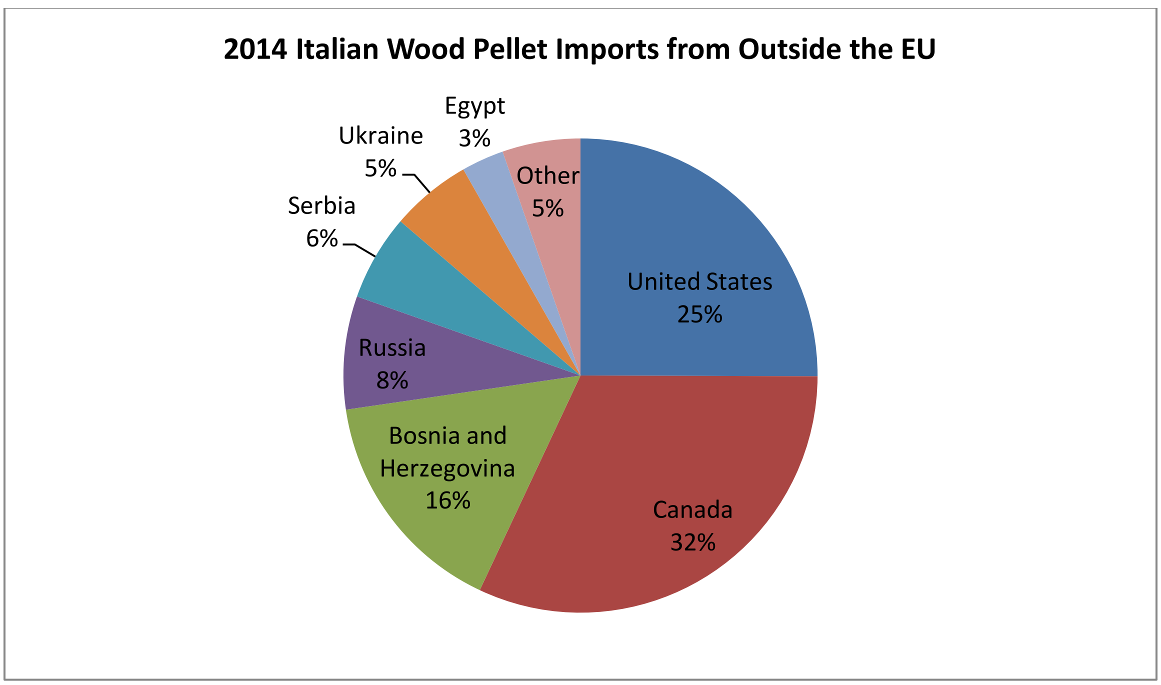


Figure 13. Italian Wood Pellet Imports from Outside the EU by Percentage. Source: Eurostat

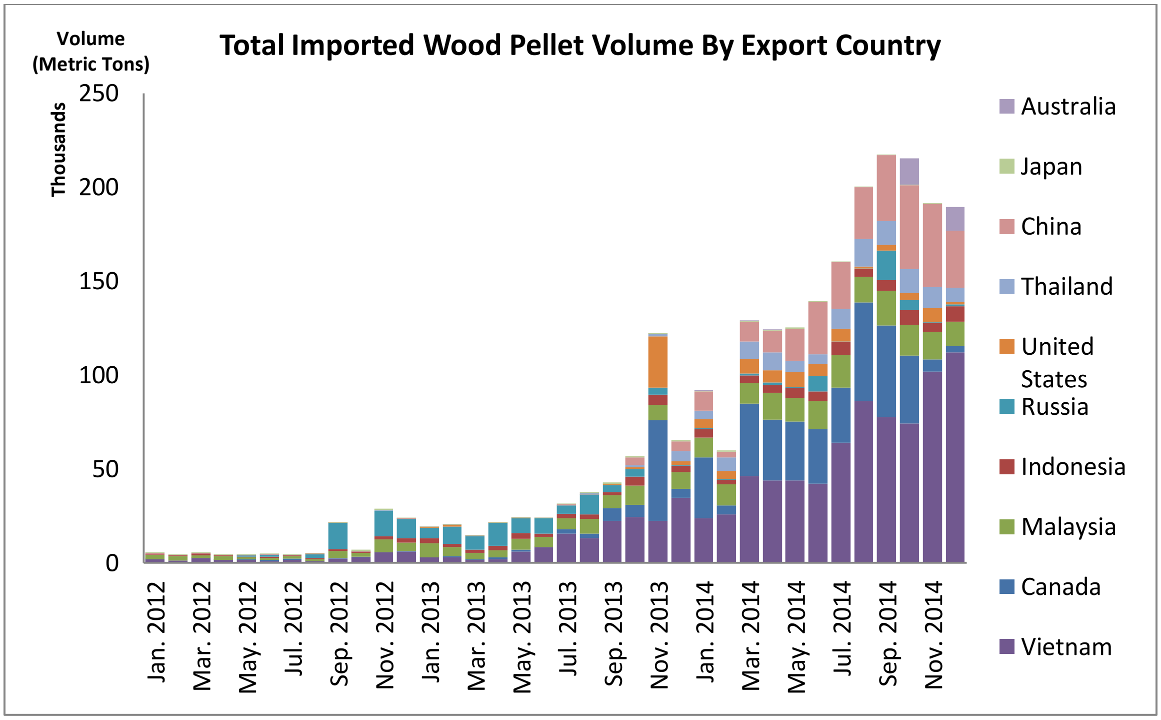


Figure 14. Korean Wood Pellet Imports 2012-2014. Source: Korea Customs Service

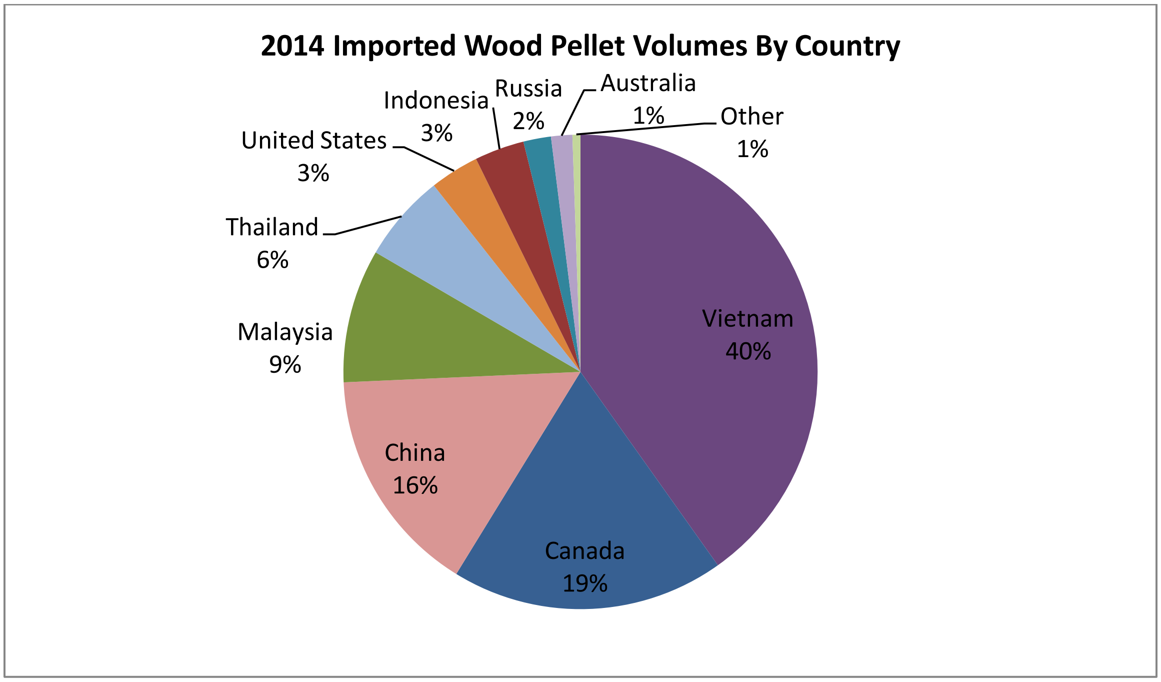


Figure 15. Korean Imported Wood Pellet Volumes by Market Share in 2014. Source: Korea Customs Service

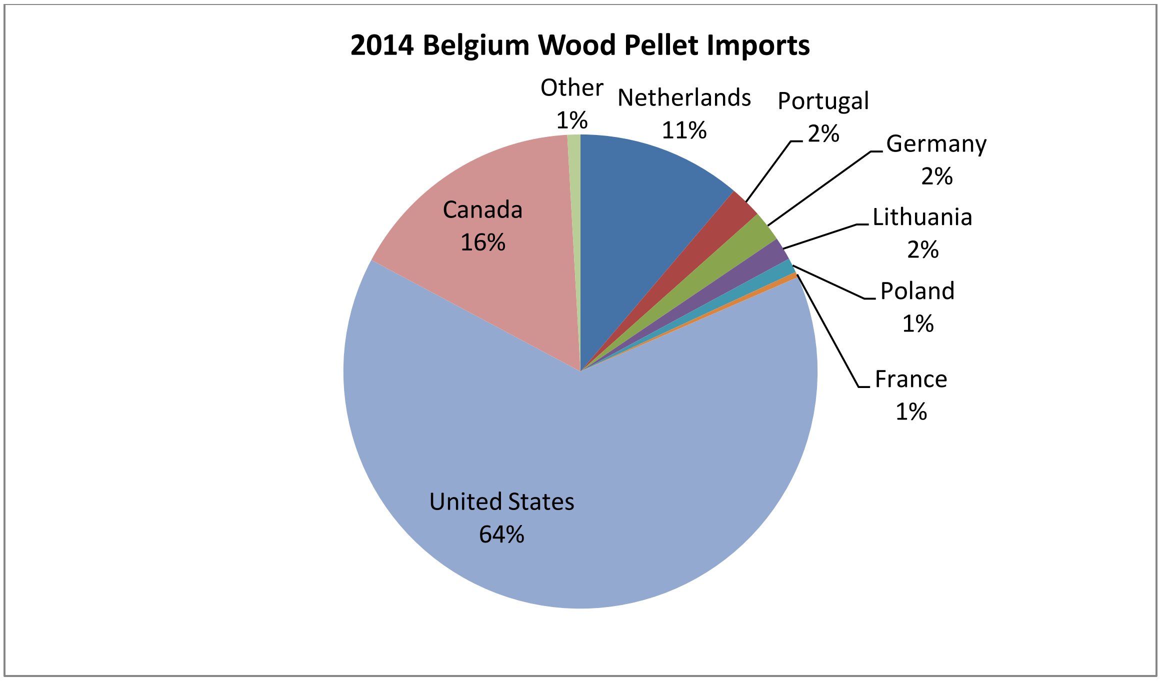


Figure 16. Belgium Wood Pellet Imports in 2014 by Exporting Country Market Share. Source: Eurostat

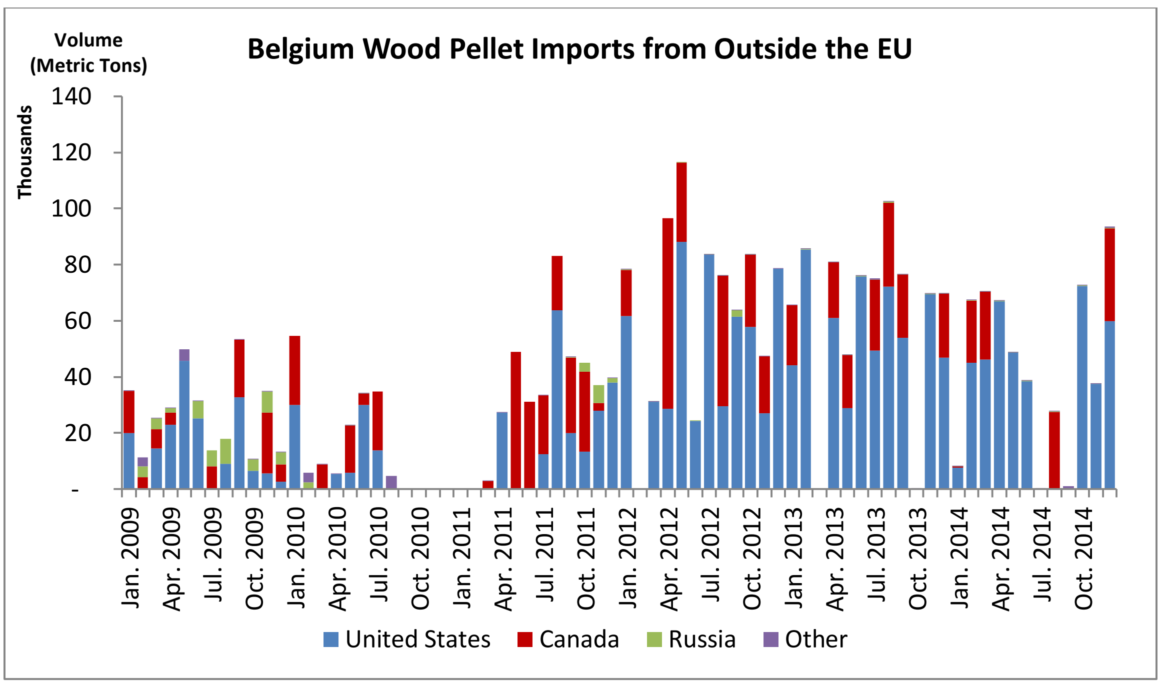


Figure 17. Belgium Wood Pellets Imports from Outside the EU. Source: Eurostat

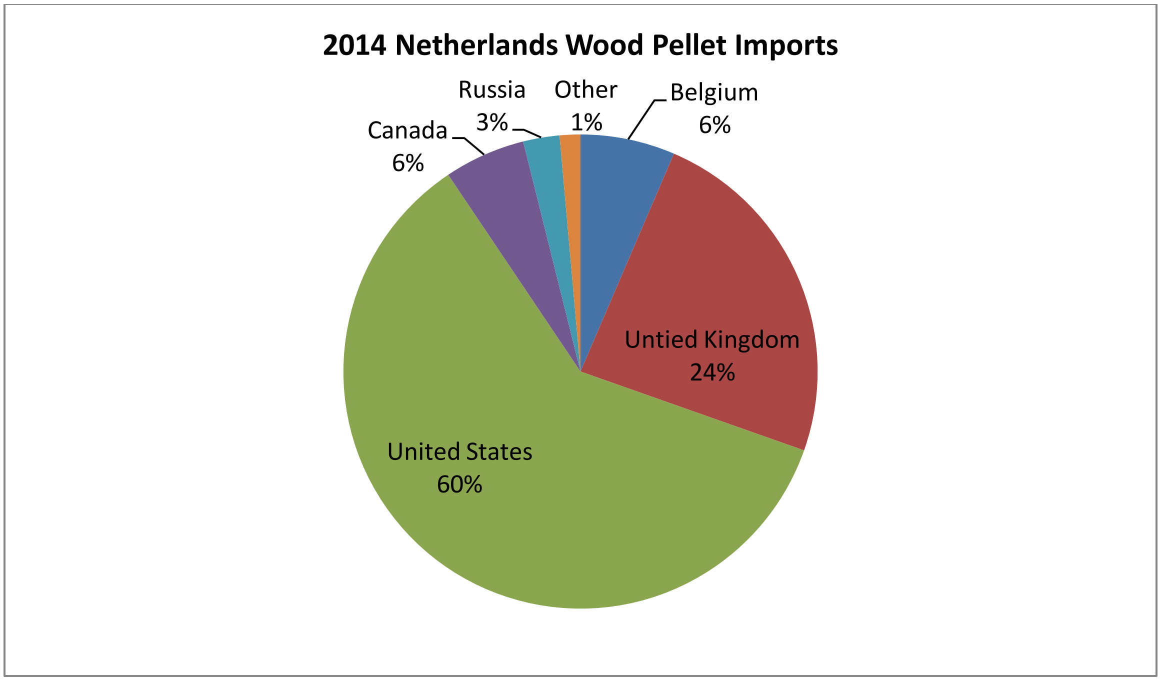


Figure 18. Netherlands Wood Pellet Imports in 2014 by Exporting Country Market Share. Source: Eurostat

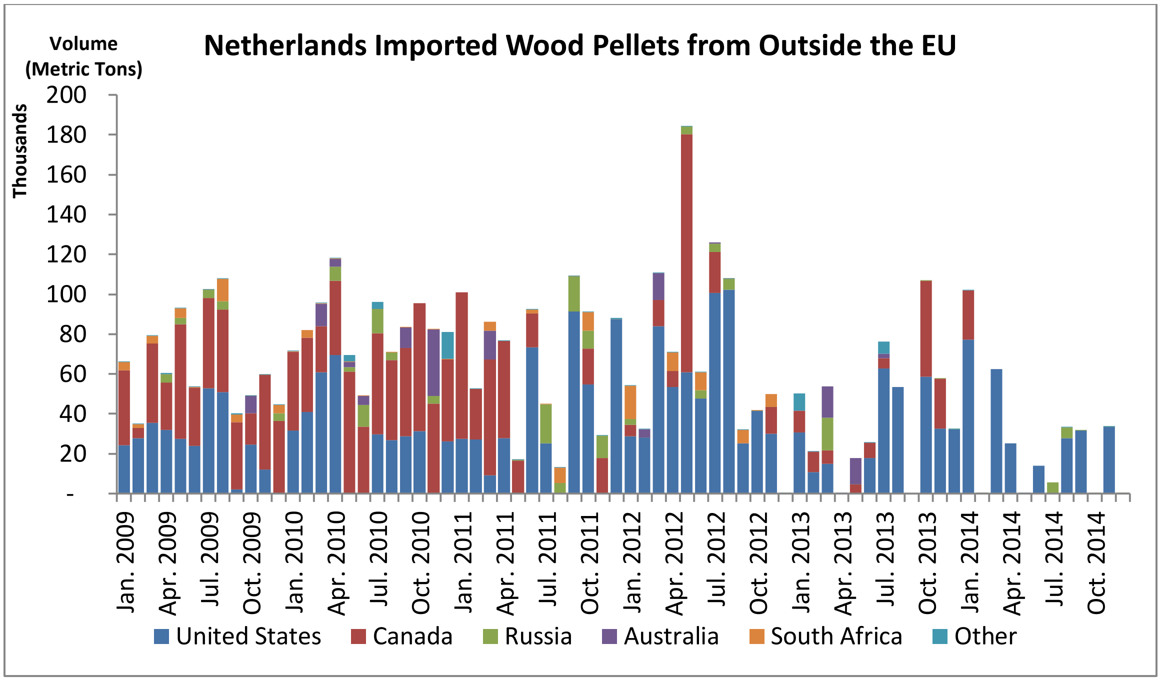


Figure 19. Netherlands Wood Pellet Imports from Outside the EU. Source: Eurostat

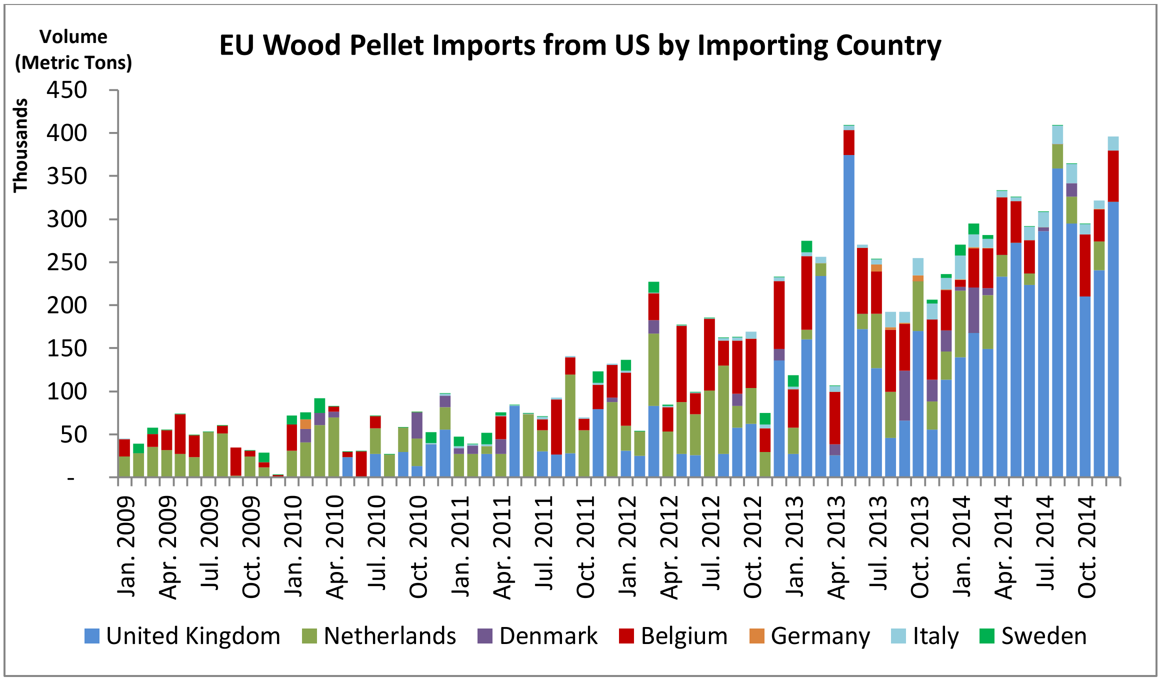


Figure 20. EU Wood Pellet Imports from the US by Importing Country. Source: Eurostat

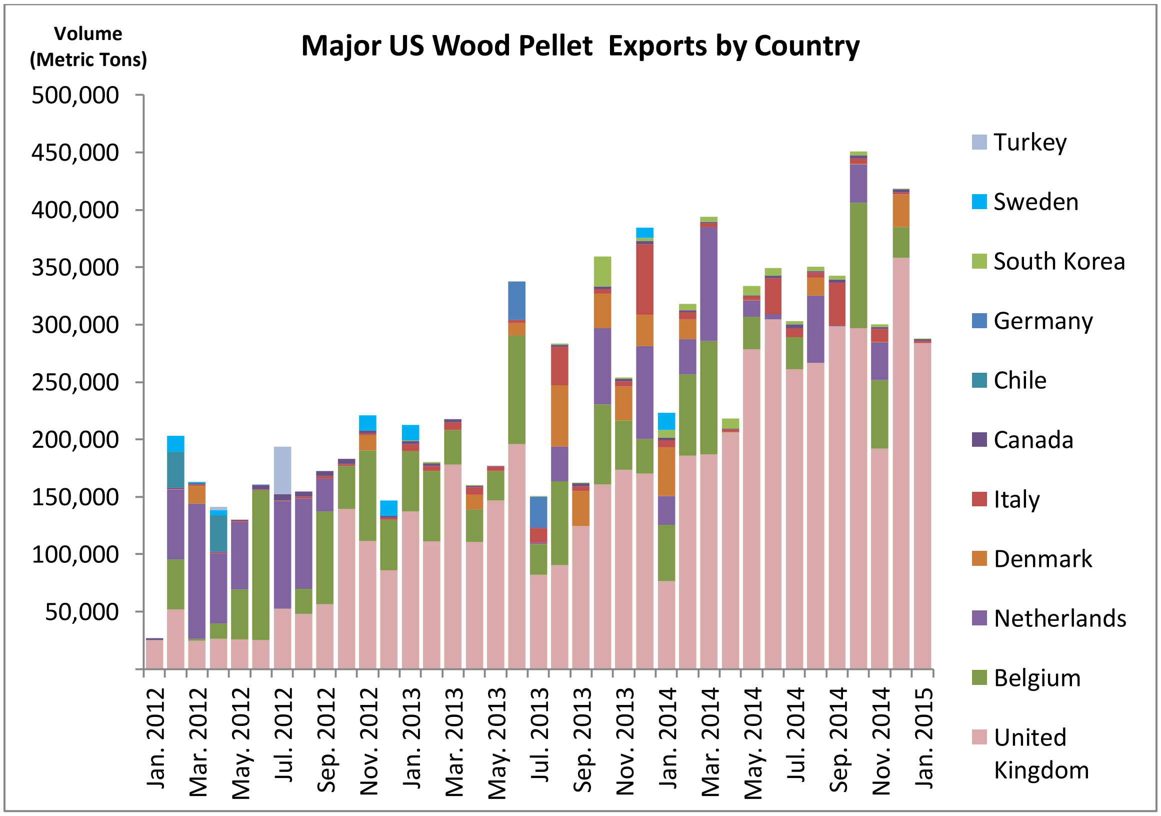


Figure 21. US Wood Pellet Exports by Importing Country. Source: US Census Bureau

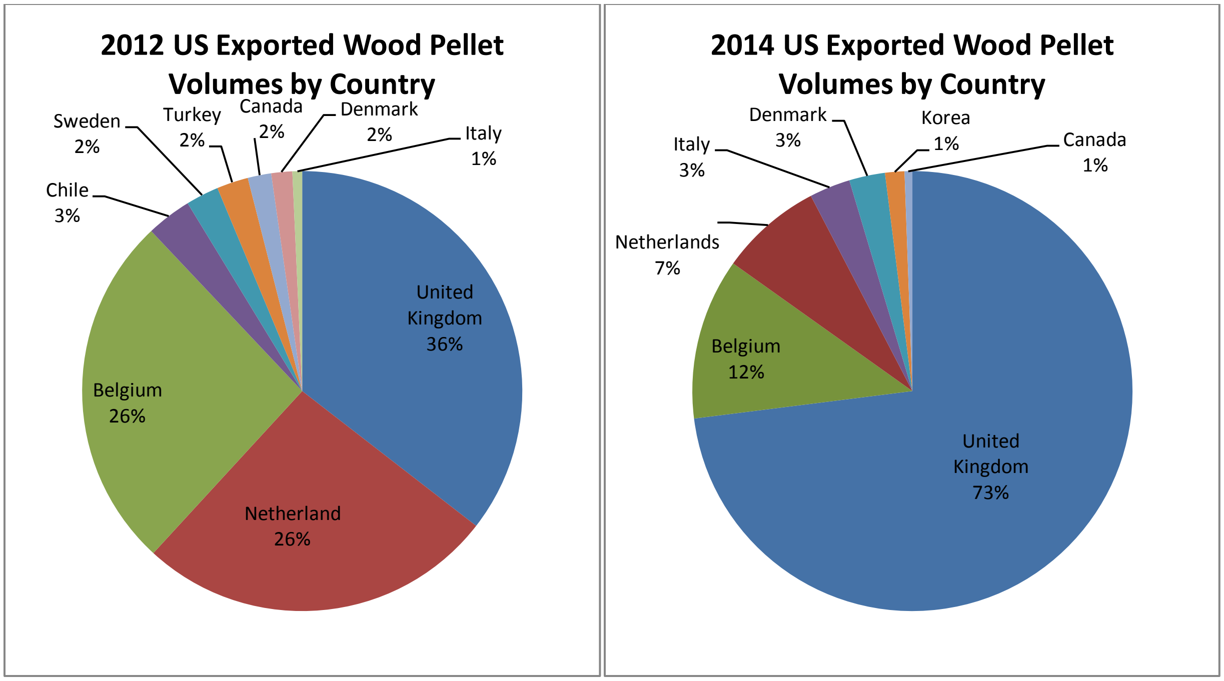


Figure 22. US Wood Pellet Export Volumes by Importing Country. Source: US Census Bureau

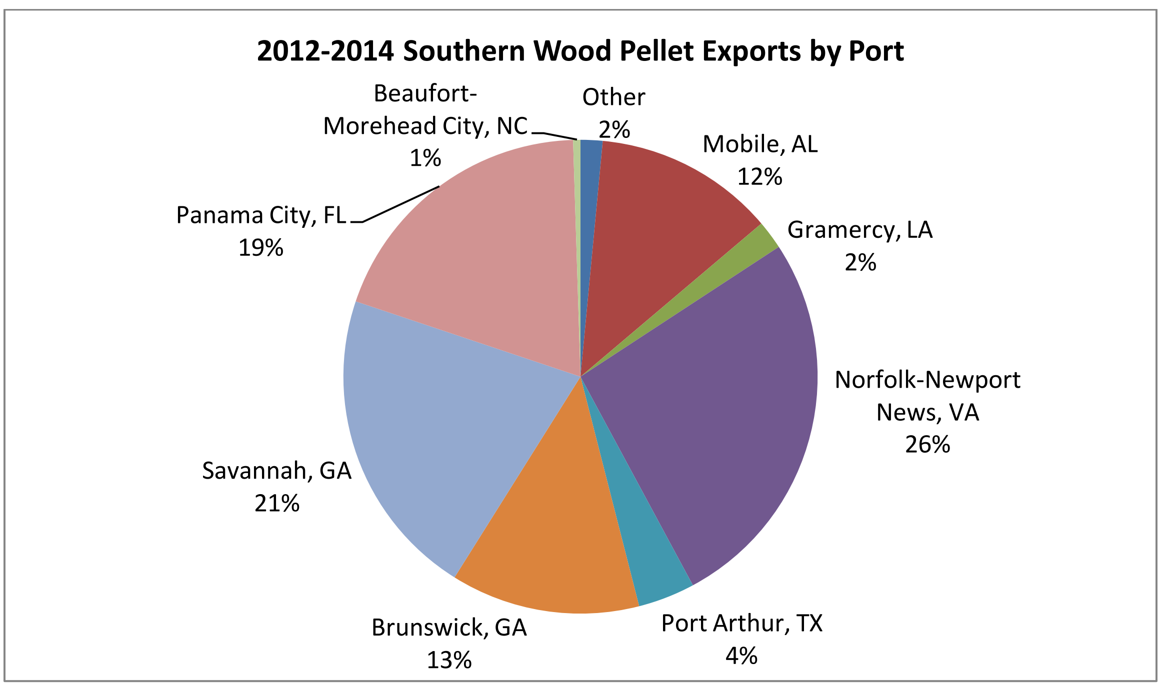


Figure 23. Southern US Wood Pellet Export Volumes by Port. Source: US Census Bureau

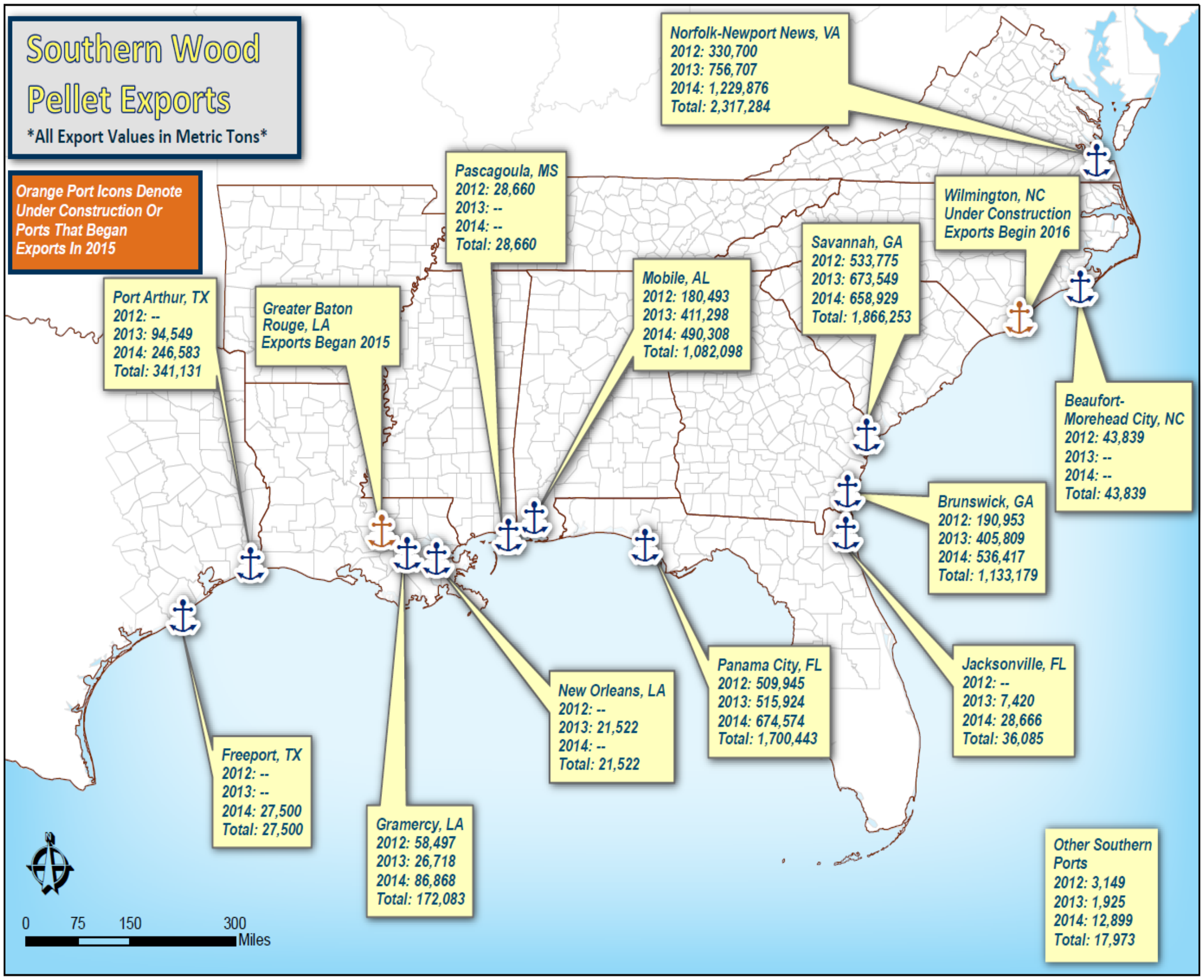
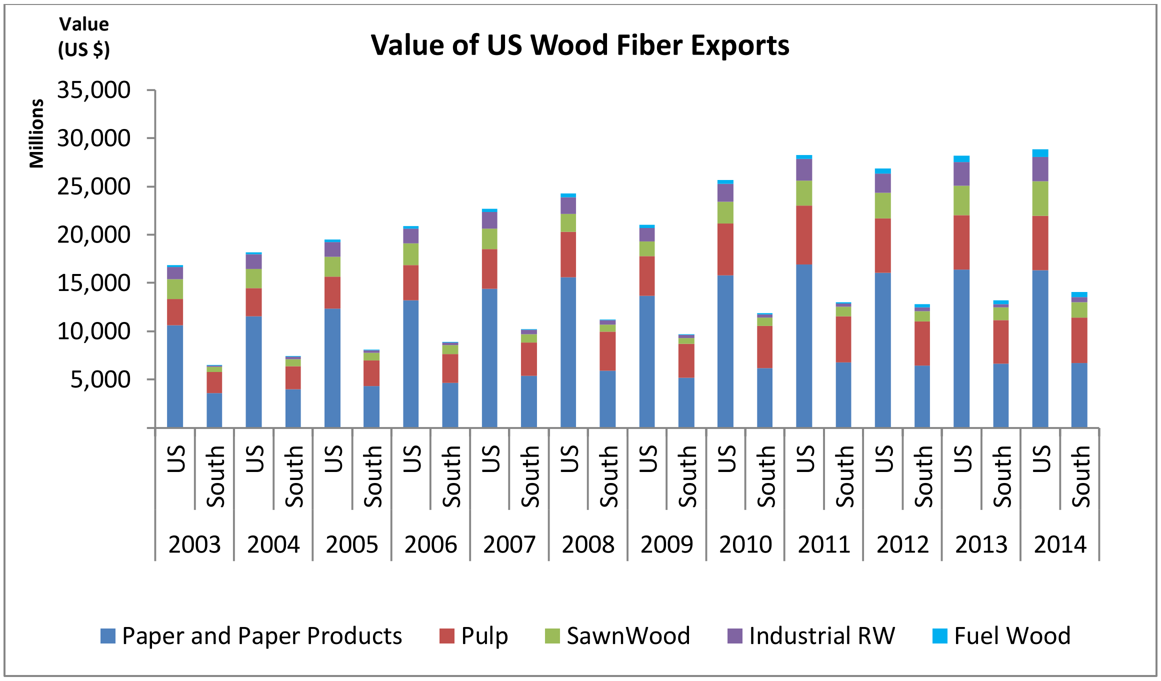


Figure 24. Southern Wood Pellet Export Volumes by Port. Source: US Census Bureau



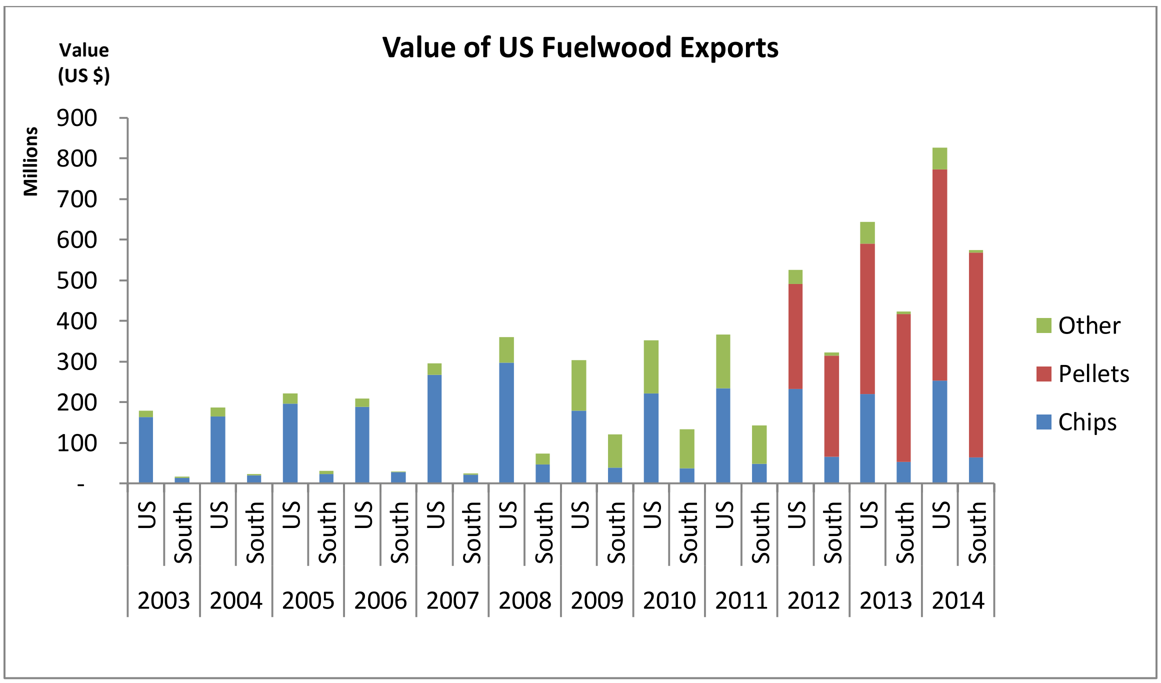
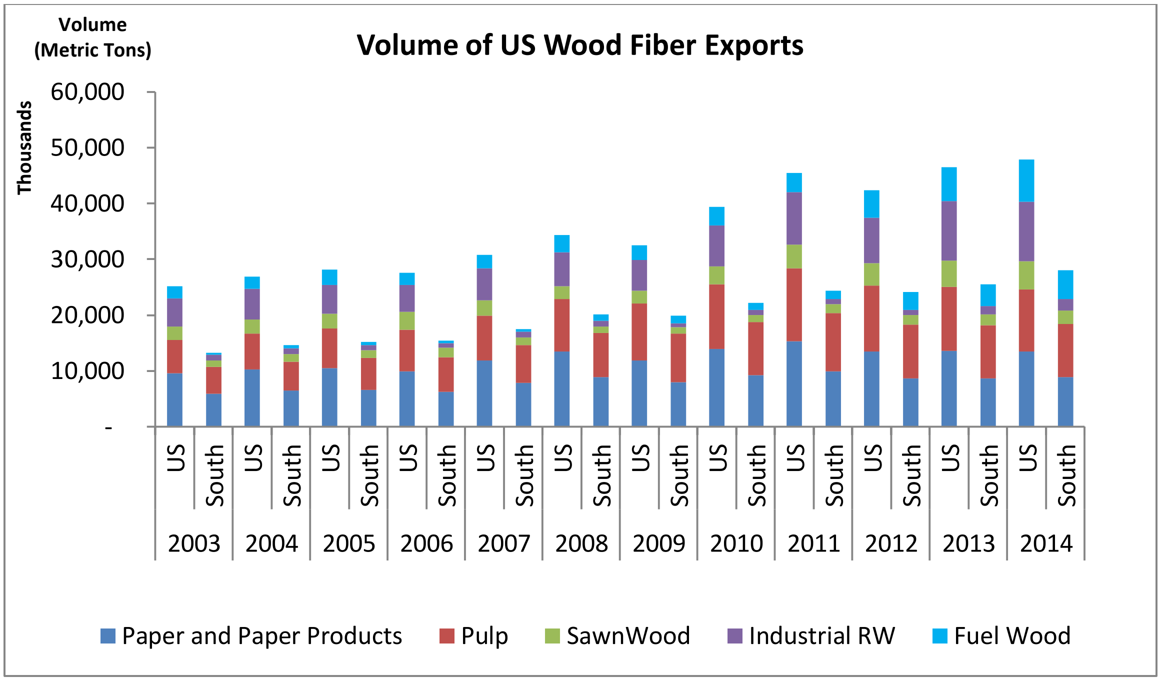


Figure 25. Value of US Wood Fiber Product Exports. Source: US Census Bureau



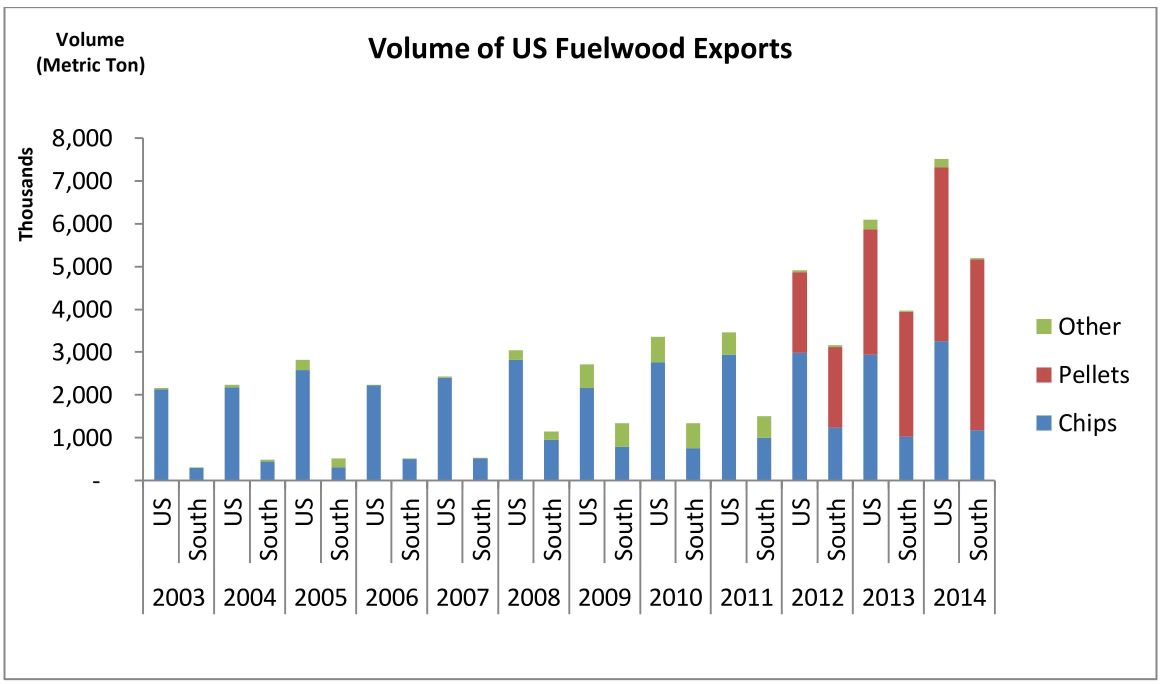


Figure 26. Volume of US Wood Fiber Product Exports. Source: US Census Bureau

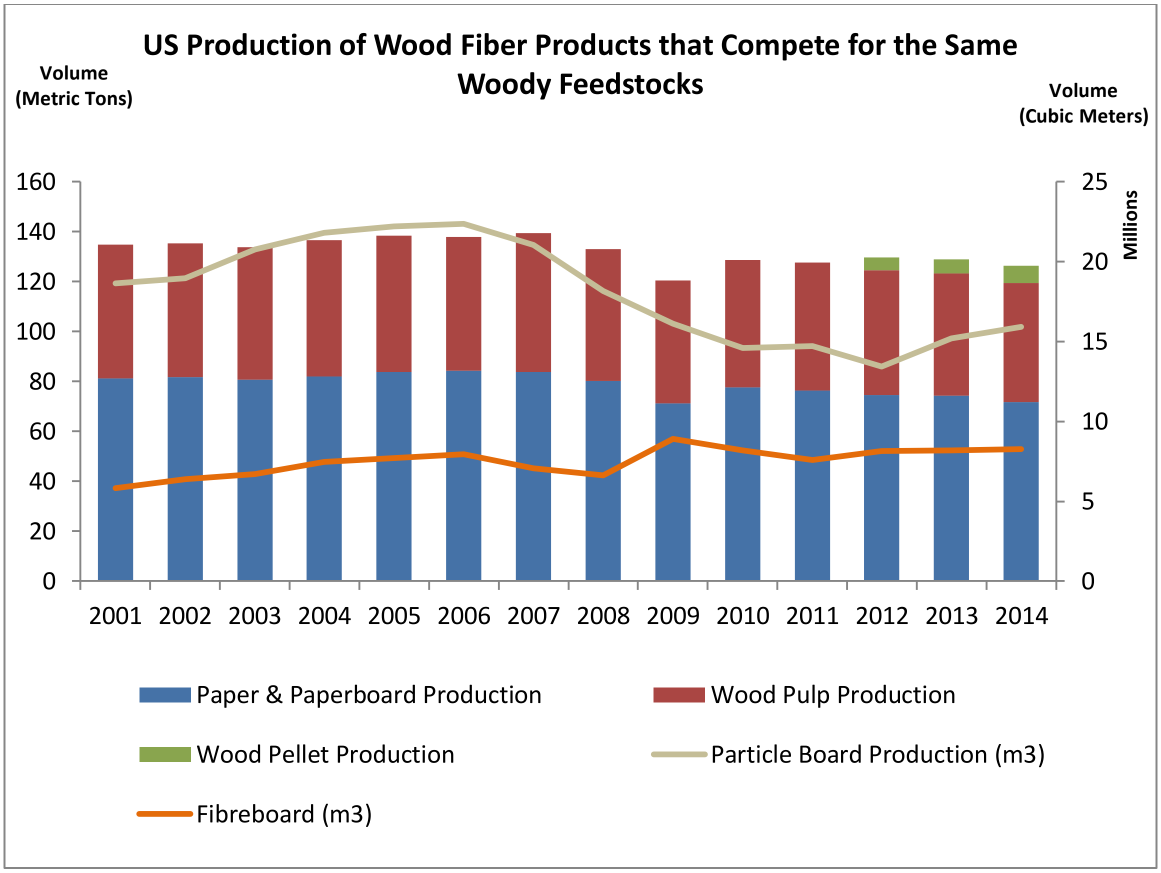


Figure 27. US Production of Wood Fiber Products that Compete for Feedstocks. Source: FAO

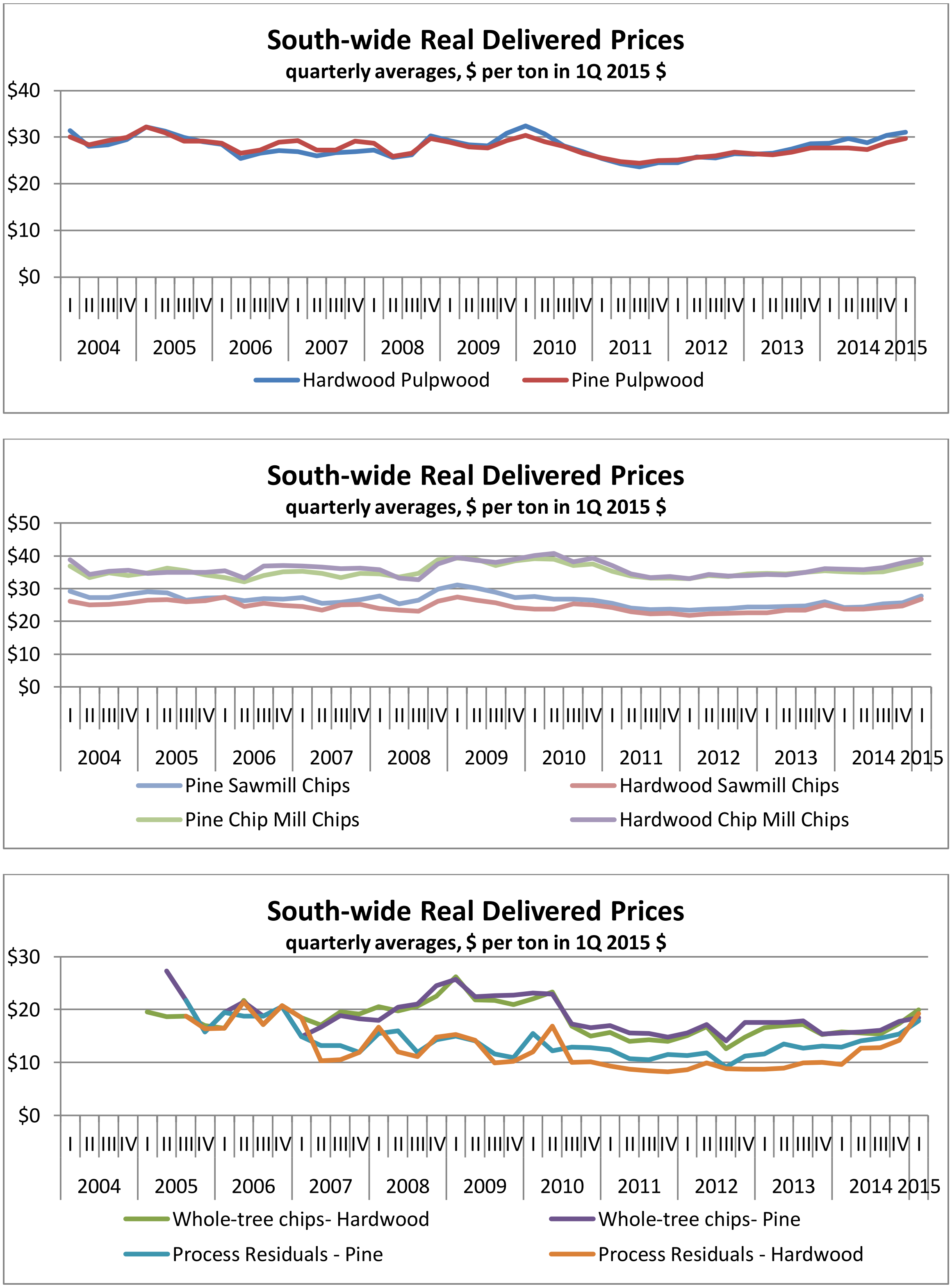


Figure 28. South-wide Real Delivered Prices for Woody Feedstocks Used in the Production of Wood Pellets. Source: Timber Mart-South

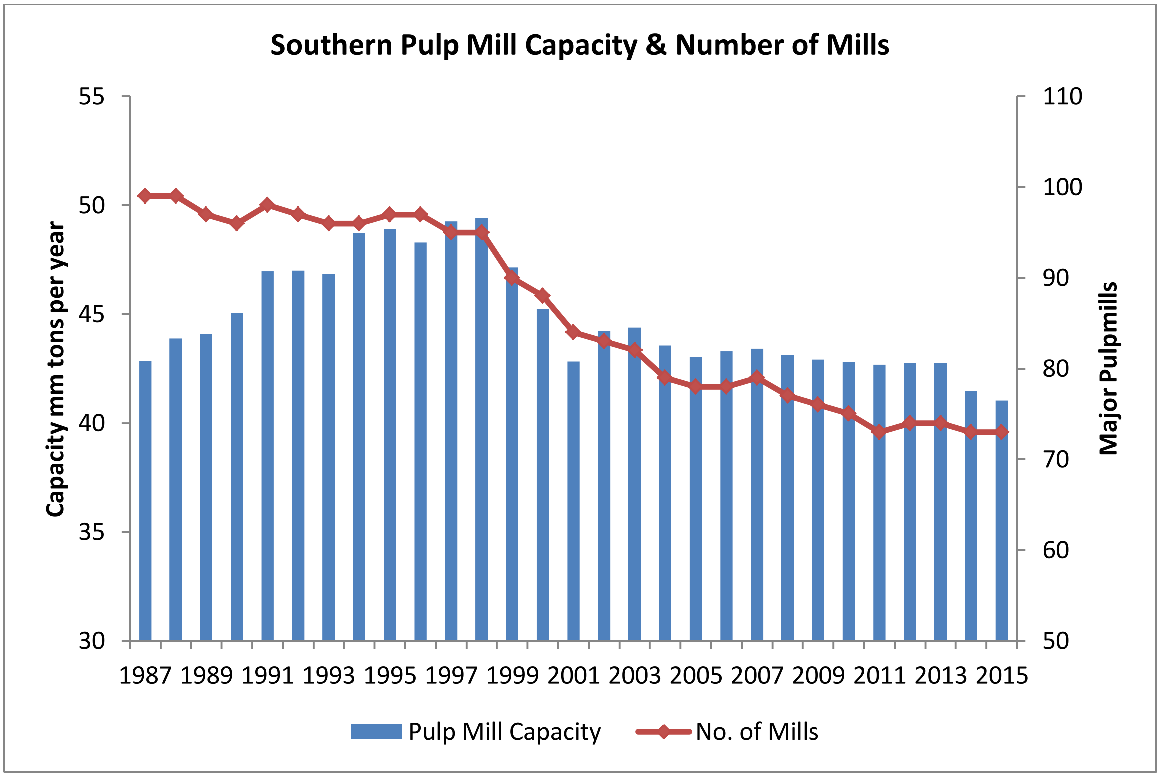


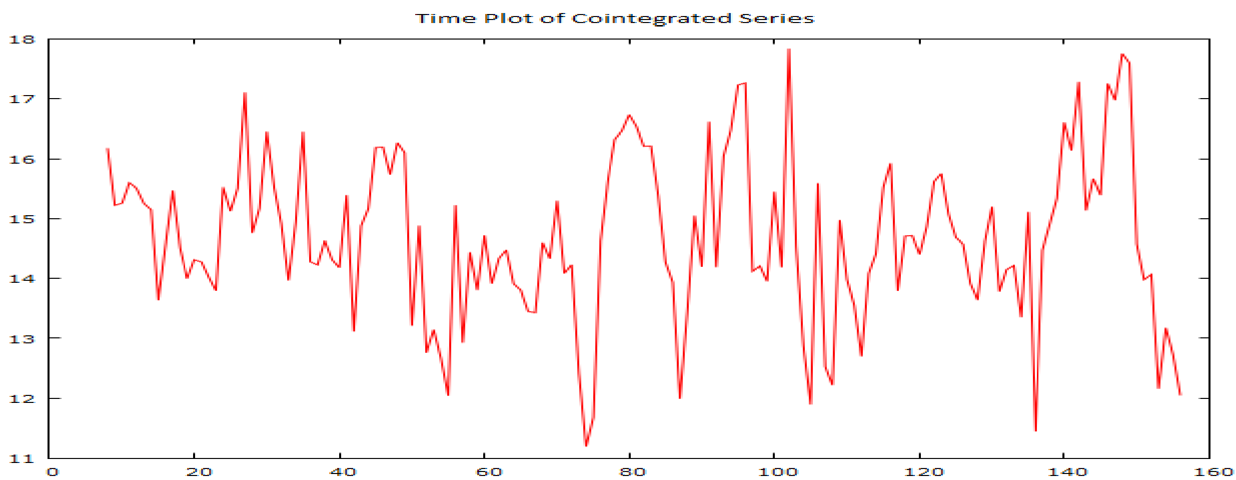
Figure 29. Pulp Mill Capacity in the 11 State Timber Mart-South Coverage Area. Source: Timber Mart-South

Table 2. Results of the unit root tests

Series	D-F statistic	P-Value	KPSS statistic	P-Value
Fpw	-0.3555	0.9088	2.5132	< .01
Fr1	-1.0492	0.6666	1.1207	< .01
Fr2	-0.5508	0.8515	2.5246	< .01
Fr3	-1.3961	0.5378	1.6826	< .01

Table 3. Cointegration test results of the Johansen-Procedure

H_0:	L_{max}	5%	1%	L_{tr}	5%	1%
$m \leq 3$	3.85	9.24	12.97	3.85	9.24	12.97
$m \leq 2$	5.39	15.67	20.20	9.23	19.96	24.60
$m \leq 1$	17.97	22.00	26.81	27.21	34.91	41.07
$m = 0$	48.07	28.14	33.24	75.27	53.12	60.16



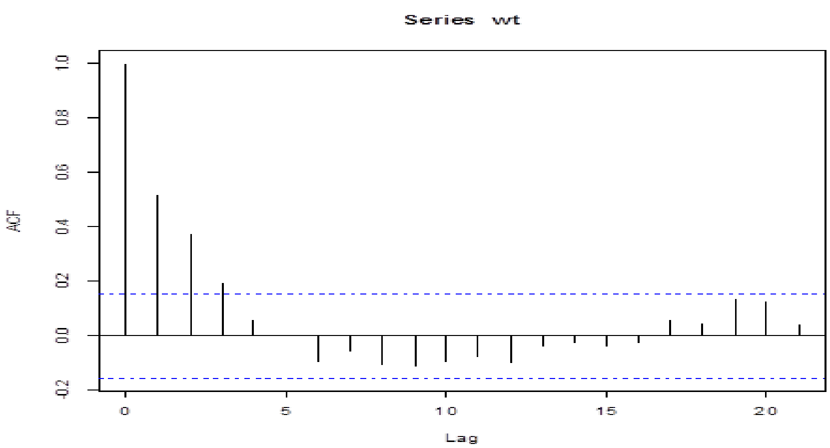


Figure 30. Plot of the Cointegrated Series and the Autocorrelation Function of w_t

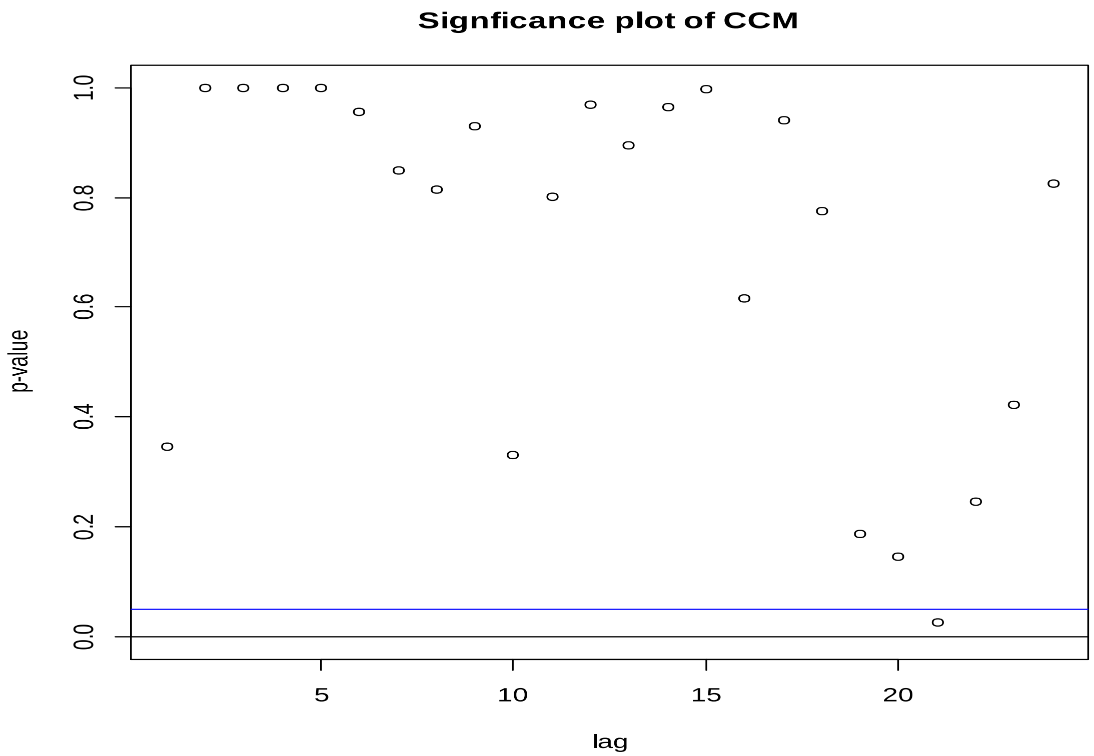


Figure 31. Cross correlation significance plot of the Modeled Time Series. The Blue Line Represents the 5% Level.

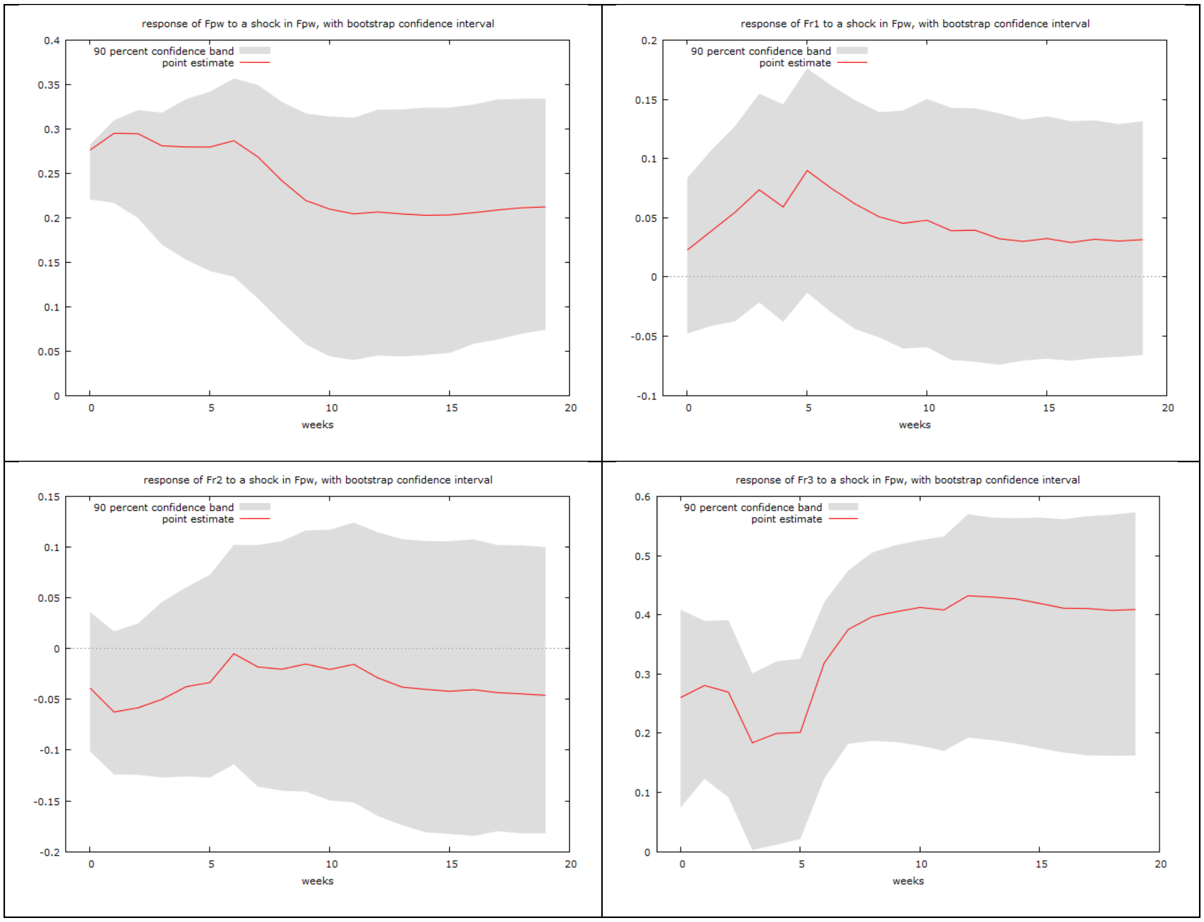


Figure 32. Impulse Response Functions to a Shock in Pulpwood Prices with a 90% Confidence Interval on a VECM

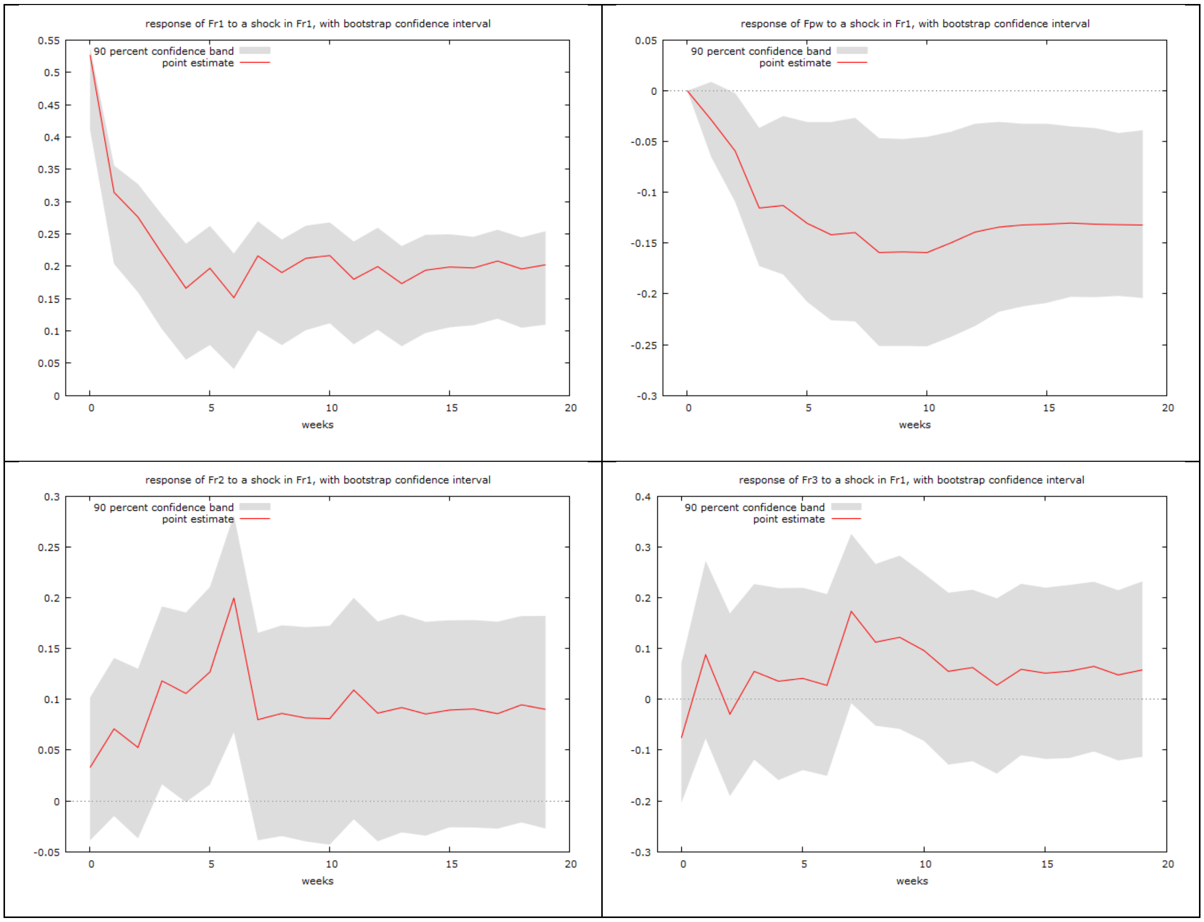


Figure 33. Impulse Response Functions to a Shock in Feedstock Residual 1 (Fr1) with a 90% Confidence Interval on a VECM.

Figure 34. Impulse Response Functions to a Shock in Feedstock Residual 2 (Fr2) with a 90% Confidence Interval on a VECM.

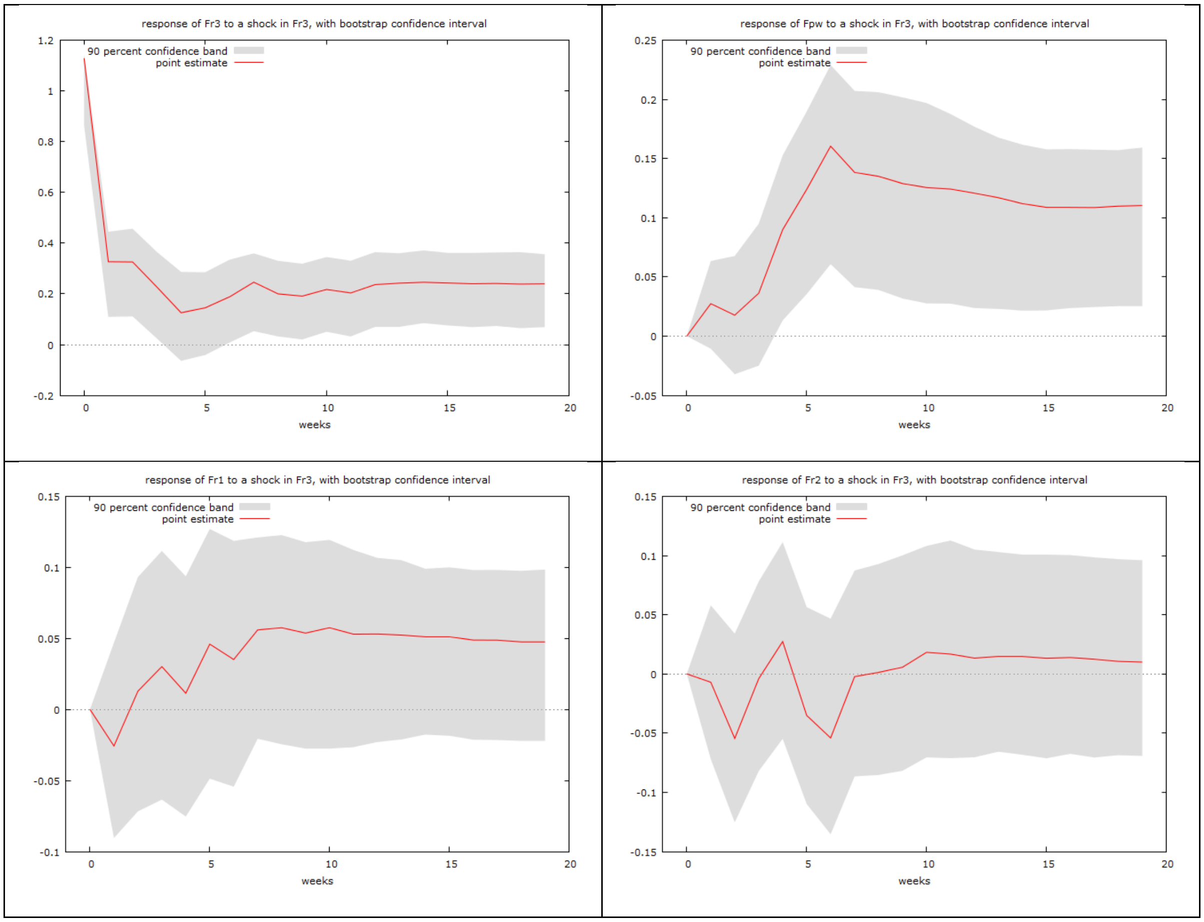


Figure 35. Impulse Response Functions to a Shock in Feedstock Residual 3 (Fr3) with a 90% Confidence interval on a VECM.

Table 4. Forecast error variance decomposition after 12 weeks

FEVD for prices	Percentage contributions of the shocks in price of Fpw	Fr1	Fr2	Fr3
Fpw	71.52	15.96	0.78	11.75
Fr1	4.31	86.20	7.25	2.23
Fr2	1.16	9.62	88.58	0.64
Fr3	36.45	2.69	6.59	54.27

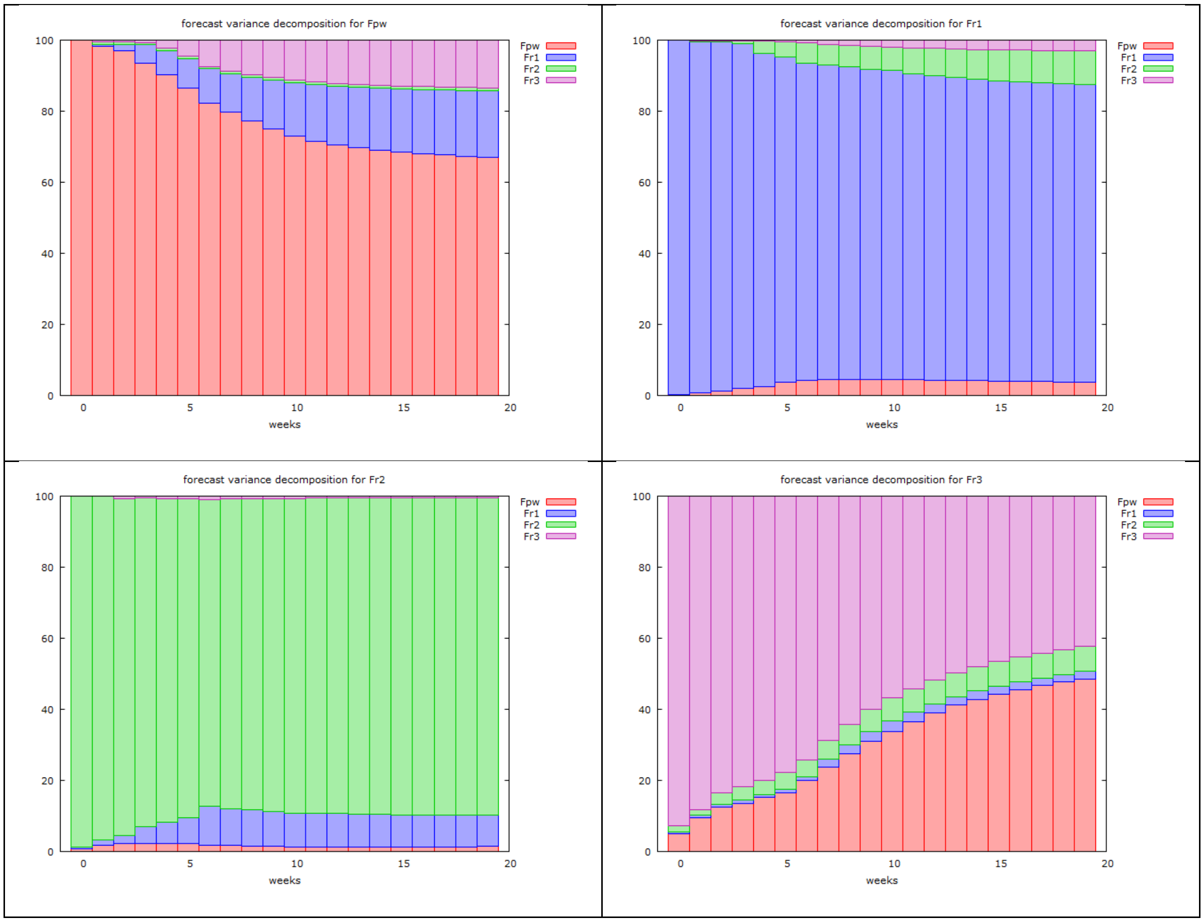


Figure 36. FEVD of the Four Woody Feedstocks over a 20 Week Period

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Market Analysis

There has been exponential growth in the production and trade of wood pellets since 2009. This growth, however, is beginning to level off. As demand for wood pellets is policy driven, competing with other sources of renewable energy for government support has created a rather volatile market to develop. Substantial changes in the dynamics of wood pellet trade flows represent this volatility.

A lack of harmonization in regards to EU policy adds to this volatility; the RED does not have binding sustainability criteria. Individual member states within the EU and other market participants employ their own safeguards to ensure they reach policy objectives. Further, sustainability requirements for to wood pellets are evolving. As scientific research into carbon mitigation of wood pellet production and use continues, policy and sustainability criteria will most likely continue to be evaluated and changed.

Constraints by individual countries have slowed the commoditization of wood pellets, limiting their growth potential and preventing a competitive market. Over the time period discussed in this thesis, significant growth in wood pellet demand has been limited to a few countries, most notably the UK and South Korea. The imports of other market participants have actually declined markedly, including the Netherlands and Belgium.

With abundant and sustainable wood fiber, comparatively low wood costs, good infrastructure, and a well-established and efficient forest industry, the US South was well positioned for the rapid expansion of wood pellet markets. The US has quickly become the dominant global supplier of wood pellets. Despite this growth, wood pellets still represent a very small fraction of the overall US forest products industry in regards to both overall production and export value. With the decline of pulp and paper production in the US, wood pellet production in conjunction with OSB and wood for energy will likely continue to replace the demand for pulpwood and residuals in fiber markets.

Despite being the global leader, US wood pellet exports are highly concentrated to just one country, the UK. Within the UK, the majority of the imported volumes are going to only one power plant, Drax. The majority of these volumes are sold through long-term off-take contacts. In the near future, the renewal of these contracts will likely increase volatility throughout the supply chain due to the lack of a truly competitive market. Such volatility will likely spill over into the spot market as well. US expansion of market share into other countries will be necessary to mitigate this risk.

To date, Asian markets have yet to materialize for US exports. With continued demand growth, this may change. The impact on Canadian exports, however, has been pronounced given Canada’s logistical advantage over the US to Asian markets. As the US continues to take EU market share from Canada, they will likely find Asian buyers for these volumes.

Regulatory uncertainty could also become a factor in US production. The forest products industry has at times been affected by erroneous information from the environmental community. Additionally, wood pellets are subject to negative lobbying by such interests as other renewable energies and traditional end users of pulpwood.

With the majority of support mechanisms for wood pellets ending in a little over a decade, the future of the industry will be determined by how the market and policy adapt. Such regulatory uncertainty, combined with a reduction in demand growth and an illiquid market, will make new wood pellet investment in the US South challenging. Aside from the high capital expenditure associated with building an industrial pellet mill, risk abounds in the market.

5.2 Price Dynamics

The production of wood pellets involves direct competition with traditional end users of pulpwood and saw mill residues–pulp, paper, and OSB producers. Production is also dependent on inputs such as shavings and sawdust, which are supplied by saw mills. Pellet mills are thus dependent on the geographical location of these plants and the economic realities of production in these industries. Flexibility in the strategic sourcing of woody feedstocks can hedge against volatility in the fiber markets and allow for the cost minimization of raw material inputs.

It has been shown that the four common woody feedstocks–Fpw, Fr1, Fr2, Fr3–are cointegrated. This stationary linear combination of the nonstationary random variables shows that there is a long-term equilibrium price relationship. The cointegrating vector does not provide insight into what this relationship is; it can instead be thought of as a constraint to the movements of the endogenous variables within the system. In other words, these feedstock prices will move randomly but only so far from each other before returning to long-run equilibrium. Thus, they are constrained from moving arbitrarily far away from each other (Dickey, Jansen, Thornton, & others, 1991).

The adjustment coefficients indicate the speed at which the feedstocks return to this long-run equilibrium. The coefficients are relatively small for Fr1 and Fr2, indicating that prices will correct 4.9% and 1% within one week. Prices for Fpw and Fr3, in contrast, will adjust to the long-run equilibrium much faster, correcting approximately 20% for Fpw and 38% for Fr3 within one week. This suggests that a deviation from the equilibrium will initiate an adjustment in Fr3 and Fpw before Fr1 and Fr2.

The impulse response functions of pulpwood, Fpw, appear correlated with Fr3. That is, a shock to Fpw leads to an increase in Fr3 prices. This suggests a possible substitutive effect. An increase in the price of Fpw will lead to an increased demand in residual Fr3 and a subsequent rise in price as a result of this increased demand. The impulse response functions of Fr3 reinforce this relationship. The decay of an impulse to Fr3 mirrors an increase in Fpw, albeit on a smaller scale. The difference in scale suggests that Fpw has a greater impact on the prices in regard to its relationship with Fr3.

Innovations to Fr1and Fr2 also appear to be correlated and suggest a substitutive effect between them. A shock to the prices of Fr1 leads to an increase in prices of Fr2; such an increase in prices to Fr2 may be attributable to increased demand of that residual as a result of the shock to Fr1. The impulse response functions to Fr2 mirror this relationship.

The structure of these price relationships are reinforced by the FEVD. The magnitude of influence on prices can be seen between Fpw and Fr3. The link between Fr1 and Fr2 is less clear in regards to FEVD. Though both feedstocks have similar contributions to the influence of the others price, the price of Fr1 is also influenced by the price of pulpwood.

Though these price movements appear to be correlated, it is important to note that only one cointegrating vector was found, establishing a long-run price equilibrium for all the feedstocks. There could have been various linearly independent cointegrating vectors within this system. For example, Fpw and Fr3 as well as Fr1 and Fr2 could have had independent long-run equilibrium relationships. This was not found to be the case however.

Despite roundwood pulpwood being the most dominant feedstock available to pellet producers, it appears that residuals Fr1 and Fr2 may be preferable for pellet production. As Fpw, as well as Fr3, will adjust to equilibrium faster than the other feedstocks in the system, the need for long-term supply agreements in regard to these feedstocks may be less desirable. With slow adjustment periods, the inverse appears to be true for Fr1 and Fr2. Therefore, the ability of residuals Fr1 and Fr2 to sustain higher prices longer may indicate a consumer's willingness to pay more for these woody feedstocks. This apparent consumer preference for these feedstocks could be a result of the supply structure, however, as these feedstocks may be more dependent on upstream economic cycles. Regardless, the ability of Fr1 and Fr2 to hold higher prices longer represents an opportunity for both procurement pricing options and long-term supply agreements.

Though these heterogeneous feedstocks are cointegrated, the dynamic nature of impulse response functions to the system suggests these feedstocks react in a segmented market way. Fr2 and, to a lesser extent, Fr1 have limited spillover variance from the other feedstocks. Their incorporation into sourcing could be used to reduce volatility in raw material input prices. Furthermore, the FEVD may indicate flexibility in price negotiations within these segments.

This thesis, through a survey of statistical sources and government policy, developed an in-depth analysis of the wood pellet market as it relates to the US South from 2009 through 2014. This comprehensive market analysis provided context for the prices of woody feedstocks used in the production of wood pellets. Furthermore, this thesis analyzed the price dynamics of four common woody feedstocks used in the production of wood pellets in the US South. It was shown that these prices are cointegrated, and there appears to be a market preference for residuals Fr2 and Fr1. Also, shocks within the modeled system suggest a somewhat divergent market. These results provide insight into cost minimization and reduction of volatility. Additionally, changes to prices of these inputs can directly impact the allocation of woody feedstocks and alter the carbon footprint of the wood pellets. Understanding of price dynamics and relationships between the various woody feedstocks used in wood pellet production in the US South is imperative for operating within the existing constraints–both policy and economic.

The analysis was limited by the inability to differentiate within wood pellet markets. Pellets are often traded in two distinct markets, the residential heating market and the industrial electricity generation market. Trade statistics, however, do not differentiate the commodity by end use. Though the market segmentation between these two products is decreasing, a specific CN or schedule B code based on end use would provide more clarity in the future.

An area of focus for future study would be structural vector autoregression modeling with sustainability constraints exogenously incorporated. Additionally, the exploration of cointegration among the prices of these four feedstocks and sawtimber is of interest. Spatial equilibrium of global wood pellet trade flows could also be examined. Of specific interest would be the interaction among the US and the external and internal EU markets.

REFERENCES

55th Annual Survey of Paper, Paperboard, and Pulp Capacity. (2015). American Forest & Paper Association. Retrieved from http://www.afandpa.org/media/news/-in-category/categories/statistics

Abt, K. L., Abt, R. C., & Galik, C. (2012). Effect of Bioenergy Demands and Supply Response on Markets, Carbon, and Land Use. *Forest Science*, *58*(5), 523–539. http://doi.org/10.5849/forsci.11-055

Bentley, J. W., & Steppleton, C. D. (2013). Southern Pulpwood Production, 2011. US Depaertment of Agriculture Forest Service, Southern Research Station.

Bentsen, N. S., Jack, M. W., Felby, C., & Thorsen, B. J. (2014). Allocation of biomass resources for minimising energy system greenhouse gas emissions. *Energy*, *69*, 506–515. http://doi.org/10.1016/j.energy.2014.03.045

Bureau of Labor Statistics. (2015). Retrieved July 31, 2015, from http://data.bls.gov/timeseries/WPU00000000?output_view=pct_1mth

Cheng, B., Mei, B., & Wan, Y. (2013). An Econometric Analysis of US Exports of Forest Products. *Forest Products Journal*, *63*(7-8), 224–231. http://doi.org/10.13073/FPJ-D-13-00045

Department of Energy & Climate Change. (2014). *Renewable sources of energy* (Digest of United Kingdom energy statistics No. Chapter 6). Retrieved from https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series With a Unit Root. *Journal of the American Statistical Association*, *74*(366), 427–431. http://doi.org/10.2307/2286348

Dickey, D. A., Jansen, D. W., Thornton, D. L., & others. (1991). A Primer on Cointegration with an Application to Money and Income. *Federal Reserve Bank of St. Louis Review*, *73*(2), 58–78.

Dwivedi, P., & Khanna, M. (2014). Abatement cost of wood-based energy products at the production level on afforested and reforested lands. *GCB Bioenergy*, 1–13. http://doi.org/10.1111/gcbb.12199

EIA. (2015). What is U.S. electricity generation by energy source? Retrieved July 31, 2015, from http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3

Electricity Market Reform-Contract for Difference: Contract and Allocation Overview. (2013, August). UK Department of Energy & Climate Change. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/233004/EMR__Contract_for_Difference__Contract_and_Allocation_Overview_Final_28_August.pdf

Electric Power Monthly. (2015). Retrieved July 31, 2015, from http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a

Energy Information Administration. (2009a). *Impacts of a 25-percent renewable electricity standard as proposed in the ACESA discussion draft* (SR/OIAF/2009-04). Washington, DC: U.S. Department of Energy.

Energy Information Administration. (2007). *Energy and Economic Impacts of Implementing Both a 25-Percent Renewable Portfolio Standard and a 25-Percent Renewable Fuel*

Standard by 2025 (No. SR/OIAF/2007-05). Washington, DC: U.S. Department of Energy. Retrieved from http://www.eia.gov/analysis/requests/2007/eeim/pdf/sroiaf(2007)05.pdf

Energy Infrastructure Update December 2014. (2015). Federal Energy Regulatory Commission. Retrieved from https://www.ferc.gov/legal/staff-reports/2014/dec-infrastructure.pdf

Engineered Wood Statistics-First Quarter 2015. (2015). The Engineered Wood Association. Retrieved from http://www.apawood.org/Data/Sites/1/documents/membersonly/marketstatistics/2015/Qtr1-15.pdf

Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251–276. http://doi.org/10.2307/1913236

European Commission. (2010). *Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling* (No. COM(2010) 11 final). Brussels. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0011:FIN:EN:PDF

European Commission. (2014a). *State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU* (Commission Staff Working Document No. SWD(2014) 259 final). Brussels. Retrieved from http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf

European Commission. (2014b). The 2020 climate and energy package. Retrieved November 4, 2014, from http://ec.europa.eu/clima/policies/package/index_en.htm

European Commission. (2015). Explanatory Notes to the Combined Nomenclature of the European Union, *58*(C 76). Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2015:076:FULL&from=EN

Eurostat. (2015). [DS-045409-EU Trade since 1988 by HS 2, 4, 6 and CN 8]. Retrieved April 3, 2015, from http://ec.europa.eu/eurostat/data/database

FAOSTAT. (2015). Retrieved July 30, 2015, from http://faostat3.fao.org/browse/F/*/E

Galik, C. S., Abt, R., & Wu, Y. (2009). Forest biomass supply in the southeastern United States—implications for industrial roundwood and bioenergy production. *Journal of Forestry*, *107*(2), 69–77.

Goh, C. S., Junginger, M., Cocchi, M., Marchal, D., Thrän, D., Hennig, C., … others. (2013). Wood pellet market and trade: A global perspective. *Biofuels, Bioproducts and Biorefining*, *7*(1), 24–42.

Gold, S., & Seuring, S. (2011). Supply chain and logistics issues of bio-energy production. *Journal of Cleaner Production*, *19*(1), 32–42. http://doi.org/10.1016/j.jclepro.2010.08.009

Goodwin, B. K., Holt, M. T., & Prestemon, J. P. (2011). North American Oriented Strand Board Markets, Arbitrage Activity, and Market Price Dynamics: A Smooth Transition Approach. *American Journal of Agricultural Economics*, *93*(4), 993–1014. http://doi.org/10.1093/ajae/aar024

Heinimö, J., & Junginger, M. (2009). Production and trading of biomass for energy – An overview of the global status. *Biomass and Bioenergy*, *33*(9), 1310–1320. http://doi.org/10.1016/j.biombioe.2009.05.017

Ince, P. J., Kramp, A. D., Skog, K. E., Yoo, D., & Sample, V. A. (2011). Modeling future U.S. forest sector market and trade impacts of expansion in wood energy consumption. *Journal of Forest Economics*, *17*(2), 142–156. http://doi.org/10.1016/j.jfe.2011.02.007

Johansen, S. (1988). Statistical analysis of cointegration vectors. *J. Econ. Dyn. Control*, *12*(2-3), 231–254. http://doi.org/10.1016/0165-1889(88)90041-3

Johansen, S., & Joselius, K. (1990). Maximum Likeiihood Estimation and Inference on Cointegration-with applications to the Demand for Money. *Oxford Bulletin of Economics and Statistics*, *52*, 2.

Korea Customs Service. Import/export By Commodity - 영문사이트. (2015). Retrieved March 27, 2015, from http://www.customs.go.kr/kcshome/trade/TradeCommodityList.do?layoutMenuNo=21032

Kwiatkowski, D., Phillips, P., Schmidt, P., & Shin, Y. (1992). Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? *Journal of Econometrics*, *54*(1-3), 159–178. http://doi.org/10.1016/0304-4076(92)90104-Y

Lamers, P., Junginger, M., Hamelinck, C., & Faaij, A. (2012). Developments in international solid biofuel trade—An analysis of volumes, policies, and market factors. *Renewable and Sustainable Energy Reviews*, *16*(5), 3176–3199. http://doi.org/10.1016/j.rser.2012.02.027

Lamers, P., Thiffault, E., Paré, D., & Junginger, M. (2013). Feedstock specific environmental risk levels related to biomass extraction for energy from boreal and temperate forests. *Biomass and Bioenergy*, *55*, 212–226. http://doi.org/10.1016/j.biombioe.2013.02.002

Lang, A. (2014, October 20). How Wood Demand from Bioenergy Affects Forecasted Pulpwood Prices in the South | Forisk. Retrieved March 6, 2015, from http://www.forisk.com/blog/2014/10/20/wood-demand-bioenergy-affects-forecasted-pulpwood-prices-south/

Luppold, W. G., & Prestemon, J. P. (2003). Tests for long-run relationships in hardwood lumber prices. *Forest Science*, *49*(6), 918–927.

Lütkepohl, H. (2007). *New Introduction to Multiple Time Series Analysis*. Berlin: Springer.

Mani, S., Sokhansanj, S., Bi, X., & Turhollow, A. (2006). Economics of producing fuel pellets from biomass. *Applied Engineering in Agriculture*, *22*(3), 421.

Mendell, B., & Lang, A. H. (2013). Update and Context for US Wood Bioenergy Markets. Forisk. Retrieved from https://www.theusipa.org/Documents/NAFO-US_Bioenergy_Markets-FINAL-201306261.PDF

National Renewable Energy Action Plan for the United Kingdom. (2010). United Kingdom. Retrieved from http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

Newes, E., Bush, B., Inman, D., Lin, Y., Mai, T., Martinez, A., … Peck, C. (2012). Biomass resource allocation among competing end uses. *Contract*, *303*, 275–3000.

Ning, L., & Rice, R. (2011). Characteristics of wood fuel pellet manufacturers and markets in the United States, 2010. *Forest Products Journal*, *61*(4), 310–315.

Oswalt, S. N., Smith, W. B., Miles, P., & Pugh, S. A. (2014). Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2015 update of the RPA Assessment. U.S. Department of Agriculture, Forest Service. Retrieved from http://www.srs.fs.usda.gov/pubs/47322

Perlack, R. D., Wright, L. L., Turhollow, A. F., Graham, R. L., Stokes, B. J., & Erbach, D. C. (2005). *Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply*. DTIC Document. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA436753

Renewable Energy Directive. (2015). [European Commission]. Retrieved April 25, 2015, from http://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

Renewable Obligation: Guidance for Generators 2015. (2015, April 13). UK Office of Gas and Electricity Markets.

Renewables Obligation: Sustainability Criteria. (2014, June 1). UK Office of Gas and Electricity Markets (Ofgem). Retrieved from https://www.ofgem.gov.uk/ofgem-publications/87988/renewablesobligationsustainabilitycriteriaguidance.pdf

Shabani, N., Akhtari, S., & Sowlati, T. (2013). Value chain optimization of forest biomass for bioenergy production: A review. *Renewable and Sustainable Energy Reviews*, *23*, 299–311. http://doi.org/10.1016/j.rser.2013.03.005

Shahi, C. K., & Kant, S. (2009). Cointegrating relationship and the degree of market integration among the North American softwood lumber product markets. *Canadian Journal of Forest Research*, *39*(11), 2129–2137. http://doi.org/10.1139/X09-110

Sikkema, R., Steiner, M., Junginger, M., Hiegl, W., Hansen, M. T., & Faaij, A. (2011). The European wood pellet markets: current status and prospects for 2020. *Biofuels, Bioproducts and Biorefining*, *5*(3), 250–278. http://doi.org/10.1002/bbb.277

Spelter, H., & Toth, D. (2009). North America's wood pellet sector. Retrieved from http://www.fpl.fs.fed.us/documnts/fplrp/fpl_rp656.pdf?origin=publication_detail

Thek, G., & Obernberger, I. (2004). Wood pellet production costs under Austrian and in comparison to Swedish framework conditions. *Biomass and Bioenergy*, *27*(6), 671–693. http://doi.org/10.1016/j.biombioe.2003.07.007

The Renewables Obligation (RO) - Low carbon technologies. (2015, March 30). [GOV.UK]. Retrieved April 22, 2015, from https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/the-renewables-obligation-ro

Timber Mart-South. (2015). *Frank W. Norris Foundation*. Athens, GA.

Timber Standard for Heat and Electricity: Woodfuel used under the Renewable Heat Incentive and Renewables Obligation. (2014, February 10). UK Department of Energy & Climate Change.

Tsay, R. S. (2014). *Multivariate Time Series Analysis With R and Financial Applications*. New Jersey: Wiley.

Uasuf, A., & Becker, G. (2011). Wood pellets production costs and energy consumption under different framework conditions in Northeast Argentina. *Biomass and Bioenergy*, *35*(3), 1357–1366. http://doi.org/10.1016/j.biombioe.2010.12.029

UKtradeinfo. (2015). [Online Database]. Retrieved March 10, 2015, from https://www.uktradeinfo.com/Statistics

U.S. Census Bureau, Common Trade Definitions - Foreign Trade. (2015). Retrieved November 1, 2015, from https://www.census.gov/foreign-trade/reference/definitions/index.html#scheduleb

U.S. Census Bureau, Foreign Trade Division. Port-level Exports. USA Trade [Online Database]. (2015). Retrieved March 9, 2015, from http://usatrade.census.gov/Perspective52

U.S. Census Bureau, Foreign Trade Division. Trade by Commodity. USA Trade [Online Database]. (2015). Retrieved March 9, 2015, from http://usatrade.census.gov/Perspective52

USDA Foreign Agriculture Service. (2014). EU Biofuels Annual 2014. Global Agriculture Information Network.

U.S. Department of Energy. (2011). *U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry*. Oak Ridge, TN: Oak Ridge National Laboratory.

U.S. Energy Information Administration. (2014). U.S. wood pellet exports double in 2013 in response to growing European demand. Retrieved November 3, 2014, from http://www.eia.gov/todayinenergy/detail.cfm?id=16391#

Washburn, C., Balter, K., Aronow, M. E., & Newcomb, T. (2013). *Hancock Timberland Investor: Southern Pulpwood Markets Approaching a Turning Point*. Hancock Timber Resource Group.

World Customs Organization. (2012). HS Nomenclature 2012 Edition. Retrieved November 1, 2015, from http://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs_nomenclature_2012/hs_nomenclature_table_2012.aspx

Yin, R. S., Newman, D. H., & Siry, J. (2002). Testing for Market Integration among Southern Pine Regions. *Journal of Forest Economics*, *8*, 151–166.