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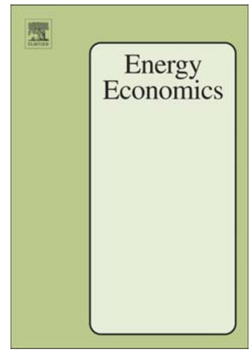

Price trends and volatility scenarios for designing forest sector transformation

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Price trends and volatility scenarios for designing forest sector transformation

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Highlights

- Price trends and volatility scenarios of the forest sector were analyzed.
- The GLOBIOM and mGARCH were the analysis tools.
- Prices trend upward in general.
- Conditional correlation between oil and woody biomass for energy were positive.

ABSTRACT

Potential scenarios for the forest bioeconomy are heavily reliant on price assumptions; in particular, any abrupt changes in prices have a profound impact the relevancy of any sector analysis. The objective of this paper was to demonstrate a new forest sector approach for incorporating price uncertainties in order to improve our assessment of investment decision making alternatives. Methodologically, we linked a multivariate generalized autoregressive conditional heteroscedasticity model (mGARCH (1,1)) with three global land use scenarios that are of strategic importance to the forest bioeconomy. The three scenarios were formulated as i) a business as usual scenario, ii) a high biomass usage scenario and iii) a no-growth scenario. Our results indicate an upward trend in prices over time for all three scenarios and for most woody biomass commodities. Under all scenarios, price volatility in the forest sector would be smaller than that for the fossil fuel energy (i.e. oil and natural gas). Price volatilities from fossil fuel markets are positively influencing woody biomass price volatility and positively influencing pulp

volatility. These results are discussed in the context of a case study describing investment alternatives for a district heating facility with options for: woody biomass, natural gas, or heating oil.

Keywords: Forest sector scenario analysis; GLOBIOM; Price trends; mGARCH model; biomass price volatility; investment decision making.

JEL Classification Codes:

Q23; Q47

1. Introduction

Many countries are developing national energy strategies or policies that are aimed to reduce their dependency on fossil fuels and at the same time, increase renewable energy use. Biomass is an important renewable energy option, since it is transportable, can be stored, and if produced and used on a sustainable basis, will contribute to greenhouse gas (GHG) emissions reduction targets (IPCC 2007). In particular, the forest sector has embraced the potential to play a role in the emerging woody bioenergy and bioproducts market as a means of diversifying markets and production (Hurmekoski and Hetemaki, 2013).

In response to these drivers, the emerging forest sector has undergone structural changes (Bael and Sedjo 2006, Palma et al. 2010, Nilsson 2015). One of the key determinants of change is finding profitability, in what is widely regarded as an underperforming industrial sector, in how forest residues and wood waste are processed and used. Many firms see the expansion of woody biomass energy production as a means to recover value (Lauri et al. 2014).

The economics of forest residue and wood waste biomass is poorly understood in most countries due to the lack of information on: feedstock supply, trade flow, transportation logistics, and the biomass price (Roos et al. 1999). Availability and price of biomass are largely determined by the performance of competing sectors, biomass transportation systems, biomass supply sources, accessibility, and scale and system of production (Graham 2007). Canadian biomass supply chains, for example, rely on the wood fibre made available through processing residues from solid wood

or pulp and paper products or logging residue left at harvest sites which makes these sub sectors important determinants of biomass supply costs and volumes (Yemshanov et al.2014). On the other hand, the price of biomass is highly dependent on other energy markets such as the price of oil and natural gas. For example, logs and energy markets are highly correlated (Hartl and Knoke 2014), or it is shown that energy markets encourage volatility in various biomass feedstock markets (Onour and Sergi, 2011; Wu et al.2011) and that these 'volatility spillovers' or 'price transmissions' have increased since the emergence of the biofuels industry (Serra and Zilberman 2013). Added to this are price uncertainties associated with frequent changes in policy and regulatory environments (Moiseyev et al. 2011, Lauri et al. 2012). This complex set of interrelated system of price movements and global environmental policies challenges economic analysis of the forest sector to forecast price and price changes (Kangas et al. 2011; Solberg et al. 2014).

Perhaps the most challenging elements of economic forecasting, in general, are capturing price movements and its volatility through time and space. Traditionally, price shocks, volatility and the transmission of volatility to other commodities are not commonly considered in forest sector based studies; in contrast the agricultural sector has considered volatility and correlated price movements, e.g. Saghaian 2010; Onour and Sergi 2011, Valin et al. 2014, von Lampe et al. 2014. Of particular interest have been studies assessing the cointegration of oil and ethanol derived from corn or sugar cane (Wu et al. 2011) because evidence of these price movements can be indicative of a strong cointegration of wood based energy carriers that substitute oil in the production of heating and transport fuels. Work by Kristöfel et al. (2014) has shown through univariate generalized autoregressive conditional heteroscedasticity (GARCH) models that price volatility for several woody biomass markets have increased within the last decade which provides greater implications for woody biomass market development.

Investments in district heating systems are of particular interest to furthering the development of woody biomass markets In Europe, utilization of woody biomass for residential and district heating has created a global demand of over 10 million tonnes per annum (Sikkema et al. 2011). In North America, however, woody biomass-based residential heating is an area of interest for reducing GHG emissions associated with the fossil fuels commonly used for residential heating such as heating oil or natural gas (Ghafgahzi et al. 2010). For instance, many northern communities in Canada rely on heating oil or diesel to supply heat and energy. The associated costs are high given the fuel needs to be transported by truck, barge or air, as well supply is often disrupted by uncertain weather conditions (Stephen et al. 2016). Assessing alternative energy sources is an important component for investment decision making in district heating systems (Ghafgahzi et al. 2010).

It can be commonly seen in studies focusing on assessments of forest-based bioenergy and bioproduct technologies investment, that naïve and simplistic approaches have been employed to project prices of considered forest products. For instance, in studies of bioenergy investments, Chau et al. (2009), Rentizelas et al. (2009), and Chong et al. (2011) applied a constant fuel cost or constant annual fuel inflation rate over the life of the energy system.

The inability to capture uncertain abrupt changes in price movements, otherwise known as price volatility, can lead to delays in the investment process (Pindyck 1999) or creates opportunities for defensive investments (Henriques and Sadorsky, 2011), and as a result, lead to sub-optimal decision making of investments. For example, price volatility in fossil fuel markets was a 'megaforce' shaping the sustainability of the European pulp and paper industry (Patari et al. 2015). Limited financial resources in conjunction with price uncertainty have become barriers for changing the strategic focus of a capital-intensive forest industry (Näyhä and Pesonen 2014). Therefore a better understanding of the determinants of price volatility remains a critical area of research since it is a pivotal variable for developing forest sector scenarios.

The purpose of this study is to demonstrate an approach to integrate price volatility into forest sector scenario analysis. In this study, we relied on the use of time series models parameterized with historical commodity prices. An important characteristic of price-time series data is the high, clustered variability; but this negates the use of statistical modelling approaches assuming independent and identically distributed errors. As an alternative we used a multivariate GARCH (mGARCH) model which allows for clustered, correlated price volatilities to move together over time and across markets (Engle and Kroner 1995).

We focus the remainder of this paper on combining price trend scenarios of biomass potentials in world energy consumption and the corresponding price volatility needed for high resolution economic analysis. The organization of the paper follows as; i) the methods used to develop the biomass scenarios and price volatility model; ii) the results and a discussion of the biomass scenario modelling incorporating price volatility. We conclude by demonstrating the usefulness of this approach using a case study of investment ranking in district heating facilities that consider options for energy sources including: natural gas, heating oil, or woody biomass.

2. Methods

2.1 Biomass scenarios

Scenario analysis is a method for dealing with price uncertainties by using combinations of qualitative descriptions of future outcomes and the quantitative modeling of global drivers. Each scenario includes definitions of problem boundaries, current and future conditions, driving processes, and assumptions of critical uncertainties (Swart et al.2005). Scenarios describing the future potential of biomass energy are continually being developed (Nakićenović et al. 1998, Hoogwijk et al. 2005, Kraxner et al. 2013, Lauri et al. 2014) and many of these scenarios are designed to reflect environmental constraints and capacities on the supply of biomass, land use conversion, global environmental and commodities polices and commodity trade. We argue that scenario analysis provides a means to describe potential contributions of biomass energy to global energy consumption in the next century, when scenarios are designed to account for the complex set of interacting factors.

The quantitative elements of scenario development typically rely on structural modelling using partial or general equilibrium methods (Serra and Zilberman 2013). These methods have enabled the development of scenarios to describe, for example, trade impacts of an expanding wood-energy market (Ince et al.2011), green-house gas effects of biomass electricity expansion (Latta et al.2013), and forest sector outlooks (Northway et al.2009; Hurmekoski and Hetemäki 2013). It is our view that these structural models provide valuable insights into the determinants of long-term commodity price movements. However, there is a problem with informational resolution which leaves investors having to rely on coarse representations of short term price processes. Combining the trends of future prices obtained from such structural models with price volatility analysis (the mGARCH model) would provide the resolution required for short term decision making.

In this study, a global land use model called the Global Biosphere Management Model (GLOBIOM, Havlík et al. 2011; Havlík et al. 2014) was used to develop price scenarios for biomass commodities. The GLOBIOM quantifies the competition for land use between agriculture, forestry, and bioenergy, which are the main land-based production sectors. GLOBIOM uses a global recursive dynamic partial equilibrium modelling structure, that covers 30 world regions, 18 agricultural crop types, a range of livestock production activities, forest products, first- and second-generation bioenergy, and water (Sauer et al. 2010). Production in the model is spatially explicit, taking land and weather characteristics into account. The market equilibrium is gained by maximizing the sum of producer and consumer surplus subject to various constraints regarding resources, technology, and policies. Its simulation period can be adjusted to from 2000 to 2100 with 10-year-step intervals. For more technical information and references on GLOBIOM see www.globiom.org.

Three scenarios were developed, including a business as usual scenario, high biomass usage scenario and a no growth scenario. These scenarios outline key drivers that might differentiate the effectiveness of potential business strategies for a transitioning forest industry to the year 2030. The assumptions are a combination of WWF (World Wide Fund for Nature, formerly named World Wildlife Fund) Living Forests Report (Taylor 2011) and an assumption by us on GDP growth per capita. All currencies are expressed in 2010 US dollars and other currencies or other base years were converted using the Organisation for Economic Co-operation and Development (OECD) deflators and exchange rates where necessary (OECD STATS, 2015).

2.1.1 Business as usual scenario

The business as usual scenario is a projection of what the world could look like if consumer behaviour continues on the path of historic trends. It anticipates land-use changes due to demands for land to supply a growing global human population with food, fibre and fuel, and the continuation of historical patterns of poorly planned resource use and continued exploitation of forest resources.

The business as usual scenario has six key assumptions. First, the world population will reach 9.1 billion and per-capita GDP almost triples by 2050. Second, demand for commodities is driven by changes in affluence (measured by GDP) and human population growth. Third, aggregate historical trends in agricultural productivity gains continue. Fourth, the average human diet in a country changes according to historically observed relationships with per-capita GDP. Fifth, forestry and agricultural production does not expand into protected areas, but unprotected natural habitats can be converted to timber plantations, cropland and pasture. Sixth, total primary energy use from land-based feed-stocks doubles between 2010 and 2050 due to projected energy demand and the competitiveness of technologies and supply chains.

2.1.2 High biomass usage scenario

The high biomass usage scenario will require a global shift towards consumers' preference of environmentally conscious energy production. As a result consumption of raw resources will decrease and deforestation is assumed to cease and an increased priority for the use of renewable energy.

The high biomass usage scenario has four key assumptions. First, remaining natural ecosystems are protected (i.e. no further conversion of these ecosystems to cropland, grazing land, plantations or urban settlement) in areas identified as important for biodiversity by any one of six separate conservation mapping processes. This scenario assumes that current land uses (e.g., cropland or forestry) in these areas remain constant and continue to produce food or timber. Second, there is a shift from historical trends in the human diet. The total global consumption of animal calories is maintained at the 2010 global average with convergence in per capita consumption across regions (i.e., those now below the global average consume more in the future, while those now above the global average consume less). This scenario means less future demand for animal calories than the business as usual scenario. Third, bioenergy feedstock demand is consistent with the 100% renewable energy vision calculated by the Ecofys Energy Scenario (Deng et al. 2010). This contrasts with the business as usual scenario in that it assumes a higher carbon price. This makes bioenergy more competitive relative to fossil fuels, although this is tempered by higher bioenergy feedstock prices as more bioenergy is used. Fourth, near zero gross rate of loss of natural and semi-natural forest by 2020 and maintained at that level indefinitely (i.e. a 90% reduction in deforestation and forest degradation).

2.1.3 No growth scenario

The no growth scenario is narrower in focus in that it only uses GDP per capita as the metric for evaluation and it explores the impacts of a slow growth formal economy at both the country level and the global scale. The focus here is more on the austerity measures being considered by many national governments combined with fears by the private capital managers to make new investments which increases their risk profile; the combined effect would lead to stagnant or no growth.

The key assumption in this scenario is directly linked to GDP per capita change. Table 1 illustrates indicative GDP per capita figures for each scenario. Under the no growth scenario, the static GDP per capita we are currently experiencing in western countries will continue and will gradually converge with the rest of the world.

For the purposes of this paper, each scenario is neither assessed for its likelihood nor do we make a formal analysis of how specific future markets and products will evolve during this time frame. We focus purely on the rationale behind each scenario by hypothesizing on how events might unfold to produce potentially different futures. The intention is to demonstrate to decision makers the need for flexible strategies in the face of an uncertain global market. More details on each of these scenarios are in the WWF Living Forests Report (Taylor 2011).

The strength of scenario analysis is in the link between changes in variables in the global economy provided by general discussion in the fuel, food and fibre debate. Please note this linkage between variables is absent in sensitivity analysis. Our methodological approach was to utilize GLOBIOM and the scenarios from the US Annual Energy Outlook (US Energy Information Administration, 2010) to provide the links between the key economic variables.

Table 1 Gross Domestic Product (GDP) per capita for each of the three global land use scenarios.

GDP (1000 $/cap)	Global land-use scenario					
	Business as usual and high biomass usage			No growth		
	2010	2020	2030	2010	2020	2030
World	9.29	11.80	14.44	9.29	9.75	10.25
China	6.44	10.53	14.94	6.44	8.87	10.88
Canada	35.23	42.83	50.44	35.23	35.16	35.40

2.2 Price volatility

2.2.1 Model

We define price volatility as the percent change in price:

$$[1] \quad \varepsilon_t = \frac{P_t}{P_{t-1}} - 1 = \sqrt{H_t} \cdot v_t$$

Where, ε_t represents volatility at time t, P_t represents price, v_t represents a white noise process with $v_t \sim iid(0,1)$; H_t represents the conditional covariance matrix. In order to model H_t we tested the use of mGARCH models. The mGARCH(1,1) model is decomposed into three components; an intercept, a first order ARCH component which uses the lagged percent change in price and a first order GARCH component which uses the lagged conditional covariance (and thus (1,1) by notation).

$$[2] \quad H_t = C'C + A'\varepsilon_{t-1}\,\varepsilon'_{t-1}A + B'H_{t-1}B$$

Where, C is an upper triangular matrix of intercepts, A is a matrix of ARCH parameters, and B is a matrix of GARCH parameters. The parameters are estimated using direct generalizations of the univariate GARCH model of Bollerslev (1986), however, to ensure positivity of the H_t matrix Engle and Kroner (1995) proposed an improved parametrization, the BEKK model (the acronym comes from synthesized work on multivariate models by Baba, Engle, Kraft and Kroner). The parameter matrices of the mGARCH model were fit using a BEKK specification with maximum likelihood techniques within the R package 'mgarch' (Schmidbauer and Tunalioglu 2006). A step-wise process was used to approach a parsimonious model whereby non-significant parameters (α*=0.1) were* fixed at zero and resulting reduced models were compared according to their likelihood and penalized for the number of parameters using information criterion (AIC).

The elements of the H_t matrix are estimated from the linear combination of the long run average of the volatility, the squares and cross products of lagged volatility (ε_{t-1}), as well as, the lagged values of the elements of H_{t-1} or the previous forecasted volatility. In this study, this means that the ARCH term ($A'\varepsilon_{t-1}\,\varepsilon'_{t-1}A$) represents the contribution of the previous quarterly volatility that

would contribute to the price volatility (new news), while the GARCH term ($B'H_{t-1}B$) represents the contribution of the lagged estimate of price volatility (old news). Since this model was fit with multiple commodity prices, volatility and lagged error can influence the prediction of the volatility in other markets.

The assumptions of an mGARCH model structure included serial autocorrelation, stationarity, and heteroscedasticity (Engle and Kroner 1995) and were tested with Box-Ljung tests, unit root test and residual graphs, respectively. Box-Ljung tests were formulated under the null hypothesis of no serial correlation for price volatilities up to 12 lags. The unit root test followed that of an Augmented Dickey-Fuller test, to test the null hypothesis of non-stationarity in the univariate price volatility time series.

2.2.2 Data

In order to parameterize the mGARCH(1,1) model, we used historic price data reported on a quarterly basis from 1995 to 2014 from several different sources; wood pulp, sawn wood, oil and natural gas used price data from the Pink Sheet (World Bank, 2012); heating oil used price data from the US energy agency and woody biomass (chips and residues) used price data from the FAOSTAT forestry price database with reference to the Swedish Energy Agency (FAOSTAT, 2015). Quarterly prices were used because this was the highest temporal resolution of reported historical prices we could source. Where necessary, other currencies or other base years were converted using OECD deflators (base 2010) and exchange rates (OECD STATS, 2015).

3. Results and discussion

3.1. Biomass scenarios

The price levels under the three scenarios are different (table 2). The price of oil, natural gas, heating oil, and biomass for sawnwood under the high biomass usage scenario is the highest, followed by the business as usual scenario, then the no growth scenario. The price of biomass for pulp is the highest under the business as usual scenario and lowest under the high biomass usage scenario in each of respective years, while its price is the highest under the high biomass usage scenario and lowest under the no growth scenario in year 2030. The price level of biomass for energy under the high biomass usage scenario is the highest. Its price levels under the business as usual scenario and no growth scenario are the same in year 2015 and 2020, while in year 2030 the price level under the no growth scenario is a little bit higher. For heating oil, the price level is the lowest in year 2015 under the no growth scenario and highest under the high biomass usage scenario. The direction of these prices is consistent with the scenario descriptions described previously and represent 3 possible futures.

Other studies (Nakićenović et al.1998, Hoogwijk et al. 2005, Kraxner et al. 2013) describing future biomass price scenarios share a common theme; lower fossil fuel dependency, increased growth in GDP and increased environmental constraints. In many of these scenarios, high fossil fuel prices and low bioenergy prices are evident. Although we choose to use scenarios consistent with the US energy agency, the analysis of price trends can be used with any plausible future the researcher is interested in, albeit the scenarios are developed with assumptions that are consistent across the price forecasts.

Table 2 Price trends under three projected scenarios

Products	Business as usual			High biomass usage			No growth		
	2015	2020	2030	2015	2020	2030	2015	2020	2030
Oil (USD/barrel)[a]	$91.84	$108.10	$123.09	$102.27	$134.04	$167.02	$91.17	$106.53	$119.97
Natural gas (USD /mill btu)[a]	$9.71	$10.62	$12.08	$10.12	$10.13	$14.12	$8.91	$8.66	$9.68
Heating oil (USD /gal)[a]	$2.58	$2.97	$3.32	$3.78	$4.77	$5.21	$2.52	$2.88	$3.16
Woody biomass (USD /GJ)[b]	$6.91	$8.15	$7.38	$7.40	$8.08	$8.97	$6.91	$8.15	$7.40
Sawnwood (USD /m^3)[b]	$98.57	$102.88	$105.66	$102.70	$106.57	$112.40	$97.05	$99.74	$99.79
Pulp (USD /odt)[b]	$79.61	$81.79	$77.49	$77.84	$76.00	$78.11	$79.21	$76.71	$73.87

a: US Annual Energy Outlook (US Energy Information Administration, 2010);
b: GLOBIOM

3.1. Price volatility

The historic quarterly price time series data from 1995 to 2014 were divided by their means to remove the effect of scale and are presented in Figure 1. In all commodity markets being studied correlation in price movements were evident within the last decade (2004-2014). Most notably was the strong positive association of crude oil prices with pulp and woody biomass, as discussed by Patari et al. (2015).

The commodity prices experienced highly clustered volatility between 2004 and 2014 (Fig. 2) which was consistent with the work by Kristöfel et al. (2014) and important for the structural assumptions of the mGARCH model (Engle and Kroner 1995). We quantified descriptive statics of price volatilities in order to gain some insight into differences across the commodity markets being studied. The unconditional standard deviation varied among the different commodity volatilities, signifying differences in the amplitude of price volatility (Table 3). Crude oil volatility ranged between -55 to 39 % while the woody biomass volatility was less, ranging between -26 to 19 %(Table 3). In general, energy based commodity prices have historically experienced almost double the volatility as biomass based commodities. Kristöfel et al. (2014) has found similar results with woody biomass volatility being lower relative to the price volatility of agricultural or fossil fuel markets.

The tests for stationarity and serial autocorrelation (Engle and Kroner 1995) are found in Table 3. The Box-Ljung tests were significant for all of the volatility time series with the exception of sawn wood, which provided evidence for autocorrelation. All of the unit root tests (Augmented Dickey-Fuller test) rejected the null, providing evidence of stationarity in the time series. Unconditional correlations of price volatilities show that there was a positive correlation of moderate strength between crude oil, woody biomass and pulp (Table 4). Heating oil was not significantly correlated with any of the price volatility which may be advantageous from a risk management perspective. The result of the preliminary analysis suggested an mGARCH model would be applicable.

Our choice for using an mGARCH model extends the univariate GARCH models developed for woody biomass price volatility by Kristofel et al. (2014). Time series models incorporating in mean autoregressive terms (e.g. vector autoregressive model (VAR), vector error correction models, etc) offer an alternative to the mGARCH model used in this study. Serra et al. (2011) have demonstrated the joint estimation of VEC and mGARCH models and found strong evidence for cointegration of crude oil, ethanol and sugar prices in Brazil from 2001 to 2008. Given the objective of our study was to link forest sector models with a price volatility model, our modelling efforts were focused on forecasting volatility. However, price prediction models (eg. VEC) with GARCH variance

structures would be beneficial to support cointegration analyses between woody biomass and fossil fuel prices which are left for future study.

The results of our single lag mGARCH(1,1) model indicated the saturated multivariate model (AIC = 1455) provided a lower AIC than the diagonal model (AIC = 1462), and thus providing evidence of an mGARCH model with cross market effects providing a better fit. However, following the removal of non-significant parameters using a step-wise process, the AIC of the reduced multivariate model (AIC = 1439) was smallest. Thus, we concluded the reduced multivariate model had the best fit and was used for volatility forecasting. The estimates of the parameter matrices are provided in Tables 5a-c.

The matrices provided in Table 5a-c can be used as input parameters into the R package 'mgarch' (Schmidbauer and Tunalioglu 2006) to provide researchers with a forecasted volatility of what we might expect to see in the future. These predictions capture the conditional correlation of price movements across markets and provide an estimate of price responsiveness from historically observed volatility. An interesting component of the price responsiveness estimates is the transmission of volatility across commodity markets.

Research has highlighted the transmission of price volatility from fossil fuel energy markets into feedstock markets for biofuels (Wu et al. 2011; Serra 2011). These studies have focused on 'spillover' effects from energy markets into non-woody biomass energy feedstocks. In this study we provide evidence of fossil fuel induced volatility into woody biomass markets. The volatility in woody biomass price was influenced by crude oil, natural gas and heating oil. In addition, the volatility in pulp prices was also influenced by fossil fuel energy markets. Volatility spill over price transmissions can be used to test the suitability and feasibly of biomass energy investments and provides decision support for a redesigned forest sector.

Volatility spill overs are the result of liberalization and cointegration of markets and have been shown to be driven by cross market hedging and changes in common information. The informational flow and the time required to process that information varies for each market and subsequently supports different patterns of observed volatility (Ross 1989). Kodres and Pritsker

(2002) explained volatility spill overs using financial market contagion, where investors transmit shocks among markets by adjusting their portfolio's exposure to macroeconomic risks.

Predictions of price volatility under different macroeconomic scenarios are necessary inputs into a portfolio approach for the forest sector. The multivariate aspect of the mGARCH model estimates the conditional correlation between the volatility of the prices in the model. The estimated conditional correlations are of the same strength as those reported in Table 4. However, the correlations in the mGARCH model are conditional on the lagged effects and so vary from period to period (Fig 3.). The integration of forest sector price trends with price volatilities assuming conditional correlations (rather than static correlations) into investment decision making for a district heating system is shown in the case study described in section 3.2.

As one might expect there is a high degree of positive correlation between the volatility of oil and natural gas prices. This expectation is based on their substitutability. If a supply or demand shock results in a short-term increase in the price of oil, the price of natural gas is likely to follow.

An interesting outcome of the mGARCH model analysis was that the conditional correlation between oil and natural gas provided information about the correlation between oil and biomass. Panel B of Fig. 3 illustrates the estimated historical and potential future correlation between volatility in oil and woody biomass energy prices. The result of mGARCH model analysis suggests that the correlations between oil and woody biomass are positive. This suggests that the volatility of oil and woody biomass prices are directional. This is just the kind of result that is useful in the portfolio approach to transitioning the forest sector or through investment opportunities. If a supply or demand shock results in a short-term increase in the price of oil, the price of woody biomass is likely to increase. On the contrary, if a supply or demand shock results in a short-term decrease in the price of oil, the price of woody biomass is likely to decrease.

The volatility figures we have discussed above are derived from historical experience and we assume they are appropriate for predicting the business as usual scenario into the future. Extrapolating price volatility under different scenarios is more difficult. Zhang and Sun (2001) found evidence that trade restriction lead to higher levels of volatility. The utility of a global model like the GLOBIOM to help explore these impacts is critical. Future work should concern perturbing

the GLOBIOM supply and demand curves to better understand in a qualitative way the impact of the different scenarios on price volatility.

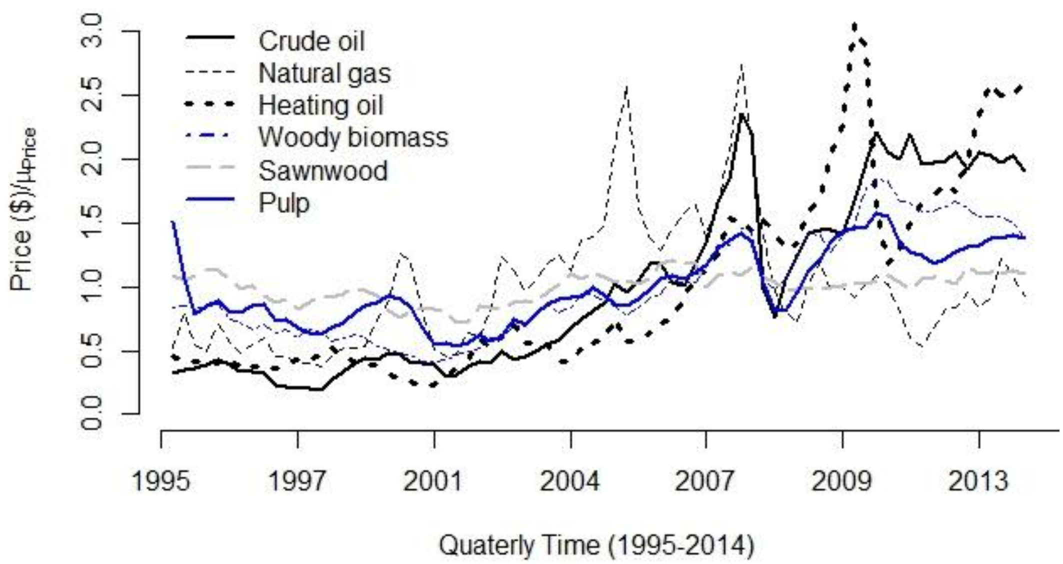

Figure 1 Historical (1995-2014) trends of quarterly prices for forest biomass and energy based markets. Y-axis is the real price (USD in 2010) divided by the mean. Data source: Pink Sheet and FAOSTAT (2015).

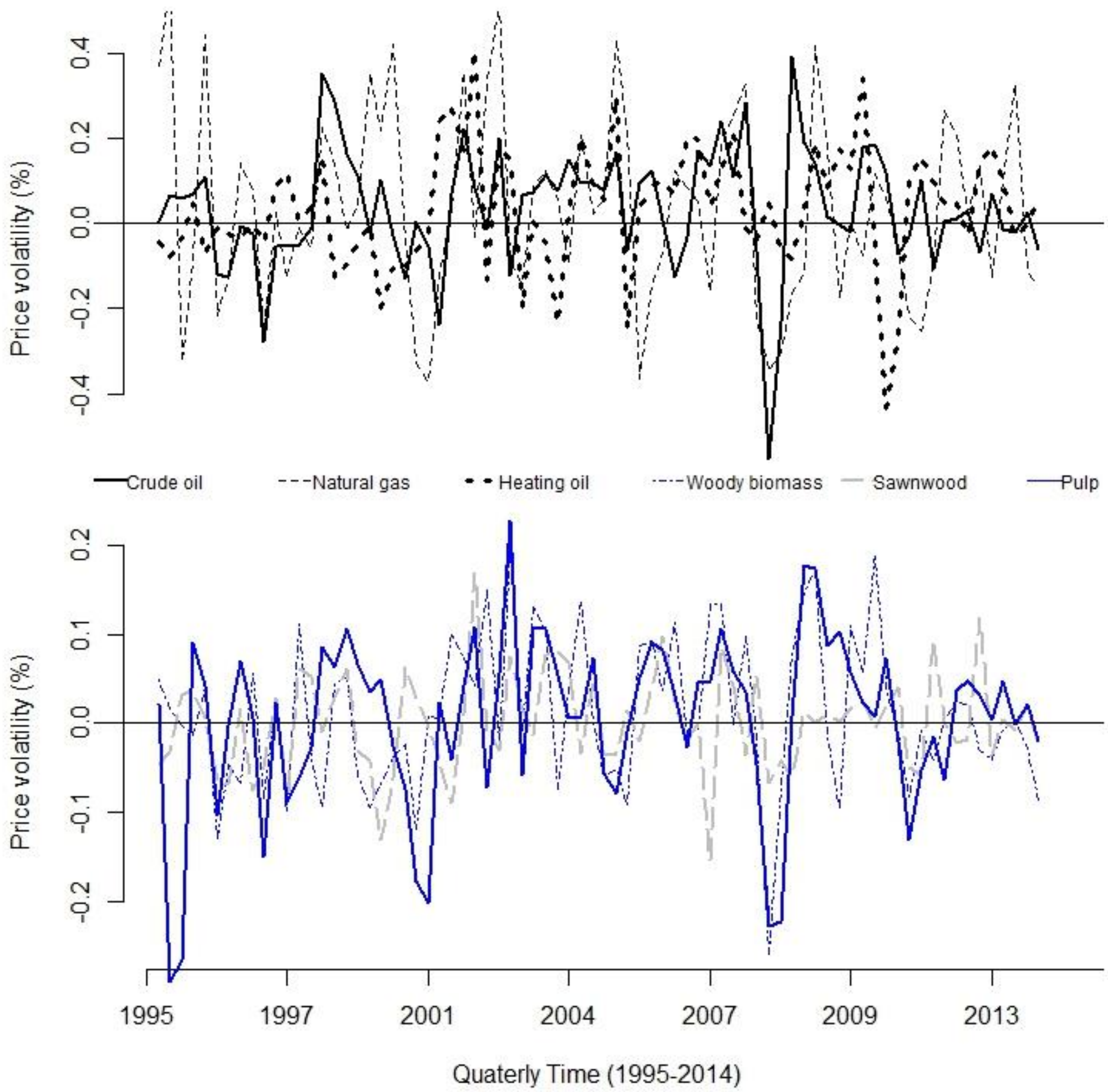

Figure 2 Historical (1995-2014) price volatility for energy based (top graph) and woody biomass (bottom graph) markets. Y-axis is the percent change in price.

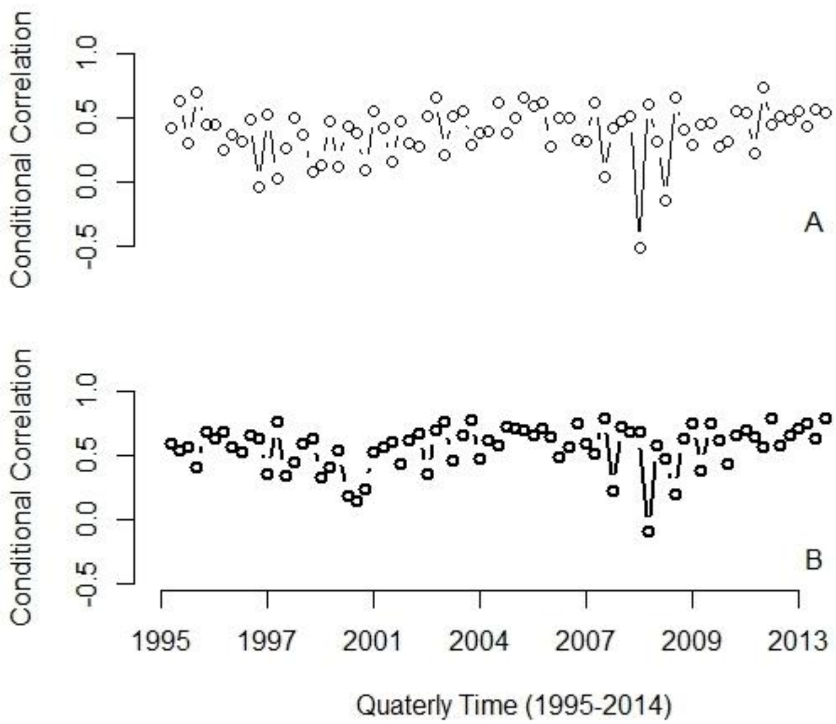

Figure 3 Conditional correlations. Panel A is the correlation between oil and natural gas. Panel B is the correlation between oil and woody biomass

Table 3 Descriptive statistics of long-term (1995-2014) price volatility.

Commodities (real 2010)	Std. dev (σ)	Min	Max	Kurtosis	Box-Ljung (lag = 12) (p-value)	Unit root (lag =1) test (p-value)
Crude oil (USD/barrel)	0.14	-0.55	0.39	2.8	21.28 (0.0461)	-6.49 (<0.01)
Natural gas (USD/mmbtu)	0.22	-0.37	0.55	-0.65	27.05 (0.007)	-7.68 (<0.01)
Heating oil (USD/gallon)	0.14	-0.43	0.41	0.79	22.90 (0.028)	-5.60 (<0.01)
Woody biomass (USD/MWh)	0.08	-0.26	0.19	0.15	20.72 (0.054)	-5.31 (<0.01)
Sawn wood (USD/m3)	0.06	-0.15	0.17	0.49	7.06 (0.854)	-7.15 (<0.01)
Pulp (USD/t)	0.10	-0.29	0.23	1.09	25.22 (0.014)	-6.15 (<0.01)

Table 4 Long term (1995-2014) unconditional correlations of price volatility.

	Natural gas	Heating oil	Woody biomass	Sawn wood	Pulp
Crude oil	0.36***	0.07	0.45***	0.07	0.44***
Natural gas	1	0.01	0.23**	-0.04	0.27**
Heating oil		1	0.11	0.06	0.19
Woody biomass			1	0.19	0.47***
Sawnwood				1	0.30***

Note: *significant when α=0.1; **significant when α=0.05; *** significant when α=0.01

Table 5a. Estimated C matrix for mGARCH(1,1) model

	Oil	Natural gas	Heating oil	Woody biomass	Sawnwood	Pulp
Oil	2.266	0.000	0.000	0.000	0.000	0.000
Natural gas		3.615	0.000	0.000	0.000	0.033
Heating oil			3.192*	0.000	-0.957	-0.004
Woody biomass				0.000	0.957	0.303***
Sawnwood					1.127*	0.000
Pulp						0.404

Table 5b. Estimated A matrix for mGARCH(1,1) model

	Oil	Natural gas	Heating oil	Woody biomass	Sawnwood	Pulp
Oil	0.074	0.195	0.120	-0.044	0.068*	-0.167***
Natural gas	-0.100***	-0.401***	0.163***	-0.019	0.056***	0.228
Heating oil	-0.013	0.000	-0.074	0.026	0.009	0.044
Woody biomass	0.166***	0.307	0.195	0.147**	0.064	0.000
Sawnwood	-0.405	0.877**	0.446	0.000	0.037	-0.574***
Pulp	0.153	-0.349	-0.028	-0.047	0.059	-0.016

Table 5c. Estimated B matrix for mGARCH(1,1) model

	Oil	Natural gas	Heating oil	Woody biomass	Sawnwood	Pulp
Oil	0.464***	0.299	-0.343	-0.152	0.006	0.304***
Natural gas	0.000	-0.324**	0.179*	0.264***	0.028	0.101***
Heating oil	0.296**	-0.230**	-0.463***	0.201***	0.264***	0.000
Woody biomass	0.000	0.000	1.512***	-0.068	0.430***	0.000
Sawnwood	1.248***	-1.126**	0.614	0.391	-0.365**	-0.147
Pulp	0.309	2.406***	-0.173	0.403***	-0.198*	0.281**

Note: two sided significance test was conducted, *significant when α=0.1; **significant when α=0.05; *** significant when α=0.01

3.2. Case study: a district heating system investment

In order to demonstrate how the proposed price volatility analysis could be used in practice, we have used the results to generate 30 scenarios for natural gas, heating oil, and woody biomass price projection. The projected price scenarios were then applied in a techno-economic study carried out by Ghafghazi et al. (2010) to identify least cost energy option for a district heating system in Canada. The case study includes feedstock options considering: i) natural gas, ii) heating oil, and iii) woody biomass residue. Techno-economic assessment studies of least cost energy options for energy systems usually implement naïve approaches to forecast future energy prices during the systems lifetime such as by applying a constant inflation rate over the life of the project (Ghafghazi et al. 2010; Stephen et al. 2016). In this section we demonstrate how the mGARCH model analysis could be used together with scenarios of future biomass energy prices which are forecasted with scenarios consistent between the US Energy Outlook (2010) and the GLOBIOM.

The configuration of the district heating system and capital cost of different technology options are described by (Ghafghazi et al. 2010). The assessment is focused on identifying the least cost energy option for the baseload system of the district energy centre. The 2.5 MW baseload heat generating system considered in the study is sized such that load variation in the system is minimal while a majority of the annual energy demand (60%) is provided. The seasonal load profile of the base-load system was 5400.00 MWh during winter, 4894.25 MWh during spring, 3650.69 MWh during summer and 5520.00 MWh in fall. Ghafghazi et al. (2010) concluded that utilizing natural gas compared to biomass would provide heat at a lower cost over the 25 year service life of the district heating system.

While the general design considerations and assumptions of the district heating system in this case study are the same as those of Ghafghazi et al. (2010), a few of assumptions are different: 1) we considered heating oil as an energy option, 2) we consider wood residue biomass as opposed to wood pellets considered in (Ghafghazi et al. 2010), 3) the service life of the system is 16 years, 4) we don't consider sewer heat recovery and geothermal as energy alternatives, since the focus is on ranking biomass against fossil fuel options. Projected price scenarios through 16 years of the baseload system's service-life were generated by a combination of the volatility model developed in this paper, the GLOBIOM and with the US Energy Outlook (2010). Expected future prices of woody biomass commodities were developed for each scenario using the GLOBIOM. These prices were consistent with scenarios of reference, high oil and low economic growth within the US Energy Outlook study (2010). The mGARCH model analysis provided 30 forecasted volatility scenarios around the expected price trend using the following equation:

[3] $\gamma_t = \mu_t + \mu_{t-1}\,\hat{\varepsilon}_t$

Where, γ is the price of a commodity used in the techno-economic analysis, μ is the price trend from the GLOBIOM and $\hat{\varepsilon}$ is the volatility forecasted from the mGARCH model. The 30 generated fuel costs were then used in the techno-economic assessment to calculate the present cost of the combined Capex and Opex cost of the various energy options. In order to provide a comparison across scenarios the same analysis was carried out using an average fuel inflation of 2% for the energy options.

As it can be seen in Table 6, using price scenarios from the mGARCH model analysis the least cost energy option for the district heating system under the "High biomass usage" scenario would be biomass instead of natural gas which is the least cost option in all inflation based fuel projection scenarios. In comparison to the constant inflation approach this outcome would not be observed. Moreover, using price scenarios from the mGARCH model analysis allows building confidence intervals around projected heat generation cost over the service life of the district heating system.

Table 6: Average and standard deviation (in paranthesis) heat generation cost (2015 USD/MWh) based on fuel costs projections using: a) 30 simulation runs of the price trends, b) constant inflation at 2% annually over 16 years service life of the systems for the 3 biomass usage scenarios. Highlighted option is the least cost. Rankings hold at 95% confidence interval.

	a) mGARCH fuel price scenarios			b) Constant inflation @ 2% annually		
(2015 USD/MWh)	Natural gas	Biomass	Heating oil	Natural gas	Biomass	Heating oil
Business as usual	28.95 (1.69)	29.92 (0.31)	46.68 (1.38)	29.17	30.25	46.17
High biomass usage	29.47 (1.74)	28.48 (0.35)	67.59 (2.15)	30.11	31.28	63.28
No growth	25.38 (1.41)	27.62 (0.33)	45.46 (1.34)	27.35	30.25	45.32

4. Conclusions

In this study we linked a land-use and trade model (GLOBIOM) to a price volatility time series model in order to forecast high temporal resolution price scenarios. The development of these scenarios included the conditional correlation between the commodities which was found to be moderate in strength. In particular, the conditional correlation between oil and wood biomass for energy was found to be positive. Incorporating this type of information into scenario development is especially useful for assessing alternative energy sources and is one of the first attempts made with forest sector models. We demonstrated this novel approach with a case study that highlighted an investment decision analysis that exposes the decision making process to price uncertainty. Future work should consider higher temporal resolution modelling, in mean volatility models, and a cointegration analysis of substitute bioenergy commodities. The supply and demand curves in GLOBIOM should be perturbed to get a better understanding of macro-economic shocks to price changes. We have also shown how taking into account price trends and price volatility will yield different outcome than naïve price projection approaches regarding technology adoption within the woody bio economy. We conclude that future investment decision making must take price trends and price volatility into account.

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