Prospects for Plantations of Improved Poplars in Alberta: Price Behaviour and Competition for Land

by

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Abstract

Poplar forestry plantations have the potential for genomic improvements in growth rates and yields. In order to examine the potential for establishing future plantations of improved poplars in Alberta, this thesis seeks to provide an understanding of the price behaviour of poplar outputs, as well as investigate the ability of these plantations to compete for land. To meet these objectives, this thesis presents two studies. The first study investigates the behaviour of the two improved poplar output prices, ethanol and hardwood pulp. Time series techniques are used to assess the process and volatility that characterize the ethanol and hardwood pulp price series. The findings indicate that both price series are best characterized by mean reverting processes around constant averages. In addition, time-varying conditional variances are identified and modelled in each series using generalized autoregressive conditional heteroskedasticity (GARCH) specifications. These time series results are then used to inform price models in the second thesis study. These price models are used to simulate potential futures for improved poplars, which are then incorporated into a real options, land use change model to assess the future land use of poplar plantations in competition with private agriculture. The real options model in this thesis extends previous approaches by including multiple options. The landowner is able to choose the land use, either plantations or agriculture, and poplar output, either hardwood pulp or ethanol. I find that the inclusion of the additional option of choosing the poplar output increases the competitiveness of plantations. Sensitivity analysis suggests that increased ethanol subsidies improve the ability of plantations to compete with agriculture. Moreover, decreases in the starting agriculture land value also result in increased plantation competitiveness only when the multiple option approach is used. The research in this thesis provides an increased understanding to landowners and policy makers regarding the expected future price levels of

poplar outputs, as well as the conditions favorable to the establishment of improved poplar plantations.

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The examining committee for this thesis consisted of: Martin Luckert, Professor, Department of Resource Economics and Environmental Sociology; Fen Qiu, Assistant Professor, Department of Resource Economics and Environmental Sociology; Grant Hauer, Adjunct Professor, Department of Resource Economics and Environmental Sociology; Jim Unterschultz, Associate Professor, Department of Resource Economics and Environmental Sociology. The non-examining chair was James Rude, Associate Professor, Department of Resource Economics and Environmental Sociology.

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Chapter 1: Introduction

Poplar is a species of tree that has been identified as a candidate for potential genomic improvements. These improvements may include increased growth rates, resulting shorter harvest rotations, and improved cell wall chemistry, which may lead to larger volumes and improved quality of harvested material. Given their candidacy for genomic improvements, these poplars are being considered as a possible species for industrial forest plantations. In addition, these improved poplar plantations are receiving attention because poplars may be a biomass feedstock for the production of cellulosic ethanol. This type of ethanol, also referred to as second generation ethanol, is of increasing interest because it can be produced from non-food sources; unlike first generation ethanol that is typically produced from starch related crops such as corn or wheat. The development of cellulosic ethanol comes as alternatives to fossil fuels are sought after and food prices rise, thereby making first generation ethanol less attractive. Cellulosic ethanol, however, is not the only output product for which improved poplars can be grown. Hardwood pulp represents an alternative poplar output for which infrastructure and markets already exist in Alberta. As such, the potential development of poplar plantations in Alberta may depend on the economic performance of two outputs, cellulosic ethanol and hardwood pulp.

Another driving factor in any future establishment of these plantations will be the ability of improved poplars to compete with alternative land uses. While the majority of Canada's forests are publicly owned, regulations in most jurisdictions prevent improved poplars from being grown on public land. As a result, the land for which these plantations are likely to compete is privately owned and allocated to agriculture uses. If poplar plantations are seen by private landowners as being more financially attractive than traditional agriculture, then it is expected that they would switch land uses to grow improved poplars. The financial viability of poplar plantations in competition with agriculture, however, is not solely dependent on the two poplar outputs, as the value of land already in agriculture production will play a significant role.

Given all the factors that influence the viability of improved poplars grown on private land (e.g. genomic improvements, output markets, and alternative land uses), the future of plantation forestry in Alberta remains uncertain. In the face of this uncertainty, the goal of this thesis is to better understand the economic drivers and policies that will influence the potential land use competitiveness of poplar plantations in Alberta.

To achieve this goal, this thesis presents two studies. The first study, titled "Examining hardwood pulp and ethanol prices as outputs for improved poplar plantations", examines the behaviour of hardwood pulp and ethanol prices through a time series analysis. The time series characteristics examined are the underlying process driving prices, that is, random walks or mean reversion, and the behaviour of the price volatility using a generalized autoregressive conditional heteroskedasticity (GARCH) approach. Investigating the time series characteristics of poplar output prices will improve our understanding of the market forces that drive producer behaviour. Given that these poplar plantations have yet to become widely established, information regarding the future behaviour of output markets is valuable in predicting future land use patterns and policy decisions. The second study, titled "Potential for improved poplars plantations in competition with private agriculture land in Alberta: A multiple option value approach", presents a real options, land use change model that aims to investigate land use competition between agriculture and poplar plantations in Alberta. This study builds on previous approaches to examine the land use decision faced by landowners but considers multiple options. The options considered are the decision to convert agriculture land to poplar plantations and the decision to sell the improved poplar harvest for either ethanol or hardwood pulp. This study uses the time series characteristic outlined in the first study to inform the price simulation models required to generate the future prices facing landowners. Furthermore, sensitivity analysis is conducted on the land use change model in order to assess the impact of ethanol subsidization policy and agriculture land value changes on the competition between agriculture and poplar plantations.

This thesis concludes with a brief summary of each chapter, discussion of the implications of the results, and suggestions for possible future research.

Chapter 2: Examining hardwood pulp and ethanol prices as outputs for improved poplar plantations

2.1 Introduction

Genetically improved poplar plantations are increasingly being considered as a potential contributor to the supply base for industrial forestry in Canada (e.g. Anderson and Luckert 2007). The prospective development of poplar plantations in Canada could depend on two potential outputs that harvesting improved poplars can yield. The first, and more developed, of the two outputs is hardwood pulp. The second output, which may require a number of years before it is a widely available, cost effective option, is the production of cellulosic ethanol. An examination of the two potential output prices provides a better understanding of the economic opportunities and challenges facing improved poplar producers and policy makers.

Investigations of processes driving prices in economies are an integral part of general understandings about the way the markets function, which have been debated for some time (Mankiw 2009; Krugman 2009). The general question involves whether markets are cyclical (i.e. follow patterns with mean reversion) or progress in fits and starts due to shocks (i.e. follow patterns with random walks). Cyclical economies are more predictable, in that periods of slow growth are followed by periods of accelerated growth. In contrast, economies that evolve in fits and starts are harder to predict, as they may be driven by unforeseen shocks.

Understanding how economies change is important to policy makers. Projections of economic growth, its accompanying employment and budget implications are central concerns of governments at all levels. Such an understanding is also important with respect to specific industrial sectors. The importance of understanding pulp and ethanol prices is particularly acute for policy makers in Canada. With respect to forests in Canada, policy makers have a large stake in their commercial development, as 93% of forest land is under public ownership (Canadian Forest Service 2005). Although the establishment of improved poplar plantations is largely excluded from public forest lands, the plantations that are established on private agricultural lands are processed in pulp mills that have largely been built and supported by public timber supplies (Luckert et al. 2011). Moreover, as biofuel technology develops, policy makers have played an active role in providing policies to encourage growth in ethanol production (Laan et al. 2011).

In investigating time series, studies have frequently focused on two important aspects. First is the question regarding what stochastic process best characterizes historic data. Two common stochastic processes used to model the mean equation of prices are random walks and mean reversion (Thomson 1992; Schwartz 1997). Examining the stochastic process that drives a time series is informed by testing for stationarity in the data. Stationary series have a fixed mean and variance (Stigler 2011) and, therefore, are characterized by a mean reverting process. A mean reverting process, however, may not always be found to be stationary. Alternatively, a random walk process implies the series contains a unit root. A stationary process mean reverts because stationarity implies future changes of a variable will be related to past changes and therefore, the expected value of that variable will be the mean. The alternative of stationarity is a unit root process. A unit root characterizes random walks because past values of a variable do not inform future values other than to act as a starting point. Empirically, random walks are frequently modelled using geometric Brownian motion (GBM). The second aspect is how to model the volatility based on historic time series. The volatility of a series is useful in understanding unexpected price movements (Stigler 2011), as well as risk and uncertainty surrounding the price. In this respect, I am interested in characterizing the volatility of time series as constant or time-dependent by testing and modelling for autoregressive conditional heteroskedasticity (ARCH) (Engle 1982) and generalized autoregressive conditional heteroskedasticity (GARCH) (Bollerslev 1986).

As prices of hardwood pulp and ethanol have not received much attention in the literature this study has two objectives: 1) Assess whether hardwood pulp and ethanol price series are best characterized by a random walk or mean reverting process and 2) Understand the volatility of the price series by evaluating each using constant volatility and a time-dependent, GARCH approaches. Both the process of the mean equation and the behaviour of the volatility equation are important for producers and policy makers to understand in order to balance risk and expected returns. The analysis conducted in this paper will contribute to a better understanding of how these prices behave empirically and, as a result, how the improved poplar output market may evolve.

The next section of this paper explores some of the existing literature surrounding price process and volatility analysis, as well as how those time series aspects have been applied to forestry and ethanol prices. The time series methods and the data are then discussed. The results section presents the results of the stationary and unit root tests. Next, the mean equation models are estimated. The series are then tested for ARCH effects and GARCH specifications, with autoregressive moving average (ARMA) terms, of both price series are considered. The models are compared using fitted values and computed statistics. The last section of this paper discusses the implications of the process and volatility findings and presents conclusions.

2.2 Literature Review

2.2.1 Price Process

The adoption of either a random walk or mean reversion to model price series is initially informed by the economic theory and assumptions that characterize each process. Reed and Haight (1996) explain that modelling prices as a random walk, like GBM, is supported by the theory of informationally efficient markets. GBM characterizes an informationally efficient market because past prices are not modelled to have an effect on future price changes. Furthermore, one theoretical distinction between the two processes is that GBM models shocks to have permanent effects on the price (Andersson 2007). Mean reversion, on the other hand, does not account for the permanent influences of technological progress or government intervention because the modelled expectation is that the price will return to its long run average (Khajuria et al. 2011). The drawback of GBM, as noted by Insley and Rollins (2005) is that GBM assumes the expected price and conditional variance may increase continuously over time with no limit, an assumption which is seen as unrealistic when forecasting far into the future. As such, random walks, like GBM, may not be useful when modelling commodity prices. Theoretically, commodity prices are expected to exhibit mean reverting behavior, particularly in competitive markets (Schwartz 1997). Commodity prices in equilibrium are thought to mean revert because when prices are high, supply would be expected to increase as firms enter the market thereby driving prices down, and conversely, when prices are low, firms may exit the market driving supply down and prices up (Schwartz 1997). General price theory, however, cannot be the only consideration given when examining price processes, as there are also implications specific to forest management.

Within the forestry literature, the effects of assuming particular price processes have been previously examined. The optimal economic rotation (OER), or harvest timing decision, is a result of the net present value of the trees harvested calculated with the expected price of harvest. Thomson (1992) found that a price that follows GBM, as compared to a fixed price, had the effect of lengthening the harvest rotation. Plantinga (1998) concluded that the stochastic process chosen to model prices could cause the optimal harvesting decision to vary. With GBM, the harvest decisions occurs when the current price level is above the point where the harvest is economical, and therefore above that level, the harvest decision is unaffected by the price (Plantinga 1998). A mean reverting price, however, indicates, relative to its mean, an expectation of what the next period price will be. This expectation may lengthen the rotation time because if faced with a lower than average price, the producer will delay harvest expecting that the price will increase towards its mean level.

The discretion of the producers to choose to delay harvesting when faced with sub-optimal conditions has given rise to the use of real options analysis in forestry. Mezey and Conrad (2010) explain that real options analysis is typically used as a way to assign value to flexibility in decision making. More specifically, there is a value associated with being able to delay the harvest of trees by one period when faced with a low price or defer from planting a stand in favour of an alternative land use given an unfavourable net present value. Therefore, real options analysis in forestry is also influenced by the process driving prices.

The effect that different price processes have on real options analysis has been previously examined in the forest investment literature. Under a random walk, there is a positive option value associated with deferring the harvest only until the price at which it becomes economical (Plantinga 1998). Laughton and Jacoby (1993), and Gjolberg and Guttormsen (2002) explain the impacts that modeling prices as mean reverting can have on option analysis. The first is that mean reversion, compared to a random walk, will cause the asset value to increase over time due to the decrease in uncertainty and risk in the assets price. The second effect is that mean reversion will decrease the option value in the long run due to the decreased uncertainty in prices. Furthermore, Plantinga (1998) states the under mean reversion, waiting one period will result in new information regarding the price and direction of change with respect to the long run average. That information will allow producers to make decisions to harvest if the price is high or delay if the price is low, which results in an overall positive option value. The study finds the positive option values resulting from mean reverting prices can lead to longer rotations and higher timber values. These theoretical assumptions associated with both random walks and mean reversion in prices have aided researchers in modelling prices for empirical examinations of forestry investments.

Studies in forestry have made various assumptions regarding price process. Early forestry investment studies assumed that prices follow a random walk process, like GBM, based on its characterization of informationally efficient markets (Thomson 1992 and Reed 1993). But, following the increase in theoretical support for mean reversion in commodity prices, many forest investment studies have taken to empirically examining prices for stationarity, thereby providing empirical support for the adoption of a particular price process. For example, Alavalapati et al. (1997) and Saphores et al. (2000) failed to reject a unit root, respectively, in their studies of Canadian wood pulp prices and U.S. quarterly stumpage prices. Conversely, Khajuria et al. (2011), Insley and Rollins (2005), and Insley and Lei (2007) all find stationary results using statistical testing and fit mean reverting processes for forest prices. Plantinga (1998) models real sawlog and stumpage prices using a mean reverting process based on the results of autocorrelation functions.

Further complicating the issue of understanding which process may be driving a series, Insley (2002) found that real Canadian softwood lumber prices failed to reject stationarity at the 5% significance level but rejected at the 1% level. Haight and Holmes (1991) find, statistically, that quarterly and monthly opening month sawtimber prices were stationary whereas quarterly average prices were found to be nonstationary. Niquidet and Sun (2012) explain that data frequency and aggregation technique can affect whether a series is found to be stationary or not. The authors empirically examine timber prices and a real aggregate Canadian hardwood and softwood pulp series. After conducting multiple stationary tests and examining autocorrelation plots, Niquidet and Sun (2012) suggest that the prices series may be fractionally integrated, implying that the series may have both mean reverting and random walk characteristics. Furthermore, through an extensive review of stationary findings in the forest price literature, Niquidet and Sun (2012) demonstrate there is no conclusion as to whether random walks or mean reversion is the dominantly found process.

Although ethanol has not been given consideration within the forest price literature, there are studies that have empirically characterized the process driving ethanol prices. Serra et al. (2011) examine Brazilian ethanol prices and reject the stationary hypothesis in favour of a unit root. Schmit et al. (2009) examine gross ethanol margins in support of an options analysis and find that for certain specifications stationarity can be rejected whereas for other specifications stationarity is not rejected. Schmit et al. (2009) state that because oil prices are typically modelled as random walks and given ethanol's known link to oil prices, they assume ethanol follows a random walk. Finally, Bastian-Pinto et al. (2009) find that for monthly Brazilian ethanol prices a unit root is rejected at the 10% significance level and, as a result, prices are modelled as mean reversion in their option analysis.

For both forest product and ethanol prices there have been studies that found stationary, mean reverting results and studies that found nonstationary, random walk results. Given the inconclusive results found in previous studies that examine similar prices, it is important to the understanding of the economic potential of poplar plantations that the processes driving hardwood pulp and ethanol prices be examined.

2.2.2 Price Volatility

While much of the time series discussion of forest prices has centered on process, there is an increasing interest in investigating forest price volatility. Price volatility, or conditional variance, is often used to try to understand the potential risk of an asset. Constant volatility within a mean reverting process implies that price changes are expected to be of similar size around an average and indicates relatively low risk (Gjolberg and Guttormsen 2002). There are, however, a number of internal and external influences that may cause a commodity price to change, and it may not be realistic to assume all shocks would have the same impact on a price series. Therefore, price volatility may not be constant and short-run changes in price may be small in one period and relatively large in another. Price volatility that changes over time may indicate a riskier asset as there is more uncertainty surrounding price movements.

Engle (1982) recognized that constant volatility may be an unrealistic assumption and developed the ARCH specification to allow for the variance of variables to be modelled as conditional on past error terms. Subsequently, Bollerslev (1986) developed the GARCH specification to allow variance to be conditional on previous conditional variances in addition to past error terms. The understanding of conditional variance, or volatility, may impact the producer's expectation of risk and affect the production decision, particularly when considering the long-time horizons in poplar plantation production.

The forest price literature has examined the potential implications that price volatility can have on decision making. Thomson (1992) described how the volatility of stumpage prices could affect the value of managerial decisions and the NPV of the stand. As volatility increased so did the possibility of receiving either a higher or lower price which made managerial flexibility, concerning when to harvest or whether to switch land uses, more valuable. This flexibility allows for managers to mitigate their losses when prices are low and increase their stand value when prices are higher, thereby increasing the NPV of the stand. The effect of price volatility on options analysis has also been examined. An increase in price volatility will lead to an increase in the option value associated with harvesting the stand (Insley 2002). The increased option value is a result of the increased potential of being able to delay the harvest results to realize a price higher above the average level (Insley 2002).

The potential for non-constant volatility in forest prices has received some empirical consideration. Mei et al. (2010) found that stumpage price volatilities in the southern US were not constant and varied with the price level over time. As a result, the authors fit bivariate GARCH models to prices in two southern regions and conclude those models effectively accounted for market risks. Mei et al. (2010) hypothesized that the changing volatilities could be a result of fluctuating timber supply and demand, uncertainty in government policy direction and the general condition of the economy. Insley and Rollins (2005) test for and confirm the presence of ARCH effects in Canadian timber price data; however, the authors note that any additional volatility analysis is outside of the article's scope. Saphores et al. (2002) found the presence of ARCH effects in two of their four Pacific Northwest quarterly stumpage rates. Saphores et al. (2002) note that while the ARCH family of models have been commonly used in financial economics for stock prices, the same models have been underutilized in their application to resource prices.

While I was unable to locate any studies that have investigated ethanol price volatility, there are studies that examine volatility transmission between ethanol prices and either crude oil or agriculture prices. Serra et al. (2011) examine Brazilian ethanol, crude oil and feedstocks for price volatility transmission. The authors find, using a multivariate GARCH approach, that ethanol price volatility is influenced by its past volatility in addition to the volatilities of oil and sugar prices. Hertel and Beckman (2012) find that increased biofuel production lead to increases in volatility transmission from energy prices to agriculture prices. Trujillo-Barrera et al. (2012) discover volatility spillovers from oil markets to both ethanol and corn markets, as well as spillovers from corn to ethanol markets. Du et al. (2009) use a stochastic volatility Merton jumps model to understand ethanol stock prices. Their estimation indicates that there is a mean reverting process present in the ethanol stock price volatility.

While volatility in forest prices has received less attention than the process driving prices, it deserves consideration given the impacts that non-constant volatilities can have on production and investment decisions. More recently, there have been a few studies that have examined price series for and confirmed the presence ARCH effects. These studies indicate price volatilities may not always be constant and ARCH or GARCH specifications should be considered. Within the ethanol literature much of the work done has examined price volatility transmission between ethanol and other prices. As there have been few studies to empirically examine hardwood pulp and ethanol price volatility, this study is important to understanding the outputs of improved poplars.

2.3 Methods

Stationary tests are conducted for hardwood pulp and ethanol that will inform the choice of whether the data is better characterized by a geometric Brownian motion or mean reversion process. Next, volatility is examined with ARCH LM tests to assess whether GARCH models are appropriate.

2.3.1 Process

The specification for the random walk process of geometric Brownian motion, in continuous time is given by (Brennan and Schwartz 1985):

$$\frac{ds}{s} = \mu\, dt + \sigma\, dz_t \tag{2.1}$$

where S is the price and μ is the drift rate. Furthermore, dz_t is a Wiener process with a standard deviation σ. A Wiener process is stochastic, continuous, and has a normal distribution with mean of zero and variance of σ^2. Meade (2010) provides the discrete time specification for GBM that can be used to empirically model a random walk:

$$Z_t = \mu + \varepsilon_t \qquad\qquad Z_t = ln(S_t/S_{t-1}) \tag{2.2}$$

The dependent variable, Z_t, is a logged price return and $\varepsilon_t \sim N(0,\sigma^2)$ represents the error term with a constant variance σ^2. This equation demonstrates that the price in the current period, S_t, will change from the past period price, S_{t-1}, due to the drift rate and error disturbances.

A mean reverting process is modelled so that the price in the current period is directly influenced by past prices and is, thereby, tied to a long run equilibrium price. In continuous time, mean reversion can be modelled as (Schwartz 1997):

$$\frac{ds}{s} = \kappa(\eta - ln(s))\, dt + \sigma\, dz_t \tag{2.3}$$

Where η specifies the long run mean price and κ gives the rate of mean reversion. In discrete time, mean reversion can be specified as (Meade 2010):

$$Z_t = \kappa(\eta - \ln(S_{t-1})) + \varepsilon_t \qquad\qquad Z_t = ln(S_t/S_{t-1}) \tag{2.4}$$

Again, ε_t is assumed to have a zero mean and to be homoscedastic, or have a constant conditional variance. From Equation 2.4, the past period logged price is shown to directly impact the price return, Z_t, which acts as the dependent variable. While the interest of this is paper is understanding the price behaviour of hardwood pulp and ethanol, it is common in the literature (Insley and Rollins 2005; Khajuria et al. 2012) to model the process driving prices using a price returns dependent variable. The price return variable reveals how price adjustments between two periods are affected by either a random walk or mean reverting process. The above GBM and mean reverting specifications both assume a constant conditional variance, or volatility. It may be the case, however, that the price series' exhibit non-constant volatility affects not captured by those models.

2.3.2 Volatility

Engle (1982) introduced the autoregressive conditional heteroskedasticity model to account for non-constant volatilities. The ARCH equation allows the error term from a previous period to impact the current volatility. Bollerslev (1986) estimated the GARCH model, a generalized version of ARCH, so that the volatility equation included a term for past volatilities.

Bollerslev (1986) defined a GARCH (*p, q*) specification as:

$$\varepsilon_t | \psi_{t-1} \sim N(0, h_t)$$

where

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \, \varepsilon^2{}_{t-i} + \sum_{i=1}^{p} \beta_i \, h_{t-i} \tag{2.5}$$

This specification allows the error term of an equation to have a mean of zero and a conditional variance, or volatility of h_t. The volatility equation is conditional on the previous error terms given by $\varepsilon^2{}_{t-i}$ and previous volatility terms, h_{t-i}. The number of GARCH and ARCH lags included in the equation are given by p and q, respectively. The ARCH constant is α_0 and α_i are the ARCH coefficients whereas β_i are the GARCH coefficients on past volatility. Bollerslev (1986) describes ε_t as a real-valued discrete-time stochastic process and ψ_t the information set (σ-field) of all information through time t. If $p=0$ then the formula is an ARCH (q) process and if $p=q=0$, then ε_t becomes white noise.

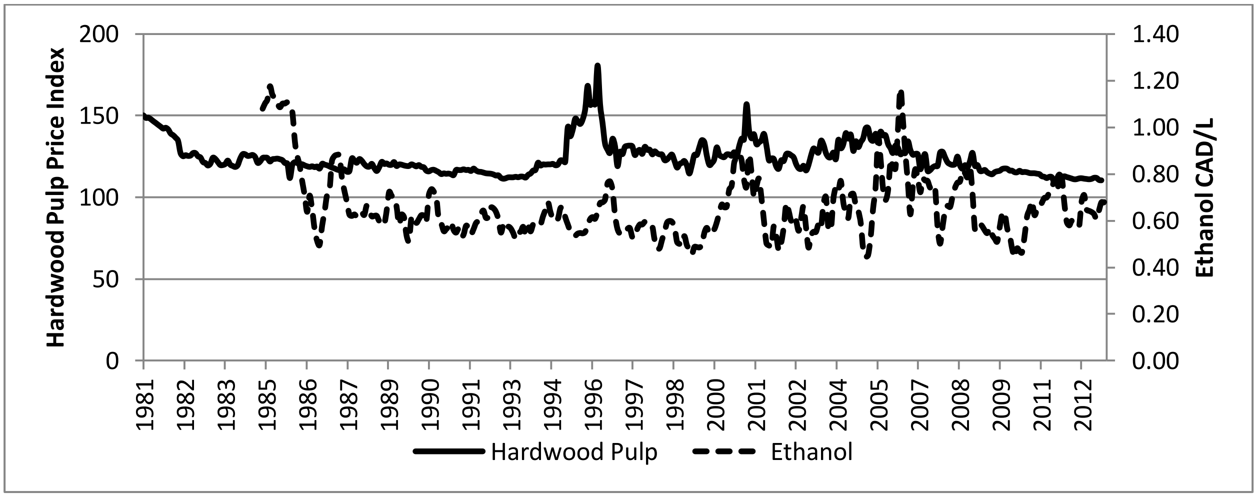
Weiss (1984) presented a model that would incorporate the ARCH error while structuring the mean equation with autoregressive and moving average (ARMA) terms. The ARMA equation is structured as:

$$Z_t = \gamma_0 + \sum_{i=1} \delta_i Z_{t-i} + \sum_{i=1} \theta_i \varepsilon_{t-i} + \varepsilon_t \tag{2.6}$$

δ_i is the coefficient on the autoregressive or mean reverting terms and θ_i is the coefficient on the moving average term. Furthermore, ε_t is the error term that can be modelled using the GARCH specification for ε_t (Equation 2.5). The ARMA equation (2.6) is an expansion of Equation (2.4) that allows the mean to depend on previous returns. Li et al. (2002) conduct a survey of studies utilizing GARCH models and find that using an ARMA structure for the mean equation is common. Likewise in this study, I employ equation (2.6). The resulting ARMA GARCH specification incorporates a mean reverting process and a time-dependent volatility, thereby allowing for the process suggested by the stationary tests and constant volatility approach to be preserved while examining the volatility structure. In the following results we find this specification to better fit the data than the model specification in equation (2.4).

2.4 Data

The prices under consideration in this study are the two potential output prices resulting from improved poplar plantations; hardwood pulp and ethanol. Hardwood pulp prices are represented by the hardwood pulp price index from Statistics Canada's Canadian Socio-economic Information Management System (CANSIM) database. The price index is made up of 387 monthly observations taken from January 1981 to March 2013. For ethanol, there is no Canadian price available. But, I assume that Canada is a price taker in the U.S. ethanol market (which accountants for 56% of global production [Renewable Fuels Association]) and employ a price series for ethanol from the United States. The ethanol series is 341 observations, reported by the United States Department of Agriculture, monthly from January 1985 to May 2013. The price is reported in USD per gallon and subsequently converted to CAD per litre using a monthly US / Canada exchange rate, reported by CANSIM database. The examination of both price series is conducted using real values so that any general trend in the data is not attributable to inflation. The price series are deflated using the monthly consumer's price index (CPI) reported by CANSIM and the real series are reported in 2012 dollars. The two real price series are shown in Figure 2-1 below. A preliminary visual inspection of the data indicates that the price series appear to exhibit mean reversion over time.



Sources: Hardwood pulp: CANSIM series v53434806

Ethanol: USDA Economic Research Service U.S. Bioenergy statistics' website

Figure 2-1: Real price series for hardwood pulp and ethanol

2.5 Results

2.5.1 Process

The first step is to analyze the stationarity of the data, which will aid in understanding which process, mean reversion or GBM, is driving the prices. A stationary process is said to be mean reverting because future changes of a variable are influenced by past levels causing reversion towards an expected mean. An alternative to stationarity is a unit root process. GBM is characterized by a unit root because past values of a variable do not influence future values, which are largely driven by error disturbances.

I take the logged values of each price series and employ the Augmented Dickey Fuller (ADF) test, using the null hypothesis of a unit root, on price level and return. The rejection of the null hypothesis would suggest that a series is stationary thereby implying mean reversion. The results of the ADF tests (Table 2-1) show that for both hardwood pulp and ethanol, logged prices and returns, the null hypothesis is rejected at the 1% significance level. Rejection of a unit root in both prices and returns provides evidence that hardwood pulp and ethanol prices are not driven by a random walk, thereby suggesting that mean reversion may be driving prices and returns for both hardwood pulp and ethanol.

Though the ADF tests rejected the unit root hypothesis, the results do not confirm the presence of stationarity. To test for the presence of stationarity, the KPSS test (Kwiatkowski et al. 1992) is employed. The KPSS test results are reported for one lagged period. The results for logged price (Table 2-1) reject the null hypothesis and fail to find either series as stationary. Results for the price returns, however, do not reject the stationary hypothesis. Hardwood pulp and ethanol price returns therefore appear to be stationary.

In summary, while the KPSS tests on the logged price levels of hardwood pulp and ethanol rejected the stationary hypothesis, the remainder of the evidence supports mean reversion. Test results show that both logged prices and logged returns of hardwood pulp and ethanol do not have unit roots, discouraging the use of random walks. Moreover, logged returns of hardwood pulp and ethanol are found to be stationary supporting mean reversion. Price returns, the dependent variable (Equation 2.4), are mean reverting and the overall conclusion is that the hardwood pulp and ethanol series are likely to be driven by a mean reverting process. Therefore, I estimate the constant volatility and GARCH models, in the volatility section below, based on the assumption of mean reversion.

Table 2-1: ADF and KPSS test results

	Hardwood Pulp Test Statistic		Ethanol Test Statistic	
Stationary Test	Logged Price	Logged Returns	Logged Price	Logged Returns
ADF (5% CV = -2.876)	-4.086***	-22.865***	-4.363***	-14.220***
KPSS (5% CV = .463)	1.19***	.0488	.996***	.0526

***** indicates significance at the 1% level**

2.5.2 Volatility

In the results that follow, mean reverting models with constant volatilities (i.e. no GARCH volatility equation) are estimated, using an ordinary least squares approach, for both hardwood pulp and ethanol. In order to select the number of lags for each model, Akaike Information Criterion (AIC) values are compared. I then test the logged prices for ARCH effects using Engle's LM test (Table 2-2). Subsequently, GARCH models are estimated for both price series. The GARCH models are estimated to have autoregressive moving average terms in order to preserve the mean reverting process. The results are compared to that of the constant volatility models using AIC values and autocorrelation tests. I also visually examine the conditional variance plots for the GARCH models.

2.5.2.1 Hardwood Pulp

The estimation results of the mean reverting model with constant volatility for hardwood pulp are given in Table 2-3. Both the constant and lagged price coefficient are found to be significant. Fitted values (Figure 2-2), resulting from this regression, appear to capture the mean reverting nature of price returns; however, they fail to characterize the variability of returns, around the mean, over time. While the actual price returns do appear to mean revert, the spread of returns around the apparent mean does not look to be constant, which is the effect modelled by the fitted values in Figure 2-2. I searched through literature trying to find market events or government policies that that would account for the jumps in volatility and price returns starting in 1994, but was unable to find an explanation. The results of Engle's LM test for ARCH effects (Table 2-2) indicate that there are ARCH effects present. To capture the ARCH effects, a GARCH model with ARMA terms is estimated (Table 2-3). The specific model estimated for hardwood pulp returns, as suggested by AIC values, is with 1 and 12 period ARCH lags, a 1 period GARCH lag, autoregressive lags of 1, 9 and 12, and moving average lags of 1 and 12. The coefficients are all found to be highly significant. The AIC values for the GARCH and constant volatility mean reverting models are compared, with smaller values typically indicating a better fit for the data. The AIC of - 1857 for the GARCH model is smaller than the -1639 for the constant volatility model and, therefore, suggests the GARCH specification provides a better fit. Furthermore, the GARCH fitted values (Figure 2-3) appear to better capture the changing spread of price returns around the mean. The AIC and fitted value examinations both support the finding hardwood pulp returns should be characterized by a non-constant volatility approach.

Examining the magnitude of the ARCH and GARCH coefficients allows for inferences to be made regarding the origins of the volatility in the prices. The coefficients on the ARCH lags of 1 and 12 are both larger in size than the GARCH coefficient which indicates that the lagged errors have a larger impact on the volatility of the price returns as compared to the previous periods volatility. This result suggests that the volatility of hardwood pulp price returns are influenced more by outside and unexpected shocks than previous volatility levels. As result, the volatility of hardwood pulp returns maybe more susceptible to shocks in other regions or resource markets. Furthermore, the volatility of price returns may be more erratic and relatively less persistent, meaning volatility shocks may not last long. The conditional variance plot in Figure 2-4 illustrates how the ARCH terms, as compared to the GARCH term, influence volatility over time. The large, sudden jumps in conditional variance shown are likely a result of hardwood pulp volatility's susceptibility to external shocks rather than previous changes in volatility. Overall, it may be inferred that there is relatively more risk and uncertainty surrounding hardwood pulp returns, given the price volatility's sensitivity to external shocks and lack of persistence.

Table 2-2: Engle ARCH LM test results

	Test Statistic	P-value
Hardwood Pulp	41.853	0.000
Ethanol	13.040	.0003

Table 2-3: Hardwood pulp volatility results

		Model	
Components	**Lags**	**Constant Volatility**	**GARCH**
Autoregressive	constant	0.37182***	-0.00209***
		(0.091)	(0.0004)
	1	-0.07736***	0.217767***
		(0.019)	(0.040)
	9		-0.02238***
			(0.007)
	12		0.887767***
			(0.043)
Moving Average	1		-0.23921***
			(0.046)
	12		-0.87062***
			(0.050)
ARCH	constant		0.00001***
			(0.000005)
	1		0.510244***
			(0.069)
	12		0.888506***
			(0.087)
GARCH	1		0.186519***
			(0.031)
AIC		-1639.93	-1857.54
Ljung-Box test Q(12):		19.66	13.09
P-value		0.0502	0.288
McLeod-Li test Q(12):		106.78	2.69
P-value		0.0000	0.988

***** indicates significance at the 1% level**

I conduct a number of additional tests to further assess the fit of the GARCH specifications. First, the Ljung-Box test (1978) is conducted in order to identify any potential remaining autocorrelation. In order to conduct the test, the residuals of the model are obtained and standardized. The null hypothesis of the Ljung-Box test is that there is no remaining autocorrelation. In the case of the constant volatility model, the null hypothesis of no remaining autocorrelation is rejected whereas for the GARCH specification the test fails to reject the null. This implies that the GARCH model as compared to the constant volatility model has eliminated any remaining autocorrelation in the error terms. In addition, the McLeod-Li test (1983) is carried out on the squared standardized residuals and is used to identify whether the volatility of model is experiencing any remaining heteroskedasticity. For the constant volatility model, the McLeod-Li test strongly rejects the null hypothesis of no remaining heteroskedasticity. The GARCH specification for hardwood pulp fails to reject the null hypothesis and suggests that the remaining heteroskedasticity has been remedied. These tests further suggest that estimating hardwood pulp returns and volatility using a GARCH approach combined with a mean reverting process provides a better characterization of price behaviour than a mean reversion specification without time varying volatility.

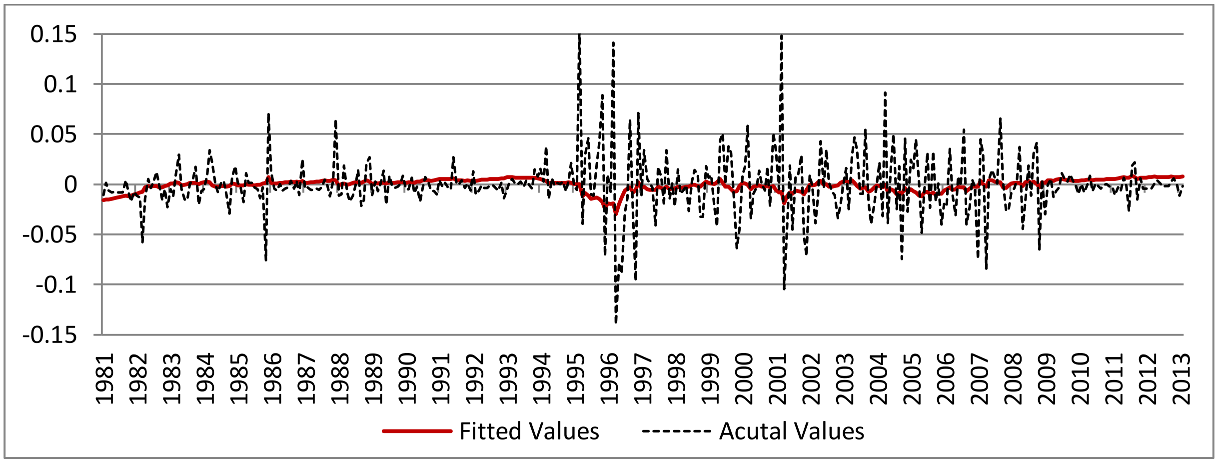


Figure 2-2: Hardwood pulp returns constant volatility actual and fitted values

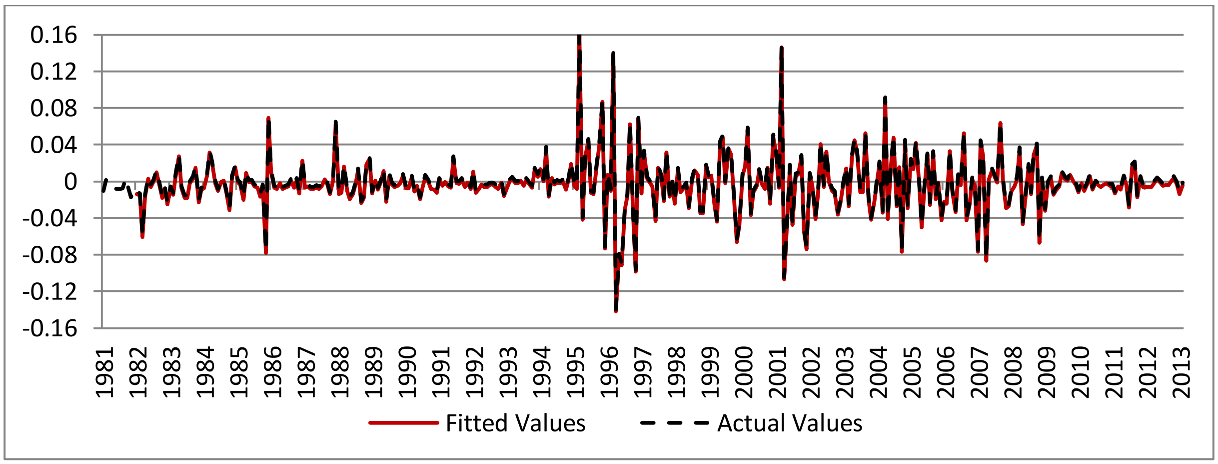


Figure 2-3: Hardwood pulp returns GARCH actual and fitted values

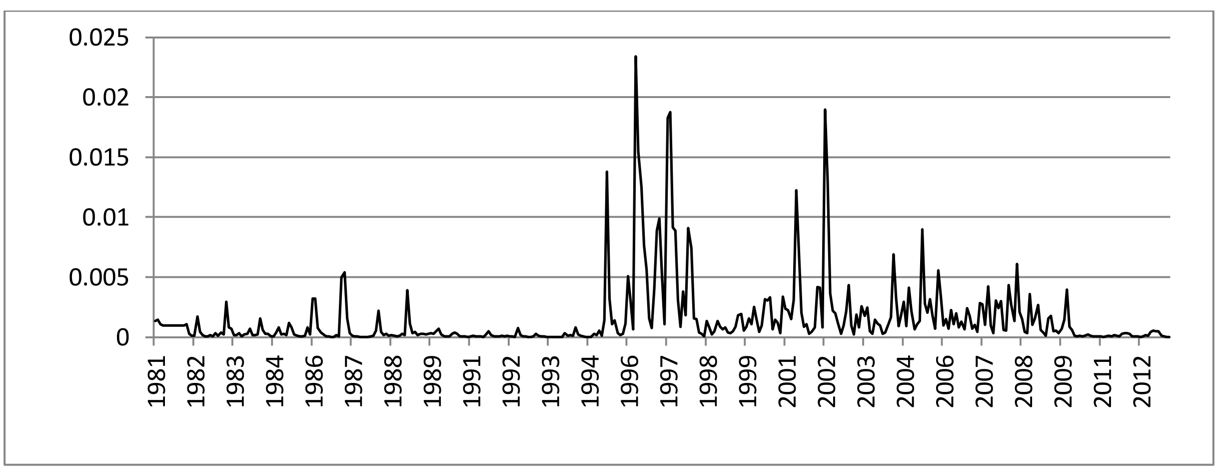


Figure 2-4: Hardwood pulp GARCH conditional variances

2.5.2.2 Ethanol

The best fit, constant volatility, mean reverting model for ethanol price returns is found, based on AIC values, to contain three lagged price terms. The results, shown in Table 2-4, find that the coefficients on the lagged previous price terms are significant. While the fitted values for ethanol returns (Figure 2-5) follow a similar path to the actual values, the spread of the actual returns around the mean are not fully captured using the constant volatility approach. This suggests that the price volatility may evolve over time. The results of Engle's LM test (Table 2-2) for ethanol prices reject the null hypothesis and suggest that ARCH effects are present. Consequently, the GARCH ARMA specification is fitted to ethanol price returns and the coefficients are found to be largely significant. The specification, supported by AIC values, has one ARCH and one GARCH term in the conditional variance equation with autoregressive lags of 1, 2, and 3 and moving average terms of 1, 2, 3, and 4 in the mean equation. In comparing the GARCH results to the constant volatility model, the AIC values indicate that a better fit for ethanol returns results from the GARCH ARMA specification. Furthermore, the GARCH fitted values (Figure 2-6) appear to better trace the actual values with respect to its path and spread.

The magnitude of the GARCH coefficient is larger than that of the ARCH coefficient, a result that indicates that changes in the volatility are impacted more by lagged volatility than lagged error terms. The implications of ethanol conditional variance being influenced more by previous volatility are that volatility changes will be more smooth and persistent. The conditional variance plot for the ethanol GARCH specification (Figure 2-7) illustrates the nature of volatility in ethanol returns. Rather than the sharp, sudden changes seen for hardwood pulp, the volatility of ethanol is characterized by periods of high and low volatility clusters. Figure 2-7 further emphasizes the impact that previous volatility has on current volatility. The ethanol volatility may indicate that there is less risk as external shocks are expected to have less of an impact, however, any shocks that do occur may last for longer periods. As well, there may be less uncertainty due to the clustering behaviour of volatility and smoother transitions between periods of high and low volatility.

Table 2-4: Ethanol volatility results

		Model	
Components	**Lags**	**Constant Volatility**	**GARCH**
Autoregressive	constant	0.238693***	
		(0.054)	
	1	-0.52265***	0.636059***
		(0.082)	(0.0616)
	2	0.179391***	-0.84264***
		(0.053)	(0.0159)
	3	-0.04791***	0.811387***
		(0.011)	(0.0615)
Moving Average	1		-0.39253***
			(0.0745)
	2		0.544656***
			(0.0493)
	3		-0.61336***
			(0.0682)
	4		-0.37543***
			(0.0577)
ARCH	constant		0.0678
			(0.0262)
	1		0.000115***
			(0.00007)
GARCH	1		0.90943***
			(0.0327)
AIC		-816.9	-842.84
Ljung-Box test Q(12):		5.63	6.06
P-value		0.897	0.869
McLeod-Li test Q(12):		42.81	7.54
P-value		0.0000	0.674

***** indicates significance at the 1% level**

The null hypothesis of the Ljung-Box test for both the constant volatility and GARCH specification are not rejected which implies neither model has any remaining autocorrelation. For the McLeod-Li test, however, the null hypothesis of no remaining heteroskedasticity is rejected in the constant volatility model, whereas with the GARCH specification the null is not rejected. Therefore, it can be concluded that there was heteroskedasticity under the constant volatility approach, and by utilizing a GARCH specification I have eliminated heteroskedasticity in the error term. This result further lends support to the conclusion that a constant volatility approach to modeling ethanol price returns is inaccurate as volatility of returns varies substantially in timing and magnitude. The findings, for ethanol and hardwood pulp, are similar and indicate that a mean reverting process with GARCH volatility provides a best fit approach to modelling the behaviour of price returns.

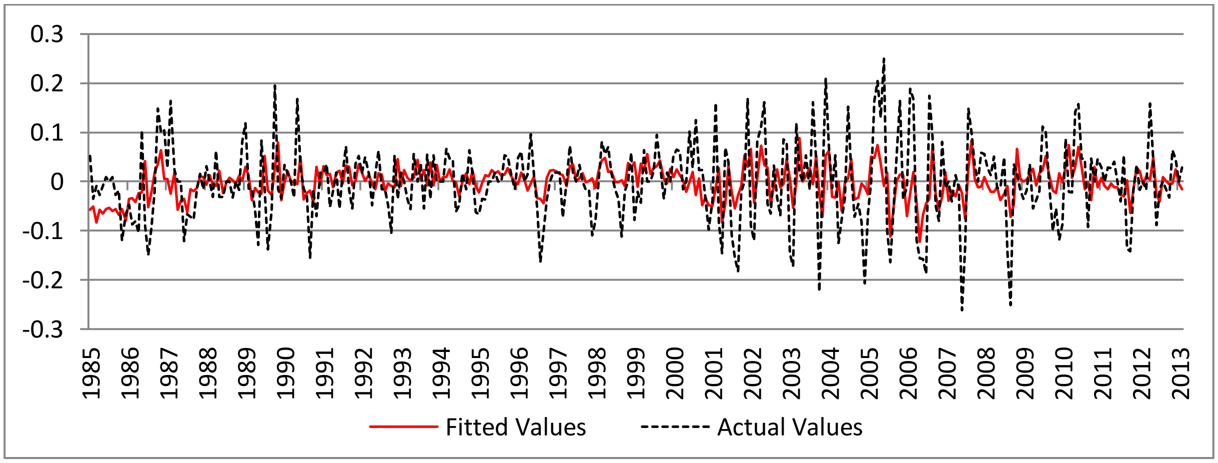


Figure 2-5: Ethanol returns constant volatility actual and fitted values

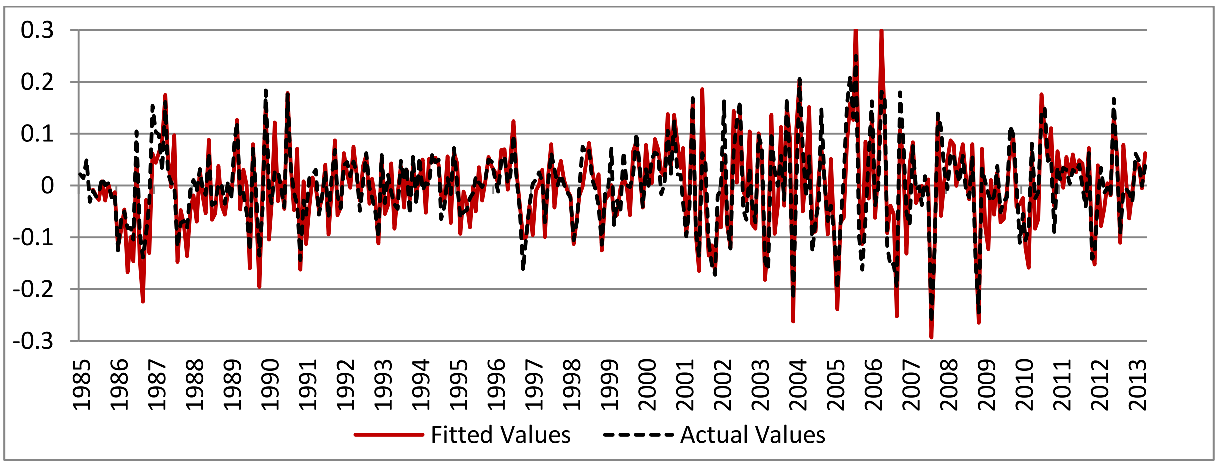


Figure 2-6: Ethanol returns GARCH fitted and actual price returns

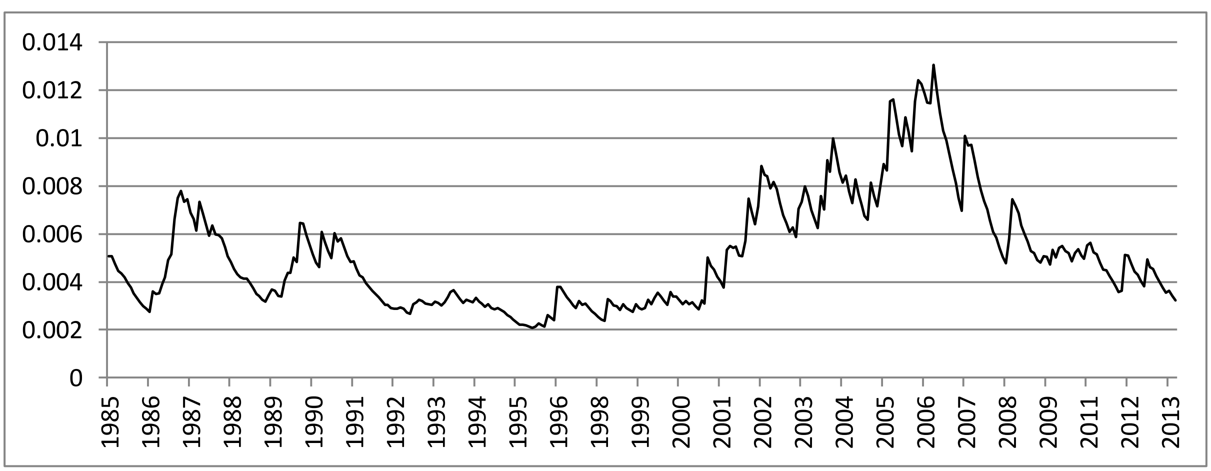


Figure 2-7: Ethanol GARCH conditional variances

2.6 Conclusion

The first objective of this paper sought to add to the existing literature on forest products and ethanol with respect to whether prices are driven by mean reverting or random walk processes. In the past, forest prices have been typically characterized by random walks such as GBM, however, there are a growing number of studies which support mean reversion. The results for the hardwood pulp and ethanol price returns support mean reversion. Statistical tests on both of the price series reject the presence of a random walk and suggest that they may both be driven by mean reverting processes, the exception being the KPSS test results on logged prices. Niquidet and Sun (2012) suggest that rejection of the null in both a unit root and stationary test may indicate a degree of fractional integration. While Niquidet and Sun (2012)'s approach is outside of the scope of the present study, future research may investigate fractional integration in hardwood pulp and ethanol prices. The implication of finding the price returns to be mean reverting is that the market adjustments of both hardwood pulp and ethanol between periods will cause the price to fluctuate around the mean. As a result, the prices may be expected to behave according to the theory of commodity prices. With respect to the harvest rotations of improved poplars, having output prices that mean revert may cause producers to delay harvests until the price rises above the mean level. Because there is an expectation of the price rising above its mean level, there is relatively more certainty, as compared to random walk prices, with regards to the prices that producers expect to receive. This characterization of prices will increase the value of an improved poplar asset, but decrease the value of any associated option value (Gjolberg and Guttormsen 2002). As a result, the economic potential of improved poplars may be improved, as producers will not be subject to widely fluctuating prices and may see the investment as relatively more stable.

The second objective of this paper was to examine the volatility of these price series, in light of both series being found to mean revert. The first mean reverting model assumes that volatility is constant and, therefore, the price changes around the mean will be similar. After testing for and confirming the presence of ARCH effects in the hardwood pulp and ethanol price series, time-dependent volatilities are modelled using Bollerslev's (1986) GARCH specification with ARMA terms. As a result, this paper further contributes to the growing literature that uses a time-dependent volatility approach in modelling natural resource prices. The volatility conclusions reached in this paper provide an increased understanding of price risk and the factors driving price fluctuations around the mean. For hardwood pulp, the volatility in price is more affected by previous errors thereby indicating external influences had a larger impact on volatility. Ethanol price volatility, on the other hand, is more strongly impacted by previous volatilities, implying that volatility changes will be more persistent than for hardwood pulp. Furthermore, the results suggest that while there is a long run tendency for prices to mean revert, there is still a degree of uncertainty in the output prices. For poplar plantation landowners, this result implies that it is more difficult to predict the changes in price around the mean level. As a result, when the price is above the mean, there is less certainty with respect to whether it is a peak price and to how long the price will remain above the average. The time dependent price volatilities driving output prices may signal to producers that the improved poplar investment has an increased level of risk. The option value effect associated with the non-constant volatility is an increase in option value due to the increased possibility of receiving a higher price in the next period than would be perceived with a constant volatility mean reverting price.

While it appears that modelling for jumps may not be appropriate given the sample study in this paper, investigating other prices may reveal that permanent jumps require consideration, similar to the study by Khajuria et al. (2011). If the mean price shifts or there is a need to model structural changes or policy intervention then adopting a jump model would allow for the mean reverting process to capture the those effects. In addition, previous studies (Mei et al. 2010; Niquidet and Sun 2012) have acknowledged the effect that the frequency, length of time period and aggregation of the data can impact the findings with respect to process and volatility. Therefore, an examination of annual prices or any regional price series may provide further insight into the behaviour of improved poplar output prices in other jurisdictions.

Being able to understand the future behaviour of these prices is an important aspect for policy makers and researchers. Failure to characterize the behaviour of improved poplar producers and potential market responses, based on expected prices and risk, could adversely affect the intended outcomes of any policy decisions made in support of forest plantations in Canada. The modelling of price process and volatility together provides a more complete understanding that can be used to assess the possibilities and challenges facing improved poplar plantation producers and policy makers.

Chapter 3: Potential for improved poplars plantations in competition with private agriculture land in Alberta: A multiple option value approach

3.1 Introduction

With their short harvest rotations and the possibility for improved genetics, poplar trees are considered to be a potential candidate for industrial forest plantations in Alberta. But, current regulations prohibit these improved poplar plantations from being grown on public land in Alberta. Therefore, under current regulations the establishment of improved poplar plantations would be on private land, thereby putting poplars in competition with existing agriculture land uses. If improved poplars are found to provide a greater return to agriculture, it is expected that private landowners would convert their land from agriculture to plantation production. The competitiveness of poplar plantations, however, may be limited. Anderson and Luckert (2007) undertook a financial analysis of improved poplar stands and found that that they would be unable to compete with agriculture given the conditions at the time.

There are two sets of influences that will affect the potential for private agriculture land to convert to poplar plantations: economic conditions and government policies. With a growing interest in alternative fuel sources, policy makers may choose to subsidize the development of ethanol biomass production. In that case, it is useful to have an understanding of the economic drivers that support the adoption of poplar plantations. Being able to model the probability that a landowner adopts a plantation, given a set of market or land characteristics, will provide regulators with information regarding what conditions and policies may be more effective to promote improved poplar production.

In their financial analysis, Anderson and Luckert (2007) assumed that improved poplars would be harvested and sold solely for the production of wood pulp. Recently, the market possibilities have expanded as improved poplars are being viewed as a potential biomass for the next generation of ethanol production (Genome British Columbia 2014). Privately owned plantations, as a result, may be managed for multiple possible output products including cellulosic ethanol biomass and hardwood pulp.

The development of a second output increases the decision making flexibility of landowners by increasing the chance that their product yields a high return because they can now choose to sell to the buyer with the most favourable price. When facing the decision to harvest, the landowner has the option to store the trees on the stump an extra year with the possibility of receiving a higher price for one of two outputs. Therefore, the introduction of the ethanol output possibility may improve the ability of poplar plantations to compete with agriculture land uses.

In order to examine the competitiveness of poplar plantations, Hauer et al. (in process) developed a real options approach that models land use change. This model optimally chooses the best land use by comparing the value of land in agriculture production to a plantation land value based on the harvest of poplars for the production of cellulosic ethanol. Cellulosic ethanol, however, is not the only poplar output, instead, the landowner may choose, to sell the plantation yield for hardwood pulp. Furthermore, cellulosic ethanol production in Canada has yet to become an established industry, whereas the infrastructure and markets for pulp are well developed. Therefore, this paper expands the Hauer et al. (in process) land use change model to consider the production of improved poplars for both cellulosic ethanol and hardwood pulp. This approach allows us to examine the effect that increased market choice has on the competitiveness of poplar plantations on agriculture land.

Given that the establishment of poplar plantations on private land has yet to occur, particularly for the possibility of producing ethanol biomass, this paper is examining a potential future of land use in Alberta. When deciding whether to establish a plantation, the landowner has to consider the expected price for poplar output prices at future harvest dates. In order to capture this uncertainty surrounding land use and prices, this paper simulates the future potential value of poplar plantations over a 100 year period.

In this paper I model the potential for land use change with land characteristics derived from the spatial data of Hauer et al. (in process). By having land characteristics that are linked to spatial data, an understanding is gained regarding the characteristics that potential land sites in Alberta may require in order for conversion to occur. Being able to forecast the potential locations of land that are most likely to undergo conversion from agriculture to forestry will aid policy makers in predicting market effects, such as changes in supply or land values.

This study has two objectives. The first is to compare a single and double option approach to modelling land use change. The single option model, which is similar to the approach of Hauer et al. (in process), investigates land use change given the sole option of converting agriculture land to an ethanol producing poplar plantation. The double option model, allows the landowners the choice of producing poplars for either hardwood pulp or ethanol. By comparing these two models I am able to analyze whether the introduction of an additional option improves the competitiveness of poplars plantations. The second objective is to examine what conditions are favourable for the allocation of land to poplar plantations given the single and double option models. Sensitivity analysis is used to examine two sets of economic conditions: 1) increases in the current level of ethanol production subsidies and, 2) decreases in the starting agriculture land value. The analyses of these scenarios help to provide information regarding the level of support necessary to encourage development as well as the possible locations of land that may be currently best suited for the establishment of private poplar plantations.

The next section of this paper discusses the existing literature of real options analysis in its application to modelling land use decisions. Following the literature review, the real options model is introduced, which uses the stochastic price models developed in Chapter 2 to help simulate stochastic price series. In addition, the model parameters including costs and conversion factors are outlined. The first results presented are for the baseline scenarios of both the single option (ethanol) and double option (ethanol and pulp) models. Next, the single and double option models are examined with sensitivity analysis on ethanol subsidies and agriculture land values. The final section of this paper offers a discussion and conclusions.

3.2 Literature Review

A real options approach has been employed to examine land use change and valuation (see Thorsen 1999; Schatzki 2003; Isik and Yang 2004). Real options account for the value that arises from having flexibility in making investment decisions. Schatzki (2003) explains that with a real options approach, the land use decision can be delayed in order to receive more information and update expectations regarding future returns. This temporal flexibility is particularly important in this study given that the time commitment to a poplar plantation is significantly greater than the commitment to agriculture production. With agriculture, the landowner receives a return each year and then has the option to switch land uses. With plantations, however, the lack of flexibility is costly in the short term until the plantation becomes harvestable, at about nineteen years. During this initial period conversion back to agriculture would require a costly (zero revenue) abandonment of the plantation. The real options approach accounts for temporal flexibility (or inflexibility) when valuing choices about land use alternatives.

A real options approach may also be beneficial because there have been discrepancies between the actual and expected amounts of land changing use, under a net present value approach (NPV) that ignores option values (Mushoff 2012). Schatzki (2003) surveyed other land use change studies and observed that a significant proportion of landowners fail to undergo land change when it is optimal to do so, as predicted by a NPV approach. Schatzki (2003) explains that real options theory may be used to understand these discrepancies and is an important tool in studying land use conversion because of cost of converting to forestry as well as the potentially large cost of converting back to agriculture. The author suggests that the landowner's behaviour is in accordance with option theory and that the magnitude of the option values may be significantly large. Similarly, Thorsen (1999) uses a real options approach for examining the conditions and policies required to make afforestation a viable option for landowners in Denmark. The study finds that a real options approach has the effect of predicting a more conservative amount of afforestation, as compared to the previously used NPV approach.

Real options analysis may also provide better estimates of the returns earned from a particular piece of land. Plantinga et al. (2002) explain that the net return of a particular piece of land should reflect the return from its current land use as well as any future more profitable land uses. Plantinga et al. (2002) used an econometric approach to investigate the factors that influence agriculture land values. The paper finds that the option values of converting farmland to developed land are capitalized into the land price.

There are a few studies that have examined using real options to model the potential for afforestation on agriculture land with the purpose of producing energy biomass. Mushoff (2012) studies the production of short rotation coppice plantations on “set-aside” (i.e. not producing crops and not generating revenue) agriculture land in Germany. The author compares the net present value and real options approaches to determine plantation investment triggers. The real options approach looks at the temporal flexibility in being able to delay plantation establishment given stochastic wood chip prices. Because the set-aside land does not generate revenue, Mushoff’s (2012) real options approach investigates the temporal flexibility based on the possibility of receiving different wood chip prices. This study differs from Mushoff (2012) because while they consider one output with one stochastic price, I consider the choice of three outputs, each with a stochastic price. In my model, landowners’ temporal flexibility of establishing a plantation is based on receiving two different plantation prices as well as the possibility of receiving an agriculture price that varies over time. Furthermore, Mushoff (2012) assumes a fixed harvest rotation of five years, whereas this study has an internal optimization of the optimal economic rotation for plantations. The decision of the landowner as when to harvest the plantation introduces flexibility, in the face of stochastic output prices, that may be advantageous to the establishment of plantations because of the ability to capture above average output prices.

Di Corato et al. (2013) uses an option approach to investigate the landowners decision to delay the investment decision of establishing short rotation coppice for biofuel, in Sweden. The model lets landowners choose between short rotation forestry and agriculture. Agriculture revenues are assumed to follow geometric Brownian motion whereas forestry net revenues assumed to be constant. Again, this differs to the current study in that the authors model only one price as stochastic whereas my approach presents three stochastic prices to capture the uncertain nature of all the potential land outputs. The model outlined in Di Corato et al. (2013) also utilizes a fixed project lifespan for plantations, which decreases the flexibility of landowners to determine their harvest rotation based on plantation output prices. There is one additional distinction between the similar approaches of Mushoff (2012) and Di Corato et al. (2013) and the model presented in this paper. The bioenergy output markets for plantations are different; the SRC is being grown for biomass used to fueling heat and power plants, whereas in this study I assume that poplars may be grown for ethanol production. Overall, this paper seeks to fill a gap in the literature by framing the land use change decision between poplar plantations and agriculture using a double option approach with multiple stochastic prices.

3.3 Methods

3.3.1 Land Use Change Model

The land use change model presented in this paper is based on the approach of Hauer et al. (in process). In evaluating the land use change decision, the model assumes that initially the landowner has their land allocated to agriculture production. From there, the landowner is assumed to be evaluating the decision of whether to keep the land in agriculture production or convert it to improved poplar plantations. The land value for agriculture, when no alternative land use options are considered, is assumed to be stochastic and is shown in Equation 3.1 below:

$$X_t^a = (1+i)^{-1}(\delta X_t^a + E[X_{t+1}^a]) \tag{3.1}$$

where X_t^a is the value of agriculture land in period t; δ is a dividend rate; δX_t^a is the expected income from the land in year *t*; $E[X_{t+1}^a]$ is the expected future land value in year *t+1* (*E* denotes expectation), and *i* is a risk adjusted discount rate.

Improved poplar plantations represent an option to the landowner that results in a yield of v_s^n , depending on the harvest age of the *s* and the output *n* selected. The landowner receives a net benefit of b_{ts}^n , for the harvesting the plantation at time *t* when the stand age is *s*. In the double option model, where the plantation may be sold for hardwood pulp or ethanol, b_{ts}^n and v_s^n will depend upon the output *n* chosen at *s*. If ethanol is the selected output, then the landowner receives a net benefit per m^3 of b_{ts}^e. The poplar yield associated with the ethanol output is v_s^e. If instead, hardwood pulp is the plantation output the landowner receives a per m^3 net benefit of b_{ts}^p and a yield of v_s^p. The difference in the yields arises because of the assumption that ethanol uses the gross total tree volume whereas hardwood pulp uses the gross merchantable volume. For example, at the minimum harvest age of 19 years the gross total volume is 332.52 m^3/ha and the gross merchantable volume is 263.91 m^3/ha. The cost of establishing the poplar plantation is C. Each year following the establishment of the plantation, the landowner must decide whether to harvest the stand in year *t* or defer the harvest decision until year *t+1*. The landowner's harvest decision is based on maximizing the net benefit of the land given its allocation to poplar plantations, W_{ts}^f, which is shown by:

$$W_{ts}^f = max\left(0, B_{ts} + W_{t0}^f, E[W_{t+1,s+1}^f](1+i)^{-1}\right) \tag{3.2}$$

where

$$B_{ts} = max(b_{ts}^e\, v_s^e\ , b_{ts}^p v_s^p) \tag{3.3}$$

$$W_{t0}^{f} = max\left(0, E\left[W_{t+m,m}^{f}\right](1+i)^{-m} - C, W_{t}^{a} - C^{fa}\right) \quad (3.4)$$

$$W_{t+1,s+1}^{f} = max\left(0, B_{t+1,s+1} + W_{t+1,0}^{f}, E[W_{t+2,s+2}^{f}](1+i)^{-1}\right) \quad (3.5)$$

The value of land in an agriculture use is W_t^a, C^{fa} is the conversion cost of switch land from poplar plantations to agriculture, and *m* is a minimum harvest age for the improved poplar plantation. Equation (3.2) presents the maximization problem where the landowner chooses to either i) abandon the site resulting in a value of 0; ii) harvest in the current period which gains a current net revenue from the stand of B_{ts}, in addition to the bare land value, W_{t0}^{f}, associated with a poplar plantation; or iii) defer the harvest one year which yields the net benefit $W_{t+1,s+1}^{f}$. The value of the one year older stand, $W_{t+1,s+1}^{f}$, is an expected value (Equation 3.2), in period *t,* due to uncertainty in the stochastic prices. In the case of the double option model, Equation (3.3) illustrates the choice of the landowner to maximize the current net revenue of the stand between the hardwood pulp and ethanol outputs. The result of the choice in Equation (3.3) is then incorporated into the maximization problem in Equation (3.2). In the case where ethanol is considered to be the only plantation output, b_{ts}^{p} is assume to be zero and Equation (3.3) defaults to the single option model. The bare land value, W_{t0}^{f}, (Equation 3.4) gives the value of forest land, immediately after harvest. The bare land values is the maximum of the expected value of future plantation harvests resulting from the option to start a new plantation and the value of the option to convert the land back to agriculture. The term $E\left[W_{t+m,m}^{f}\right]$ is the expected value of the plantation at the minimum rotation age *m*. Hauer et al. (in process) notes that a special case arises because harvesting costs before the minimum age are prohibitive. Equation (3.5) shows the one year later maximization problem which results in $W_{t+1,s+1}^{f}$.

The value of agricultural land with the option to convert to plantations in the future, W_t^a, is defined as a maximization equation:

$$W_t^a = \max\Big(\big(\delta X_t^a + E\big[\max[W_{t+1}^a, W_{t+1,0}^f]\big]\big)(1+i)^{-1}, E\big[W_{t+m,m}^f\big](1+\ i)^{-m} - C, 0\Big) \quad (3.6)$$

The first term is the summation of the income (δX_t^a) gained immediately in the year the land is in agriculture and the expected value, in the next year, that results from the selecting either agriculture or poplar plantations as the optimal land use. The second component is the current period expected value of converting land from agriculture to plantations.

3.3.2 Stochastic Price Processes

In Equations (3.1) to (3.6) the net benefit, b_{ts}^n, is made up of components which differ according to the output, either hardwood pulp or ethanol. For ethanol, the net benefit ($\$/m^3$) is:

$$b_{ts}^e = (p_t^e - c_s^e + d)\,\theta - h_s^e \qquad (3.7)$$

where p_t^e is the per litre price of ethanol, c_s^e is the per unit processing cost of ethanol at the plant, d is the per litre ethanol subsidy, and h_s^e is the plantation harvest costs, at age *s,* for ethanol, which includes all transportation costs associated with getting the ethanol biomass to a processing center. Because the harvest cost and poplar yield units are per m^3, and the ethanol units are per litre, a conversion factor, θ, is a used to convert from litres to m^3.

The net benefit ($\$/m^3$) for hardwood pulp is:

$$b_{ts}^p = p_t^p - h_s^p \qquad (3.8)$$

where p_t^p is the price of hardwood pulp and h_s^p is the cost of harvesting the planation at age *s* and the transportation costs associated with the production of hardwood pulp.

The prices of ethanol and hardwood pulp are each modelled using a different generalized autoregressive conditional heteroskedasticity (GARCH) specification:

$$p_t^n = \lambda^n + \varepsilon_t^n \tag{3.9}$$

where

$$\varepsilon_t^n | \psi_{t-1}^n \sim N(0, g_t^n) \tag{3.10}$$

$$g_t^n = \alpha_0^n + \sum_{i=1}^{k} \alpha_i^n (\varepsilon_{t-i}^n)^2 + \sum_{i=1}^{l} \beta_i^n g_{t-i}^n \tag{3.11}$$

In the mean equation (3.9), λ^n is a constant and acts as a long term, average real price. ε_t^n is the error term, which is defined in Equation 3.10 as being normally distributed with a mean of 0 and a conditional variance of g_t^n, given the information set ψ_{t-1}^n. The conditional variance equation (3.11) allows the price volatility of p_t^n to be dependent upon a constant, α_0^n, lagged error terms, ε_{t-i}^n , and lagged volatilities, g_{t-i}^n. α_i^n and β_i^n are the coefficients on the lagged error and volatility terms, respectively, where k and l denote the total number of lagged error and volatility terms included, respectively. Again, n denotes the poplar output, which may be ethanol, e, or hardwood pulp, p.

The specifications used to model prices in this paper are based on the analysis done in Chapter 2. That chapter found evidence of mean reversion and GARCH effects in both monthly ethanol prices and a monthly hardwood pulp price index. Those results informed the monthly simulation models for hardwood pulp and ethanol. The models were estimated to be a GARCH (1,1) process and used to simulate 50,000 price paths of monthly observations for 100 years. In order to obtain yearly prices, as required by the land use change model, the January observation was used as the value for each year. This approach allowed us to preserve the mean reverting and time-varying volatility behaviour, described in Chapter 2, in the simulated annual prices.

The structure of the GARCH specifications (Equations 3.9 to 3.11) is such that large past volatilities, g_{t-j}^{n}, or large past errors, $(\varepsilon_{t-j}^{n})^{2}$, may lead to large current volatilities, g_{t}^{n}, and by extension extreme price, p_{t}^{n}, values. The large volatilities may compound as *t* increases thereby leading to a series of extreme values that I assume are unrealistic over the simulation period. As a result, I impose maximum and minimum values on the simulated volatility, g_{t}^{n}, and price, p_{t}^{n}, that are based on actual, historical observations from the price data. The maximum and minimum values for ethanol volatility are 0.3147 and 0.0014, respectively whereas the maximum and minimum values for ethanol prices are 1.5 and 0.3 $/L, respectively. For hardwood pulp, the volatility maximum and minimum are 3731.69 and 5.2764, respectively and the maximum and minimum price index values are 361.356 and 54.7075, respectively. By imposing these constraints on the price and volatility, the result is a simulation of 50,000 distinct price paths over a period of 100 years that contain values that are assumed to be reasonable given the historical data. The hardwood pulp price index, base year 2002, used to estimate the simulation model, is from Statistics Canada's Canadian Socio-economic Information Management System (CANSIM) database series v53434806, from 1981 to 2013. Because the data series for hardwood pulp is a price index, the index must be converted to dollars m^3 using a ratio of the mean index value (i.e. 119) and an assumed mean dollar value of 43 dollars per m^3. The data used to estimate the ethanol price simulation model is from the United States Department of Agriculture Economic Research Service's bioenergy statistics for the years 1985 to 2013.

In simulating the behaviour of agriculture land values, this paper adopts the model outlined in Hauer et al. (in process). The authors found that geometric Brownian motion provided a best fit for the agriculture land value data and estimated a model based on an annual data set for Alberta from the years 1921 to 2013. The agriculture land value data is from CANSIM series v381841.

The equation for modelling the agriculture land prices as a geometric Brownian motion is expressed by:

$$\ln(X_{t+1}) - \ln(X_t) = \gamma + \sigma^a \mu_t \tag{3.12}$$

The model parameters used in the price simulations are shown in Table 3-1.

Table: 3-1: Ethanol, hardwood pulp, and agriculture land price simulation parameters.

	Price Model	Parameter Description	Parameter Values
λ^e	Ethanol	Mean constant	0.60336
α_0^e	Ethanol	Volatility constant	0.00127
α_1^e	Ethanol	Lagged error	0.86745
β_1^e	Ethanol	Lagged volatility	0.09775
λ^p	Hardwood pulp	Mean constant	119.0387
α_0^p	Hardwood pulp	Volatility constant	4.54703
α_1^p	Hardwood pulp	Lagged error	0.92613
β_1^p	Hardwood pulp	Lagged volatility	0.13407
γ	Agriculture land value	drift rate	0.01893
σ^a	Agriculture land value	volatility	0.08469

3.3.3 Costs and Model Parameters

The values for the costs and model parameters, described below, and their sources are shown in Table 3-2. The dividend rate, δ, is needed to calculate the expected value of agriculture land in year t, δX_t^a, (Equation 3.1). Furthermore, the constant risk-adjusted discount rate, i, is determined by adding the dividend rate to the growth rate of agriculture land values. The discount rate calibrates the land use change model so the net present expected land value with no option value is equal to the simulated agriculture land value.

Minimum and maximum plantation rotation ages are imposed on the model because it simplifies the computational complexity of the model while not significantly affecting the results (Hauer et al. in process). The minimum rotation age is based on how harvest costs change with stand age. With current logging technology, costs of harvesting before 19 years, is prohibitive; however, past 19 years the costs drop rapidly and flatten out after 21 years. The costs are prohibitive because harvesting costs vary according to logging productivity. At young plantation ages logging equipment productivity is extremely low given the small trees but productivity increases once a threshold of merchantable tree size is crossed. The maximum rotation was chosen because after approximately 30 years poplar yields begin to decrease, therefore it becomes less economical and less likely that harvest will occur past that point.

In Equation (3.7) a conversion factor, θ, is used to change the price and processing costs of ethanol from dollars per litre to dollars per m^3. This is required in order to determine the net value of an ethanol harvest given that the yield and harvest costs are calculated in units per m^3.

It is assumed that converting agriculture land to land that can be used for poplar planting has a cost of zero. On the other hand, converting land previously used to grow poplar plantations to land that is ready for agriculture use has an associated cost of 354 $/ha (Table 3-2).

The harvest costs for ethanol, h_s^e, and hardwood pulp, h_s^p, vary according to the age of stand. As a result, the harvest costs are affected by the volume of the harvest, v_s^n. For both outputs the harvest costs include the costs of cutting and moving the poplar to the roadside, chipping and loading for transportation, and transporting to the mill or processing plant. The harvest costs for pulp and ethanol are based on Kuhnke et al. (2002). The distances to the mill for transporting biomass for hardwood pulp and ethanol are assumed to be 50 km. The yield curve of poplars, v_s^n, is from (Joss et al. 2007). Hauer et al. (in process) uses the same yields and scales the curve according to soil quality and climate conditions. This paper scales the base yield curve to the maximum yield data presented in Hauer et al. (in process). Therefore, this study presents a somewhat optimistic approach for the yields of improved poplars.

2.3.4 Solving the Model

The real options land use change model presented in this paper is solved according to the process outlined in Hauer et al. (in process), which is built on the simulation based, least-squares approach of Longstaff and Schwartz (2001). The stochasticity of prices in the model, ethanol, hardwood pulp, and agriculture land, results in a number of expected land values in the model, as shown by $E[X_{t+1}^a]$ (Equation 3.1), $E[W_{t+1,s+1}^f]$ (Equation 3.4), and $E\left[W_{t+m,m}^f\right]$ (Equation 3.5). To calculate these expected values, Longstaff and Schwartz's (2001) method uses a large sample size of simulated prices. For this paper, 50,000 price paths are simulated for 100 years to estimate expected future land values. Therefore, the expected land values are functions of current simulated prices:

$$\boldsymbol{E}\left[\boldsymbol{W}_{t+1,s+1}^{f}\right] = \boldsymbol{f}(\boldsymbol{p}_t^n, \boldsymbol{X}_t) \qquad (3.13)$$

where *n* designates the poplar output, either hardwood pulp, *p,* or ethanol, *e.* Regressions are used to determine the expected values, with the current simulated prices acting as the independent variables. The dependent variables in the regressions are simulated realized land values calculated by simulated future prices. The model is able to use future simulated values and current simulated prices to calculate expected values because the process of solving the model starts in year 100 and works backwards to year 0. The expected future land values calculated from the least-squares approach inform the optimal decisions, during the current period, in the model.

Table 3-2: Costs and model parameters

Parameter	**Value**
Agriculture dividend rate (δ)	0.03 [1]
Risk adjusted discount rate (i)	0.053 [1]
Minimum rotation age (m)	19 years [2]
Maximum rotation age	35 years [2]
Ethanol conversion factor (θ)	115.2 L/m^3 [2]
Processing cost for ethanol (c_s^e)	0. 75 $/L [3]
Conversion cost: plantation to agriculture	354 $/ha [5]
Cost to establish a plantation	2755 $/ha [6]
Distance to mill	50 km

Sources: [1] Hauer et al. (in process) derives these values based on the agriculture land value data which is the same series used in this paper.
[2] Hauer et al. (in process)
[3] The value taken from Hauer et al. (in process) is based on the analysis done in Kazi et al. (2010)
[5] The value is from D.A. Westworth and Associates (1994) and has been adjusted for inflation.
[6] Anderson et al. (in press) from Tim Keddy, Canadian Wood Fibre Center, (personal communication 2013)

Those decisions are to harvest the poplar in the current period or wait (Equation 3.2) and to choose the optimal land use (Equation 3.6). The process then repeats; the previous period expected values are calculated and the optimal decision is recorded until t=0 is reached. While the model considers 100 years, option decisions are only recorded for 65 years because the 35 years, the maximum poplar rotation, from 100 to 66 are required to calculate the value of poplar plantation planted in year 65. The algorithm for the model presented in this paper is described in Appendix 1.

2.3.5 Result Indicators: Option Values and Land Use Probability

To assess the land use change and differences between the single and double option models two result indicators are calculated. The first result indicators are option values (OV_t). Option values are presented to quantify the impact on land values of having the flexibility to choose either a land use or plantation output and are calculated according to:

$$OV_t = \boldsymbol{W_t^a} - \boldsymbol{X_t^a} \tag{3.14}$$

The option value represents the value to agriculture land that arises from the possibility of converting to a poplar plantation in the future. The expected value of agriculture land with plantation options is W_t^a, and X_t^a is the expected value of agriculture land without plantation options. In this paper, two versions of the option value (Equation 3.14) are calculated: i) a single option value where W_t^a is based on poplar plantations harvested solely for ethanol production, and ii) a double option value where W_t^a is based on plantations that may be harvested for either hardwood pulp or ethanol. In both the single and double option models, the landowner receives values from being able to choose the optimal harvest rotation.

If $W_t^a > X_t^a$, the option value is positive and the landowner gains by having flexibility of an additional land use or plantation output. If $W_t^a = X_t^a$, the option values are zero and for that model, it can be concluded that the option(s), either land use, poplar output or both, have no value to the landowner as plantations are unable to compete with agriculture land. Taking the difference of the double option and single option values allows us to assess the impact of the additional plantation option (hardwood pulp). If the difference is positive, then the increased flexibility of having two poplar outputs adds value to the land and increases the competitiveness of poplar plantations. If the difference is zero then it can be concluded that the additional poplar output has no added value to the landowner.

The second indicator presented in the results is the probability of poplar plantation land use in a given period, t. The probability of plantation land use is based on the expected value of each land use that considers the option to convert the current land use into the alternative. The expected value of plantation land with agriculture options is compared in each period to the expected value of agriculture land with plantation options over all 50,000 sample price paths. If the value of plantation land is greater than that of agriculture land the land use is assumed to be poplar plantations. The probability in year t is the proportion of price paths where the land use is a poplar plantation at year t to the total number of price paths. Furthermore, a positive option value (Equation 3.14) corresponds to a positive probability of establishing a plantation because even a small probability of allocating land to poplars implies the landowner receives a benefit from that option.

2.4 Results

The analysis begins with a set of baseline parameters that are a representation of the conditions that landowners may currently be facing. The baseline parameters are shown in Table 3-3. Following the baseline, sensitivity analysis is presented for two scenarios. The first scenario examines increasing levels of the ethanol production subsidy. Increases in the ethanol subsidy can be interpreted in three ways. The first interpretation is the level of continued government support that the production of ethanol would receive. The second interpretation is a shift in the price of ethanol. Because the ethanol prices are modelled as reverting around a constant mean, adding 0.11 $/L, the baseline subsidy, to the price of ethanol in every period effectively shifts the mean price of ethanol upwards by 0.11 $/L. This interpretation is useful in investigating the potential effect of market changes. The last interpretation is a decrease in the per unit cost of processing cellulosic ethanol. The addition of 0.11 $/L to the price is equivalent to decreasing the processing cost by the same dollar per litre amount. If there is a technological advancement that makes the processing of cellulosic ethanol less expensive, then it is helpful for policy makers to understand the corresponding effect on land use change. Furthermore, any combination of the sensitivity analysis interpretations would allow policy makers to adjust subsidies accordingly as changes in either costs, or prices, occur.

The second sensitivity analysis scenario that I conduct is changing the starting (i.e. t=0) simulated agriculture land value. The changes in the value per hectare of agriculture land represent downward shifts of all the sample agriculture land price paths. In this part of the sensitivity analysis, the ethanol subsidy level is held constant at the current level of 0.11 $/L (Table 3-3). The agriculture land value analysis allows us to identify potential sites where land use change may occur.

Table 3-3: Baseline parameters

Mean hardwood pulp price	43.00 $/m3
Mean ethanol price	0.60 $/L
Agriculture land value at $t = 0$	2000 $/ha
Ethanol Production Subsidy	0.11 $/L [1]

Sources: [1] Alberta Energy's website states the subsidy for second generation ethanol is 0.14 $/L for the first 150 million litres per year and 0.09 $/L after that. 0.11 $/L is assumed as a midpoint. [http://www.energy.alberta.ca/BioEnergy/1826.asp]

2.4.1 Results with Baseline Parameters

Under the assumed baseline parameters (Table 3-3), I examine the single option model and find that, across the 65 year simulation period, the single option value (Equation 3.11) and the probability of the land being allocated to poplar plantations are both zero. These results indicate that with a single output option of ethanol, improved poplar plantations are unable to compete with private agriculture land uses under the current conditions. I also find the same results for the double option model. Sensitivity analysis is undertaken to assess the ethanol subsidy and starting agriculture land value changes needed to induce land conversion from agriculture to poplar plantations.

2.4.2 Ethanol Subsidy Results

Four different ethanol subsidy increases, to the baseline level of 0.11 $/L, are examined to assess the level of support necessary to encourage the establishment of plantations: 0.19, 0.21, 0.23, and 0.25 $/L. The sensitivity analysis is first presented for the single option model. Those results are compared to the double option model to evaluate whether the addition of a pulp market has an impact on the effect of a subsidy increase.

The option values for the single and double option models across the simulation period, given each subsidy level, are shown in Figure 3-1. Increasing the subsidy levels, for either model, results in larger option values, particularly in the early years of the simulation. The positive option values for the single option model indicate that there is a value to landowners of having the option to convert agriculture land to poplar plantations. Moreover, the positive double option values reveal the value gained by landowners when they are presented with the option to choose the land uses as well as the option to choose the poplar output. The option values for each model, however, decrease substantially over time given the assumed constant growth in agriculture land values. There are sharper, early period declines in the option values associated with 0.23 and 0.25 $/L subsidies, whereas the lower subsidy option values decrease at a more gradual rate. At the lower subsidy levels, the option values in the later years eventually reach zero.

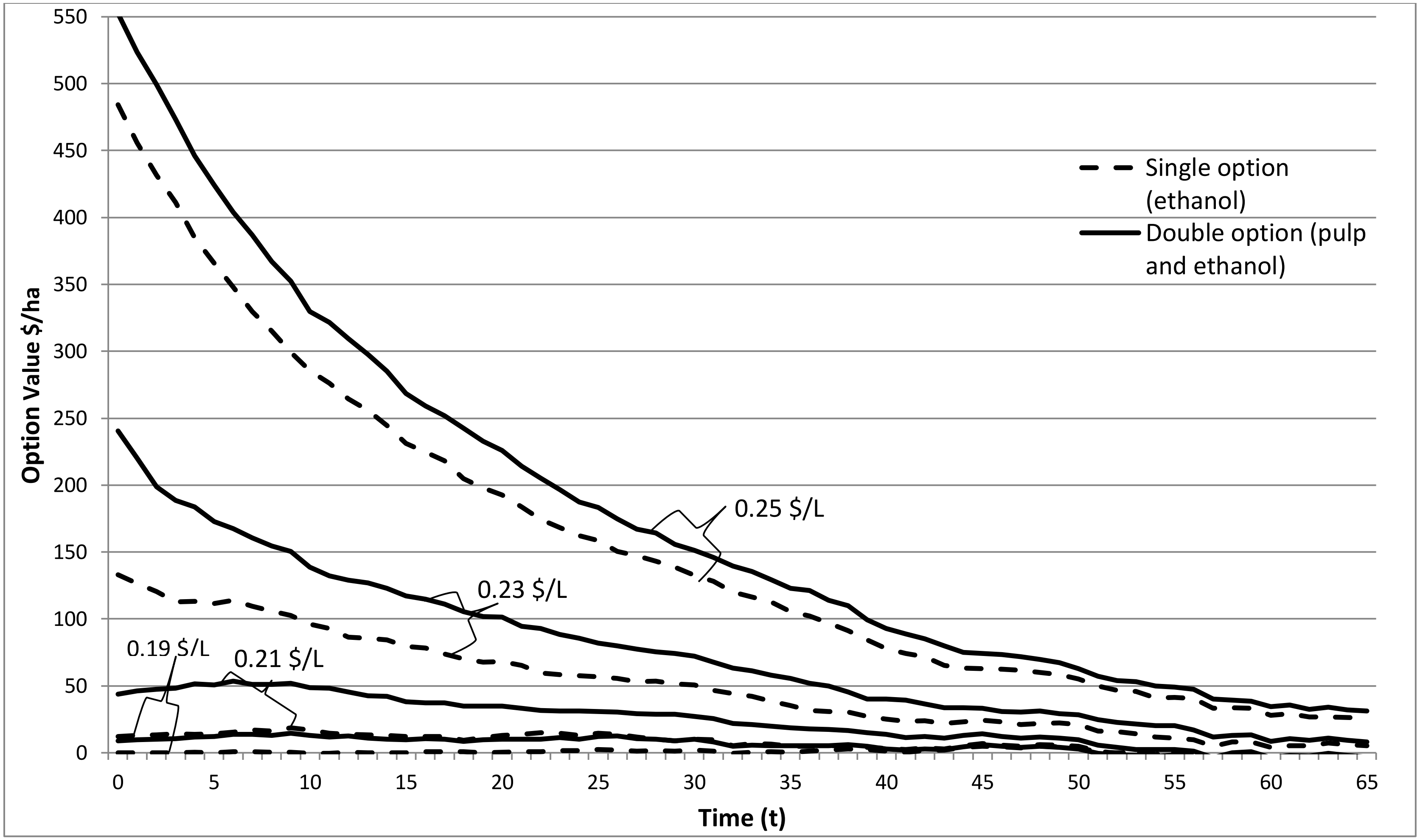
Comparing the single and double option models at the different subsidy levels, I find that the magnitude of difference (Table 3-4) is small when the subsidy is 0.19 $/L and 0.21 $/L. The largest option value gain (Table 3-4), as a result of the double option, occurs when the subsidy is 0.23 $/L, whereas at the highest subsidy, 0.25 $/L, the gain is reduced. The reduced option value gain at the 0.25 $/L subsidy is likely due to the high ethanol value crowding out the pulp option. Table 3-4 shows the magnitude of option values for both models at t=0. The option values at the start of the simulation period reveal the value that each option has to the landowner before the initial land use decision is made. For example, the landowner who is given a 0.25 $/L ethanol subsidy in the double option model faces an option value of 552.26 $/ha going forward by having the option to choose a land use and an output for poplar plantations.

Table 3-4: Option values ($/ha) at t=0 for different ethanol subsidies

Subsidy	Model		
$/L	Single (Ethanol)	Double (Ethanol + Pulp)	Difference
0.11	0	0	0
0.19	0	8.99	8.99
0.21	12.10	43.76	31.66
0.23	132.80	240.63	107.83
0.25	484.19	552.26	68.07

The probability of plantation land use at the different subsidy levels for the single and double option models are shown in Figure 3-2. Again, dotted lines represent the values for the single option model, whereas the solid line represents the double option model. Overall, for both models, I find that the probability of establishing a plantation increases as the subsidy level increases. At the 0.19 and 0.21 $/L subsidy levels, the probability of plantation land use, for both models, starts at zero and then increases until approximately period 25. Increasing the subsidy to 0.23 $/L and 0.25 $/L causes a threshold to be crossed in both models. The probability of plantation land use is now 1 at $t=0$ (Figure 3-2), representing an immediate allocation of land to poplar plantations. The probabilities, however, start to drop off around period 20 due to the assumed growth in the simulated agriculture land values, as compared to the constant mean reverting ethanol and hardwood pulp prices.

Furthermore, the addition of the hardwood pulp output option generally increases the probability of plantation land use. At a subsidy of 0.19 $/L, the probability increases from close to zero in the single option model to a high of 0.12 (Figure 3-2) in the double option model at period 20. Increasing the subsidy further to 0.21 $/L causes the difference to grow even larger.



Note: The base ethanol subsidy level of 0.11$/L resulted in an option value of 0 across the entire period.

Figure 3-1: Option values ($/ha) at different ethanol subsidy levels ($/L)

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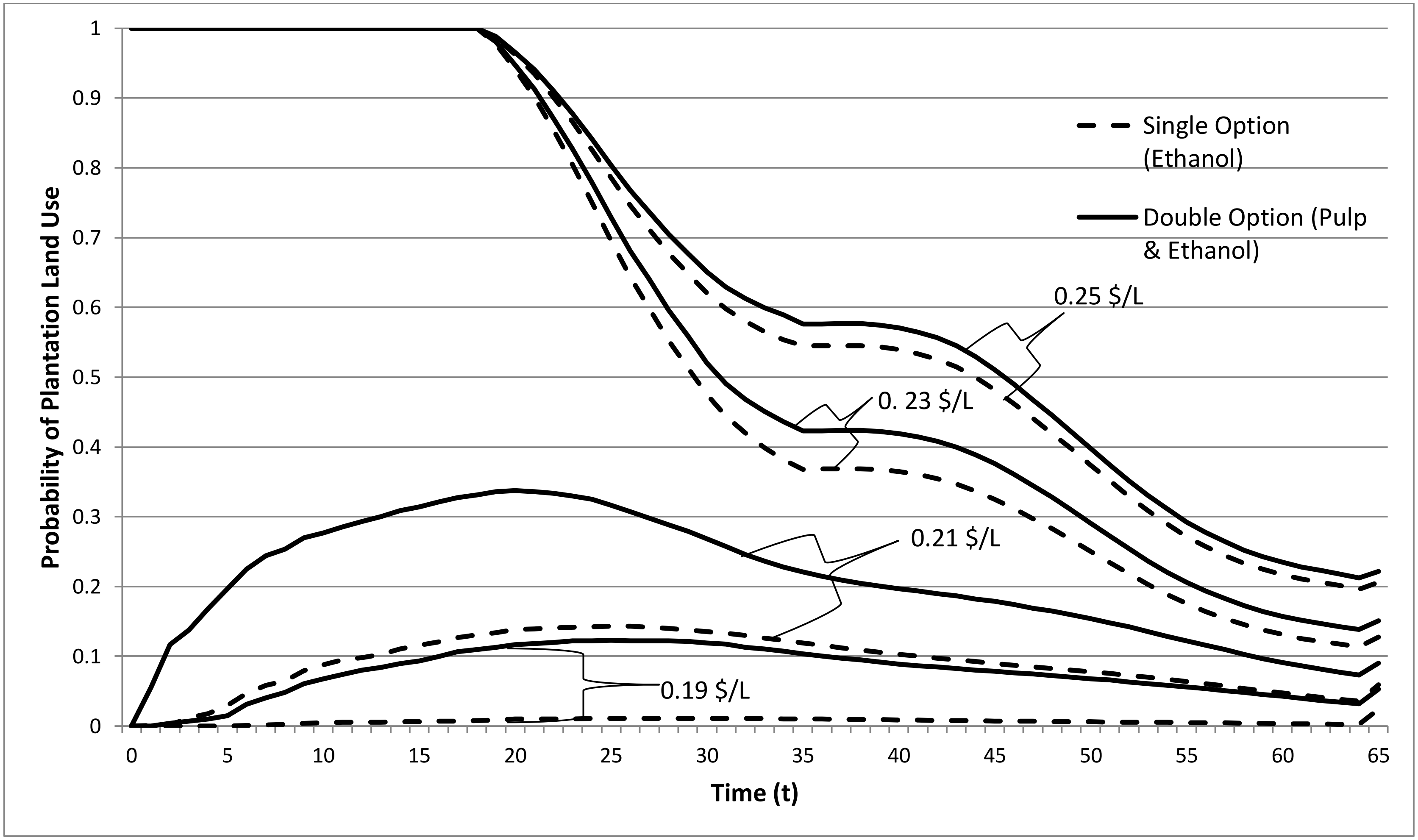
The inclusion of the additional option results in the peak plantation land use probability being 0.2 greater than the single option model (Figure 3-2), at period 20. The reason that hardwood pulp option at the 0.21 $/L subsidy has a larger effect than at 0.19 $/L and even the baseline (0.11 $/L) is that the introduction of the additional option is not significant enough by itself to induce land change. While the ethanol subsidy remains low, either 0.11 $/L or 0.19 $/L, the landowner is unwilling to establish a plantation based solely on a pulp price that may only be periodically be above its average. When the ethanol subsidy increases to 0.21 $/L, the combined effect of a higher ethanol price and the additional output market appears to be enough to significantly increase the probability that the landowner establishes a plantation. However, even with the additional option, at the low subsidy levels it appears that land use change from agriculture to poplar plantations is generally unlikely, and if it occurs, may not happen immediately. The differences between the single and double option model at the two highest subsidies, 0.23 and 0.25 $/L, are considerably smaller than the differences at lower subsidies, 0.19 and 0.21 $/L. The reason for the decrease in the probability gaps is that the pulp prices now have less of an impact because the value of ethanol is consistently high given the large subsidy. Therefore, at subsidies of 0.23 $/L and greater, the double option model behaves similar to the single option model.



Note: The base ethanol subsidy level of 0.11$/L resulted in a forestry land use probability of 0 across the entire period

Figure 3-2: Probability of plantation land use at different ethanol subsidy levels ($/L).

2.4.3 Agriculture Land Value Results

Sensitivity analysis is conducted at different starting agriculture land values to identify current potential land values that result in poplar plantation adoption. By assessing different land values it is possible to identify potential sites in Alberta for conversion. The current agriculture land value was assumed to be 2,000 $/ha and the sensitivity analysis is carried out at initial land values of 1,000, 750, 500, 100 $/ha.

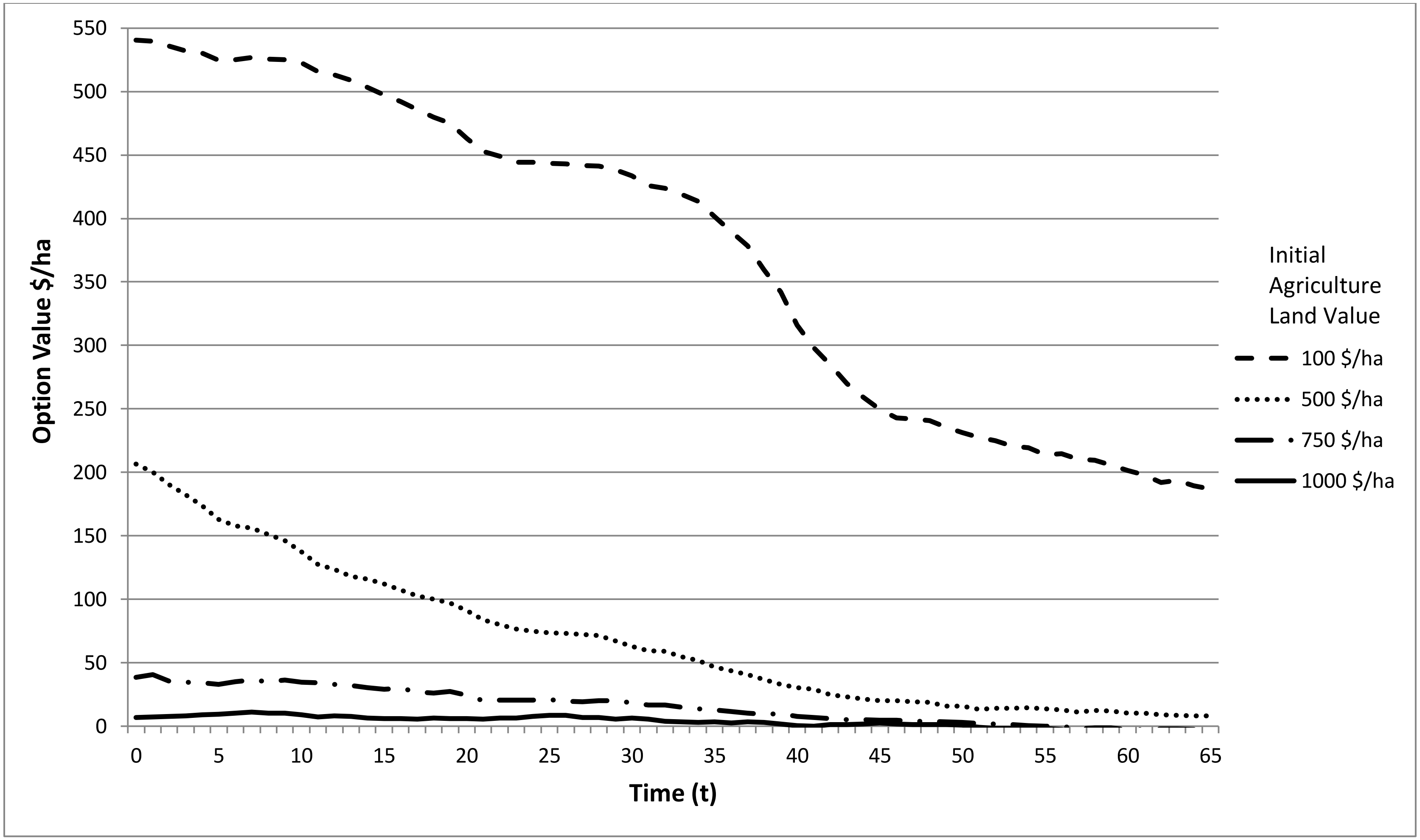
In the single option model, the probability of plantation land use and option values are zero across the simulation period for all agriculture land values analyzed. The reason for the zero probabilities and option values is that given the price and subsidy (0.11 $/L) for ethanol, the expected value of a plantation that only produces ethanol is negative.

For the double option model, as agriculture land values decrease, there are increasingly large option values at *t=0* (Table 3-5). This result signals that the additional option represents a significant value to landowners when they make the initial land use decision, particularly at the lower agriculture land values of 500 and 100 $/ha. As shown in Figure 3-3, however, the option values begin to decrease immediately and continue to do so until the end of the 65 year period, though option values associated with 100 $/ha agricultural land values remains relatively large at the end of the simulation.

Figure 3-4 shows that, for the double option model, once the hardwood pulp option is introduced and the starting agriculture land values is lowered to 1000 $/ha, there is a small probability, approximately 0.1, of the land being allocated to poplar plantations after 17 years. The probability of plantation land use increases as the initial agriculture land values decrease. The sale of poplars for hardwood pulp is driving land use change at these lower agriculture land values, given the negative expected value of an ethanol plantation. At 750 $/ha a substantial chance of land allocation to poplar plantations occurs after 3 years, with the probability of plantation land use rising above 0.6 after 10 years. At initial agriculture land values of 500 and 100 $/ha there is an immediate change from agriculture to poplar plantations. Most increased plantation probabilities are, however, subject to later period decreases as the value of agriculture land grows. At 65 years, the agriculture land that started at 1000 and 750 $/ha has increased in value enough to make poplar plantations less than 50% likely. With starting values of 500 $/ha, poplar plantations remain more likely than not, the chosen land use at 65 years into the simulation. Moreover, the 100 $/ha is the only scenario found in all sensitivity analyses to result in a probability of poplar plantation land use close to 1 for the entire 65 year simulation.

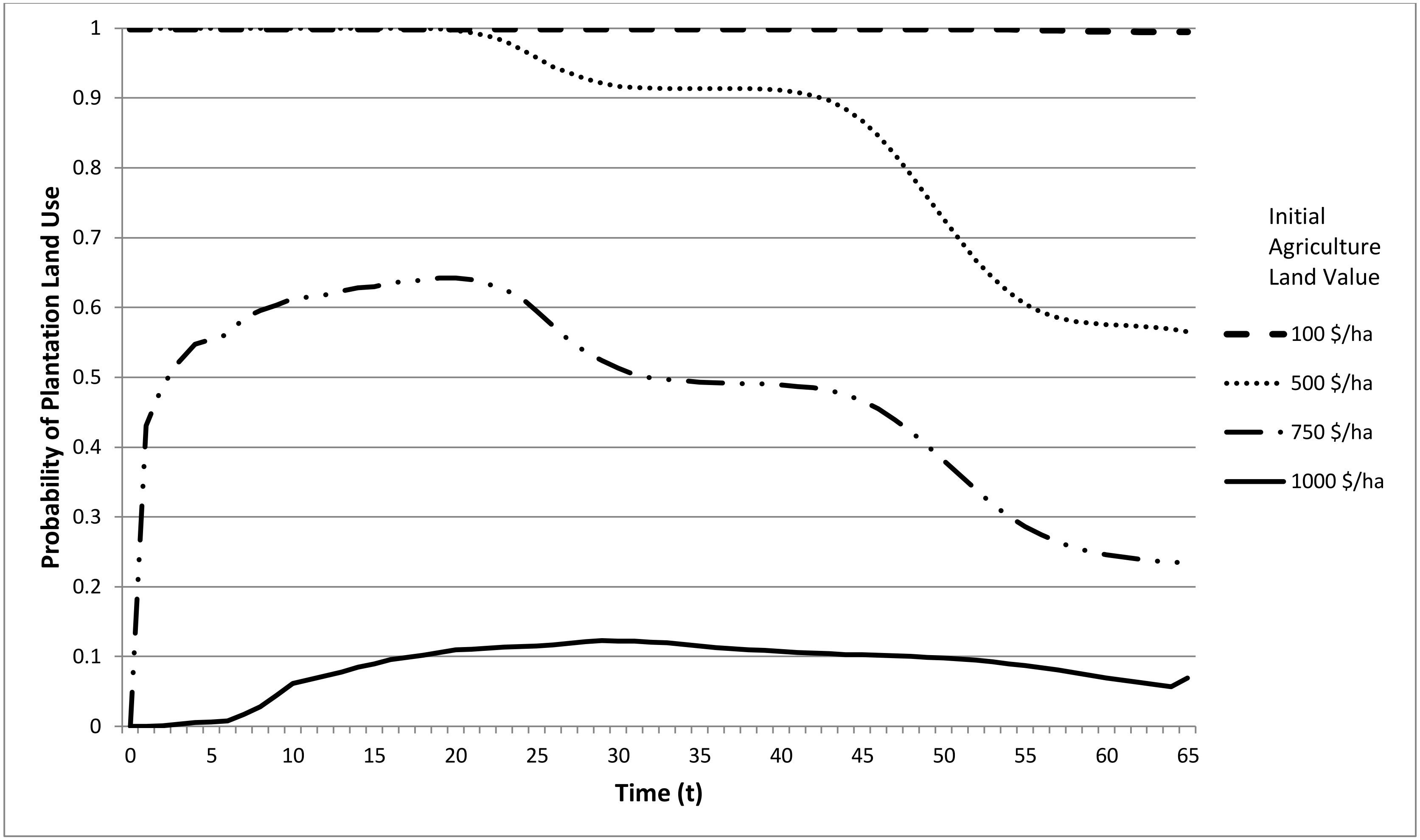
Table 3-5: Option values ($/ha) at t=0 for different agriculture land values

Agriculture Land Value	Model		
$/ha	Single (Ethanol)	Double (Ethanol + Pulp)	Difference
2000	0	0	0
1000	0	6.938	6.93
750	0	38.48	38.46
500	0	206.68	206.68
100	0	540.45	540.45



Note Sensitivity analysis on the single option model resulted in 0 $/ha option values for all starting agriculture land values. Furthermore, the baseline starting agriculture land value of 2000 $/ha resulted in an option value of 0 $/ha for the length of the simulation.

Figure 3-3: Option values ($/ha) at different agriculture land values ($/ha) [double option model only]



Note Sensitivity analysis on the single option model resulted in a for all starting agriculture land values. Furthermore, the baseline starting agriculture land value of 2000 $/ha resulted in a probability of plantation land use of 0 for the length of the simulation.

Figure 3-4: Probability of plantation land use at different agriculture land values ($/ha) [double option model only]

2.5 Conclusion

The first objective of this study is to investigate the differences in modelling potential land use change, from private agriculture land to improved poplar plantations, between a single option and a double option approach. A simulation based real options land use change model from Hauer et al. (in process) is adopted and expanded to include an alternative output market to ethanol. Therefore, the impact on the competitiveness of poplar plantations using two models is assessed. The first model assumes landowners have a single option: to convert agriculture land to poplar plantations which only produce ethanol. The double option model allows landowners to choose the land use, as well as whether to sell any plantation harvest for hardwood pulp or ethanol depending on which output will result in the largest return. By doing so, this paper fills a gap in the literature by framing the land use change decision in the context of there being multiple options considered by the landowner.

Overall, the double option model resulted in larger option values and increased probabilities of land being allocated to plantations at each subsidy level. This finding could be an important factor in policy decisions. If increased ethanol support is given, policy makers may not want to restrict poplar plantation landowners to selling their stands for just ethanol. Giving landowners the option of an alternative market should increase plantation production, for which some of the plantations would be used to produce ethanol. Furthermore, the positive difference in option values between the double and single option models reinforces the finding that there is value to the landowner owner of having an additional output market. Plantations on private land become more attractive to landowners when they are able to decide between outputs, as they are able to sell for one while the price of the other is low. This conclusion is, in part, attributable to the mean reverting behaviour of both the ethanol price and hardwood pulp price. Being able to defer the harvest while waiting for one of two prices to increase to an above average level increases the chances of a favourable return on the plantation investment.

Previously, much of the land use change literature modelled landowner behaviour with a single option to choose the land use. This approach, however, may be too simple and could result in distorted empirical findings. The results of this study suggest that expanding the model to include the additional options available provides value to landowners and may impact their land use decision. For instance, at an ethanol subsidy of 0.21 $/L I found that the double option model increased the option values at t=0 by 31 $/ha (Table 3-4) and increased the minimum rotation age probability of plantation land use by 0.2 (Figure 3-2), as compared to the single option model. In the agriculture land value sensitivity analysis, the single option model resulted in zero option values and probability of land use change; however, the double option model resulted in positive option values and probabilities for all land values considered. The approach in this paper may provide a better estimate of the expected values of land uses because it takes into account multiple potential land uses. Furthermore, the double option model may better reflect the land use and harvest decisions of the landowners by considering the multiple options available.

The second objective of this paper is to examine the conditions required to induce agriculture land conversion to poplar plantations. With the baseline parameters, for both the single and double option models, poplar plantations may not be a viable private land use option in Alberta. Both option values and plantation land use probabilities indicated that land will not be allocated to improved poplar production. Sensitivity analysis was conducted on both models, first at increasing ethanol subsidies, and then at decreasing starting agriculture land values.

For the single option model, an increase in the ethanol subsidy to 0.23 $/L results in immediate plantation land use. For the double option model, there are positive probabilities of plantation land use at the 0.19 and 0.21 $/ha subsidies, however, similar to the single option model a subsidy of 0.23 $/L is required to ensure an immediate plantation establishment. In all cases, the simulated agriculture land values grew large enough so that there were significant declines in option values and land use probabilities in the later periods of the simulation. At no subsidy level for either option model was the probability of plantation land use above 0.3 by the end of the 65 year period (Figure 3-2). These results would seem to indicate an uncertain future for poplar plantations. Policy makers may be unwilling to commit to increased subsidy levels if there is a chance that the effects of doing so are short lived. Furthermore, given the large sunk costs of establishing a cellulosic ethanol industry, companies may be reluctant to build processing plants in the face of an uncertain supply of biomass.

The agricultural land value analysis revealed that no matter the starting price of agriculture land, poplar plantations in the single option model are unable to compete for land. This result arises because when all parameters, except initial agriculture land value, are held constant at the baseline level (Table 3-3) the expected value of plantation land used for ethanol production is negative. In order to induce land use change to poplar plantations in the single option model, even at low initial agriculture land values, a change in the mean price, subsidy or production cost level would likely have to occur. For the double option model, when the value of land is 750 $/ha there is a large probability of plantation land use after year 3 (Figure 3-4). At starting agriculture land values of 500 and 100 $/ha there occurred an immediate allocation of land to poplar plantations. The lowest initial agriculture land value of 100 $/ha was the only sensitivity analysis scenario examined where the probability of plantation land use remained close to 100% over the entire study period (Figure 3-4). Therefore, in order to ensure that improved poplar plantations are present beyond the first rotation, without additional production support or a market change, they will likely have to be grown on marginal lands. This result may not be encouraging for advocates of cellulosic ethanol production, which represents one of the major draws to improved poplars. While the landowner is now converting land to plantations, it is possible that the majority of the harvests are being sold for hardwood pulp rather than ethanol production. In order to observe an ethanol driven land use change at any of the initial agriculture land values, an ethanol price, or subsidy, increase or cost decrease would likely have to occur.

The best case for improved poplar plantations may be represented by the findings of both sensitivity analyses. If the goal of policy makers is to establish a cellulosic ethanol industry, then increased ethanol subsidies are likely required; however, policy makers may be able to limit the increase in ethanol subsidies if the land that plantations are competing with has a lower value. While the agriculture land values in Alberta may currently be too high, there is the possibility that in other Canadian provinces the value of land is lower. One issue that may arise with establishing plantations on lower valued agriculture land is that there would likely be a decrease in the yield of poplar given the soil quality and climate conditions associated with that land.

Although the current market conditions in Alberta appear unfavorable to the establishment of improved poplar plantations, there is the potential for alternative outputs, government support and different land sites to make a difference. As renewable fuels become more sought after, policy makers may wish to establish new production sources. In addition, technological advancements may also improve the competitiveness of poplar plantations either in terms of cellulosic ethanol production cost decreases or improved poplar yield increases. This paper demonstrates that the competitiveness of poplar plantations may be improved when multiple options, in combination with policy support and price changes, are considered.

Appendix 1: Algorithm for solving land use change, options model [adapted from Hauer et al. *in process*]

Initial Steps

1. Let j=1,….,J represent trials of yearly time series simulations of agriculture land prices, hardwood pulp prices, and ethanol prices.
2. Given the definition of j, $p_{t,j}^{p}$ represents the simulated hardwood pulp price in period t for the jth trial, $p_{t,j}^{e}$ represents the simulated ethanol price in period t for the jth trial, and $X_{t,j}$ represents the simulated agricultural land price in period t for the jth trial.
3. Let $\overline{p^{p}}$ be the expected long run mean price for hardwood pulp and let $\overline{p^{e}}$ be the expected long run mean price for ethanol.
4. Let V be the soil expectation value for improved poplar plantations, which is maximized given the two plantation outputs, using the traditional Faustmann optimal economic rotation calculation for forests as follows:

$$V = \max_s\left(\frac{\overline{p^e}\, v_s^e - C(1+i)^s}{(1+i)^s - 1}, \frac{\overline{p^p}\, v_s^p - C(1+i)^s}{(1+i)^s - 1}\right).$$

Note: For the single option model, where the only plantation output is ethanol V becomes:

$$V = max_s \frac{\overline{p^e}\, v_s^e - C(1+i)^s}{(1+i)^s - 1}$$

5. For periods t=66,….,100, let $\widehat{W}_{t0,j}^{f} = R_{t0,j}^{f} = \max(0, V, X_{t,j} - C^{fa})$ be the estimated expected value and the realized value for plantation land immediately after harvest with the option to switch to agriculture.

6. For period t=66, let $R^a_{t,j} = \max(0, V, X_{t,j})$.

7. For j=1,…,J and t=0,…,99 compute the following Laguerre Polynomial functions of the prices:

   a. $L_0(P^p_{t,j}) = \exp(-(p^p_{t,j}/\overline{p^p_t})/2)$

   b. $L_1(P^e_{t,j}) = \exp(-(p^p_{t,j}/\overline{p^p_t})/2)(1-(p^p_{t,j}/\overline{p^p_t}))$

   c. $L_0(P^e_{t,j}) = \exp(-(p^e_{t,j}/\overline{p^e_t})/2)$

   d. $L_1(P^e_{t,j}) = \exp(-(p^e_{t,j}/\overline{p^e_t})/2)(1-(p^e_{t,j}/\overline{p^e_t}))$

   e. $L_0(X_{t,j}) = \exp(-(X^e_{t,j}/\overline{X_t})/2)$

   f. $L_1(X_{t,j}) = \exp(-(X_{t,j}/\overline{X_t})/2)(1-(X_{t,j}/\overline{X_t}))$

   Note: Hauer et al. (in process) explains that all the prices are normalized first by dividing by the mean prices over all trials in a period. While this step is not required by the Laguerre Polynomial function, having normalized prices ensures that the price functions are not “too close” to zero.

Algorithm

1. Set t=65 and s=35.

2. Define maximization of the total net benefit received from plantation land sold for either hardwood pulp, p, or ethanol, e, as (Equation 3.3):

$$B_{ts} = max(b^e_{ts}\, v^e_s\, , b^p_{ts} v^p_s),$$

Note: For the single option model where the only plantation output is ethanol, it is assumed that $b_{ts}^{p} v_{s}^{p} = 0$ and the total net benefit defaults to the net benefit received from ethanol production.

3. For j=1,…,J compute $R_{t+s,s,j}^{f} = \max(B_{t+s,s,j} + R_{t,0,j}^{f}, 0)$, the realized value of harvesting if a plantation is harvested at the end of the harvesting window. Set the optimal rotation age for each j, that is planted at period t, to $s_j^*(t) = s$ (s = 35).

4. Set s=s-1.

5. Using ordinary least squares estimate the expected value of deferring harvest by 1 year, $\hat{E}[W_{t+s+1,s+1,j}^{f}](1+i)^{-1}$ (Equation 3.2) for each trial, j, with the following regression model:

$$\frac{R_{t+s+1,s+1,j}^{f}}{1+i}$$

$$=\beta_0 + \beta_1 L_0(P_{t,j}^{e}) + \beta_2 L_1(P_{t,j}^{e}) + \beta_3 L_0(P_{t,j}^{p}) + \beta_4 L_1(P_{t,j}^{p}) + \beta_5 L_0(X_{t,j}) +$$

$$\beta_6 L_1(X_{t,j}) + \varepsilon_j$$

Note: For the single option model both $L_0(P_{t,j}^{p})$ and $L_1(P_{t,j}^{p})$ = 0 and the right hand side of the regression (and all subsequent regressions) becomes:

$$\beta_0 + \beta_1 L_0(P_{t,j}^{e}) + \beta_2 L_1(P_{t,j}^{e}) + \beta_3 L_0(X_{t,j}) + \beta_4 L_1(X_{t,j}) + \varepsilon_j$$

6. For each j, compute the expected value of harvesting immediately using the following:

$$B_{t+s,s,j} + \widehat{W}_{t+s,0,j}^{f}$$

where the first term is the net benefit received for the harvest, see step 2, and the second term is the estimated bare land value calculated in Initial step 5, if t+s>65, or in Algorithm step 14 if t+s<=65.

7. Given the state of prices, determine the optimal rotation decision to either harvest immediately or defer harvest, according to the following test:

$$\text{if} \quad B_{t+s,s,j} + \widehat{W}^{f}_{t+s,0,j} \geq \hat{E}[W^{f}_{t+s+1,s+1,j}](1+i)^{-1}$$

then harvest in the current period and set the optimal rotation age for trial j as $s_j^*(t) = s$. In addition, set the realized value for each trial j as follows:

$$R^{f}_{t+s,s,j} = B_{t+s,s,j} + R^{f}_{t+s,0,j}$$

Otherwise, defer the harvest decision one year, $s_j^*(t)$ remains unchanged, and the realized value is updated to:

$$R^{f}_{t+s,s,j} = R^{f}_{t+s+1,s+1,j}/(1+i).$$

8. If s>m, where m is the minimum rotation period, then go to step 4. Otherwise go to step 9.

9. For each j, discount the realized plantation value to time t and subtract the cost of establishing the plantation as follows:

$$V^{f}_{t,0,j} = R^{f}_{t+m,m,j}/(1+i)^{m} - C.$$

10. For each trial j, estimate the expected value of establishing an improved poplar plantation $E(V^{f}_{t,0,j}) = E\left[W^{f}_{t,0,j}\right](1+i)^{-1} - C$ with the possibility of switching back to agriculture in the future, using the following regression model:

$$V^{f}_{t,0,j} = \beta_0 + \beta_1 L_0(P^{e}_{t,j}) + \beta_2 L_1(P^{e}_{t,j}) + \beta_3 L_0(P^{p}_{t,j}) + \beta_4 L_1(P^{p}_{t,j}) + \beta_5 L_0(X_{t,j}) + \beta_6 L_1(X_{t,j}) + \varepsilon_j$$

and then using the above regression calculate the fitted values to compute $E(V^f_{t,0,j})$.

11. For each j, compute the realized value of agriculture, with the option to later switch to poplar plantations, as follows:

$$V^a_{t,j} = \frac{\delta X^a_{t,j} + R^a_{t+1,j}}{(1+i)}$$

12. For each j, estimate the expected value of agriculture, $E(V_t^a)$ (see Equation 3.5) , with the option to later switch to plantations, by first estimating the following regression model:

$$V^a_{t,j} = \beta_0 + \beta_1 L_0(P^e_{t,j}) + \beta_2 L_1(P^e_{t,j}) + \beta_3 L_0(P^p_{t,j}) + \beta_4 L_1(P^p_{t,j}) + \beta_5 L_0(X_{t,j}) +$$

$$\beta_6 L_1(X_{t,j}) + \varepsilon_j$$

and then use the fitted values to compute $E(V^a_{t,j})$.

13. Estimate $W^a_{t,j}$ (Equation 3.5) as follows:

$$W^a_{t,j} = max\left(0, E(V^a_{t,j}), E(V^f_{t,0,j})\right)$$

14. Estimated $W^f_{t,0,j}$ (Equation 3.6) for each trial as follows:

$$W^f_{t,0,j} = max\left(0, E(V^f_{t,0,j}), E(V^a_{t,j}) - C^{fa}\right)$$

15. For each j, first set $R^a_{t,j} = 0$ as the minimum realized value of agriculture land, and then compute the realized value of agriculture land using:

$$R^a_{t,j} = \begin{cases} V^a_{t,j} & \text{if } E(V^a_{t,j}) \geq E(V^f_{t,0,j}) \text{ and } E(V^a_{t,j}) \geq 0 \\ V^f_{t,0,j} & \text{if } E(V^a_{t,j}) < E(V^f_{t,0,j}) \text{ and } E(V^f_{t,0,j}) \geq 0 \end{cases}$$

This step sets the realized value of agriculture land equal to the realized benefits for agriculture (step 12) if the expected value of the agriculture option is greater than the expected value of the plantation option. If not, the realized value of agriculture land is set to the realized benefits for the improved poplar plantation (step 10), as the expected value of the plantation option is greater than the expected value of the agriculture option.

16. For each j, first set $R_{t,0,j}^{f} = 0$ as the minimum realized value of land currently allocated to improved poplar plantations, and then compute the realized value of plantation land using:

$$R_{t,0,j}^{f} = \begin{cases} V_{t,j}^{a} - C^{fa} & \text{if } E(V_{t,j}^{a}) - C^{fa} > E(V_{t,0,j}^{f}) \text{ and } E(V_{t,j}^{a}) - C^{fa} \geq 0 \\ V_{t,0,j}^{f} & \text{if } E(V_{t,j}^{a}) - C^{fa} \leq E(V_{t,0,j}^{f}) \text{ and } E(V_{t,0,j}^{f}) \geq 0 \end{cases}$$

This step sets the realized value of plantation land equal to the realized set of benefits for agriculture (step 12) minus the cost of conversion if the expected value of agriculture minus the conversion costs is greater than the expected value of having the land remain allocated to poplar plantations. If this holds, the land switches to agriculture use. If not, the land stays allocated to plantations and the realized set of benefits for improved poplar plantations is set to equal the realized land value of currently existing plantations.

17. If t>0, then set t=t-1 and return to step 1. If t=0, stop.

Chapter 4: Conclusions

The goal of this thesis is to provide a better understanding of the factors driving, and the potential future establishment of, poplar plantations in Alberta. While these poplars have the potential for genomic improvements, regulations prohibit their development on publicly owned lands. As a result, improved poplars will have to compete with agriculture for private land in Alberta. Before, this competition can be examined, knowledge of the future price behaviour of poplar outputs, hardwood pulp and ethanol, is required. Chapter 2 examined these prices using time series techniques to characterize the process and volatility that drive prices. The results indicate that hardwood pulp and ethanol price returns are stationary, and suggest that both price levels do not contain unit roots. The paper models the underlying price process of both hardwood pulp and ethanol as reverting around a mean. Autoregressive conditional heteroskedasticity effects are tested for and found to be present in both price series. The result is that a generalized autoregressive conditional heteroskedasticity (GARCH) approach is used to characterize the price volatility of each series. By utilizing a GARCH approach, price volatility is allowed to be time dependent and fluctuate according to past error disturbances and past volatilities. The GARCH specifications are modelled with autoregressive moving average components in mean equation to capture both the time dependent variance and mean reverting behaviour. The information gained regarding price behaviour in Chapter 2 is used to inform price simulations required by the land use change model presented in Chapter 3.

The land use change model uses a real options approach to analyze the competitiveness of poplar plantation for land against existing agriculture uses. Two base models are examined. The single option model considers only one option for landowners: to convert agriculture land to poplar plantations produced for ethanol. The double option model introduces the additional option of choosing whether to harvest the plantation for hardwood pulp and ethanol. I find that overall the double option model increases the value of the plantation land use option as compared to the single option model. Under the baseline parameters, however, the results for both option models indicate that improved poplars are unable to compete with agriculture for private land. Sensitivity analysis is conducted on the magnitude of the ethanol subsidy and then the starting agriculture land value. The sensitivity analysis reveals that the inclusion of the hardwood pulp output in the double option model improves the competitiveness of poplar plantations as compared to the single option model. Furthermore, large increases in subsidies or large decreases in agriculture land values are necessary to ensure that landowners switch to plantation production immediately. Although, over time the growth in agriculture land prices diminished the competitiveness of plantations. This result, however, is conditional on the assumed constant agriculture growth rate in the model. Over a long period it is not certain that growth rates, of both agriculture land prices and poplar output mean prices, will remain constant.

The findings presented in Chapters 2 and 3 are important for a number of reasons. First, they provide important information to landowners and producers regarding the future potential of different land uses. Having knowledge regarding the behaviour of prices allows landowners to better understand market conditions, demand and supply fluctuations, and potential future payoffs. Second, the price study in Chapter 2 may also be beneficial to policy makers who want to understand the future of poplar output markets and tailor regulations to future conditions. The land use change model results may also be useful in this respect. While current conditions may not encourage the establishment of poplar plantations, the sensitivity analysis reveals that increased ethanol subsidization may improve plantations' competitiveness. In addition, if plantations are established on lower valued agriculture land, that too may improve the ability of poplar to compete with agriculture land. Furthermore, the land use change model indicates how the land competition may be altered given the outputs considered. Allowing for multiple outputs, such as hardwood pulp and ethanol, provides landowners with different options at the time of harvest, thereby minimizing the risk of below average prices.

Chapters 2 and 3 also seek to fill gaps in the forest and land economics literature. The time series analysis adds to the existing debate whether forest prices follow random walks or mean revert, in favour of the latter. In addition, this thesis examines two prices that have not previously received consideration in the literature with respect to GARCH specifications. The third chapter of this thesis provides a multiple option view to examining competition between forestry and agriculture on private land in Alberta.

There are a number of areas where further investigations could build on this research. The multiple option approach is not limited to the options presented in this paper. The options model could be expanded to include a third land use option, such as recreational land, or a third poplar output, such as carbon sequestration. Such an approach could be used to expand the landowners' choice set to represent the land uses and outputs available in a particular region or to account for future considerations. Moreover, in the current model, a landowner is not able to abandon the plantation before age 19, at which time they may harvest the poplars and then convert the land to agriculture. It could, however, be the case that the growth rates or prices of hardwood pulp and ethanol reach a level where abandonment of the plantation becomes the optimal decision, even when considering the cost to convert the plantation to agriculture. Future models may want to account for such cases and allow the landowner to abandon the plantation before age 19.

The future for improved poplar plantations in Alberta presented in this paper is not without challenges. Agriculture land values are expected to grow steadily whereas hardwood pulp and ethanol prices appear to revert around a constant mean. These price paths suggest that market shifts, either in poplar output or agriculture land prices, would likely have to occur for plantations to become competitive. In order to analyze market shifts or structural changes in the mean reverting prices, future research could include simulating the prices with a stochastic mean level. This analysis would be useful in assessing a potential future for ethanol prices where increased demand results in a permanent shift in the mean price of ethanol, or conversely where the mean of one poplar output drops substantially. Furthermore, the yields and growth rates of improved poplar may play a large role in determining their future. Factors such as soil conditions, climate, and potential genetic improvements all have the ability to affect the yields and growth of poplar plantations. Given the above considerations, future research may include modelling the potential for jumps in mean price levels or examining changing growth rates in agriculture prices. Furthermore, examining different poplar yields or soil conditions based on land characteristics outside of Alberta may be useful in investigating the prospects of Canada wide plantation establishment. Given that the production of ethanol from corn or wheat may have undesirable consequences, the desire for alternative fuel sources will likely increase, and cellulosic ethanol produced from improved poplars may become an important commodity in the coming years. The time series investigation and real options analysis of improved poplars presented in this thesis contributes to the understanding of the future of poplar plantations as a source for cellulosic ethanol while taking into consideration alternative output markets and competing land uses.

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