A REAL OPTIONS-NET PRESENT VALUE APPROACH TO ASSESSING LAND USE CHANGE: A CASE STUDY OF AFFORESTATION IN CANADA

Denys Yemshanov*
Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre
1219 Queen Street East, Sault Ste. Marie, Ontario P6A 2E5
dyemshan@NRCan.gc.ca, Ph.705-541-5602, Fax 705-541-5700.

Geoffrey R. McCarney
The Institute of the Environment, University of Ottawa
555 King Edward Ave., Ottawa, Ontario, Canada K1N 6N5
G.McCarney@uOttawa.ca, Ph. 613-562-5800 x1190

Grant Hauer
Department of Resource Economics and Environmental Sociology, Faculty of Agricultural, Life and Environmental Sciences, University of Alberta
515 General Services Building, Edmonton, Alberta, Canada T6G 2H1
ghauer@ualberta.ca,

M.K. (Marty) Luckert,
Department of Resource Economics and Environmental Sociology, Faculty of Agricultural, Life and Environmental Sciences, University of Alberta
515 General Services Building, Edmonton, Alberta, Canada T6G 2H1
marty.luckert@ualberta.ca, Ph. 780-492-5002.

Jim Unterschultz
Department of Resource Economics and Environmental Sociology, Faculty of Agricultural, Life and Environmental Sciences, University of Alberta
515 General Services Building, Edmonton, Alberta, Canada T6G 2H1
Jim.Unterschultz@ualberta.ca, Ph. 780-492-5439.

Daniel W. McKenney
Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre
1219 Queen Street East, Sault Ste. Marie, Ontario P6A 2E5
dmckenne@nrcan.gc.ca, Ph. 705-541-5569.

* Corresponding author

1. INTRODUCTION

Economic analyses of land-use change have often assumed that conversion decisions can be modeled based on the Net Present Value (NPV) of alternative land uses (Adams et al., 1993; Parks and Hardie, 1995). However, actual land use decisions may appear ‘irrational’ when assessed in simple NPV terms, as large areas of marginal agricultural land have been found to persistently remain in agriculture despite NPV comparisons that suggest they could be attractive for other land uses (Parks, 1995; Stavins and Jaffe, 1990). Several other factors may influence land conversion decisions, yet are typically omitted in NPV analyses; including potential irreversibility in land use change (Dixit and Pindyck, 1994; Pindyck, 1995), or the possibility that land owners derive non-market benefits from alternative uses (Parks and Schorr, 1997; Van Kooten et al., 1999).

More recently, econometric models have been used to address some of these broader economic considerations by utilizing actual data of observed land-use change to estimate the relationship between land-use choices and relative returns to investment (Lubowski et al., 2006; Plantinga, Mauldin and Miller, 1999). In fact, several econometric studies of the marginal cost of converting agricultural land in the US provide evidence that economic models based upon NPV decision rules alone underestimate the costs of land use change (Isgin and Forster, 2006; Isik and Yang, 2004; Lubowski et al., 2006; Newell and Stavins, 2000; Plantinga, Mauldin and Miller, 1999; Schatzki, 2003; Stavins, 1999). However, econometric approaches also have limitations. In a detailed econometric analysis, Lubowski et al. (2006) utilize comprehensive data for the contiguous U.S. with repeat observations of land use and land characteristics for 844,000 sample points. This sample land base represents about 74% of the total land area and about 91% of non-Federal land in the contiguous U.S.[i] The authors argue that this fine-scale information on land quality and land use dynamics is a critical determinant of actual land conversion decisions, the omission of which has been a limitation in previous econometric studies (Stavins, 1999). Yet, while this is clearly a comprehensive analysis, such detailed, fine-scale information is unlikely to be available in many locations or jurisdictions. The stricter data requirements necessary to obtain reliable econometric estimates of land use change may therefore preclude their effective application in situations where data are sparse or absent.

As an alternative, we explore a method where the NPV approach to estimating opportunity costs is enhanced by adding a sequential real options model to address potential irreversibility in land use change (Thorsen 1999; Geltner et al., 1996; Malchow-Moeller et al., 2004). Several analytical and empirical models have been developed which show that potential irreversibilities in land-use change may be reflected as the value of a 'real' option in an investment decision (Isgin and Forster, 2006; Isik and Yang, 2004; Schatzki, 2003; Thorsen, 1999; Zinkhan, 1991). Thorsen and Malchow-Moeller (2003) proposed a mutually exclusive real options model to characterize afforestation decisions to plant trees on non-treed land. Geltner et al. (1996) explored the choice between mutually exclusive options in forest management decisions, and Malchow-Moeller et al. (2004) developed a real option model which extends the two exclusive options approach to handle the spatial adjacency problem in forest management decisions. Jacobsen (2007) proposed a numeric solution of the two-option harvest and regeneration decision model by linking the option to harvest the stand with the option to regenerate harvested sites. Cunha and Fontes (2009) proposed real options model for the valuation and optimal harvest timing of forestry investments in eucalyptus plantations. Their model used two sequential options to harvest trees for industrial pulp processing and estimated the option values by solving a stochastic dynamic programming model. Option values have also been noted as good descriptors of rigidities in land use change (Roberts and Lubowski, 2002) and have been shown to be capitalized into the value of agricultural lands (Plantinga et al., 2002). Note, however, that none of these modeling efforts have been developed to produce spatially explicit projections of land use change, the task that we address in this paper.

The intuition behind applying a real options model to an afforestation decision is to capture both the fixed costs of undertaking land-use conversion and decision-making inertia (due to the multiple-year rotation lengths of forest 'crops') which creates an incentive for landowners to delay or abandon afforestation decisions. When trees are planted on agricultural land, the landowner loses flexibility to convert the land back to agriculture (or other land-uses) - tree plantations can't usually be re-converted to agriculture before commercial harvest without significant financial costs. The anticipated loss of managerial flexibility can make land-owners reluctant to convert agriculture to forestry and thus would require considerably higher anticipated premiums from forest plantations to trigger land conversions. Another implication is that landowners may choose to remain in one-year agricultural production cycles to take advantage of the managerial flexibility to change the crop cycle every year, so that they can more easily adjust to possible future changes in agricultural markets, climate and technology.

Our modeling real options framework captures this potential loss of flexibility by adding a switching value to the net present value of the land use cycle, often called a spread option value. This framework provides a more complete depiction of the opportunity costs of planting trees on agricultural lands and alters the estimates of the opportunity costs of land-use change in an agriculture-forestry production system. The result in practice is similar to the hysteresis effect described by Dixit (1989a,b): for a given area, there will be a range of expected net returns where the relative NPV's suggest land use should change, but the land owner will not change land use (i.e. agricultural land will not be afforested, but land in forest plantation will not revert to traditional agricultural crops).[ii]

We argue that a combined real options-NPV approach to evaluating land-use decisions performs better in approximating patterns of land use change than traditional methods based on plain NPV criteria. Furthermore, by incorporating such an approach within a spatially explicit, modeling framework, land use decisions may be better estimated in data-poor environments where the potential to apply econometric approaches is limited. Spatially explicit models can account for regional variation in growth rates, land values and management costs and delineate financially attractive regions for each particular land use. The use of geographical data also leads to more precise estimates of regional net return values and land conversion patterns that may help both policy-makers interested in broader-scale land use patterns and land-owners/investors in a normative or prescriptive sense.

In section 2 we explain our methods, beginning with a bioeconomic model and then integrating option values. In Section 3, we develop a case study that applies our modeling framework to estimate the afforestation potential of private agricultural lands in Alberta. Conclusions are presented in section 4.

2. METHODS

We begin in Section 2.1 with a bio-economic model of land use change based solely on NPV calculations, and then proceed to integrate real option values into this framework by describing: (i) how real options enter the decision problem for landowners in general terms (Section 2.2.1); (ii) how option values are computed (Section 2.2.2); and (iii) how simulations including real options are performed (Section 2.3).

2.1. The bioeconomic model

Our starting point is the Canadian Forest Service Forest Bio-economic Model (CFS-FBM; Yemshanov et al., 2007). The model is designed to link biophysical models of agricultural and forest plantation productivity with an economic cost-benefit analysis framework. Simulations within the CFS-FBM are performed on a year-to-year basis, evaluating investment opportunities for different land-use options over a finite planning horizon. The CFS-FBM is spatially explicit in that it analyses land use options in a spatial, regular grid setting. While some spatial models simulate land use dynamics via conversion probabilities derived exogenously from historical land use dynamics (Verburg et al., 2002, 2004; Verburg et al., 2008) or biophysical information (Chomitz and Gray, 1996; Veldkamp and Fresco, 1996), the CFS-FBM simulates the potential of land conversions directly based on the NPV of alternative land uses.

Given a finite planning horizon S, the CFS-FBM simulates land use decisions for each individual period s by evaluating for each land parcel (map cell) p:

$$LU_{s,p} = \max(\pi^{a}_{s,p}, \pi^{f}_{s,p}) \qquad [1]$$

where $LU_{s,p}$ is a binary land-use selection indicator for land parcel (or pixel) p in period s, which can be allocated to either agriculture or a forest plantation, while $\pi^{i}_{s,p}$, $i=\{a,f\}$, are the expected annualized returns (or land values) to land in agriculture (a) or forest plantation (f), with:

$$\pi^{i}_{s,p} = -c^{i}_{s}(i_{s-1}) + e^{-\delta}E\left[R^{i}_{(s+1),p}\left(p^{i}_{(s+1)}, h^{i}_{(s+1)}, q^{i}_{p}\right)\right] + e^{-\delta}E[\pi^{i}_{(s+1),p}] \qquad [2]$$

Here, index i denotes the land use type (agriculture or forestry in our study), c^{i}_{s} is the cost of planting and establishing land-use i in period s, which is dependent on land-use selection in the previous period since land-use conversion may incur additional costs. $R^{i}_{(s+1),p}$ is the expected revenue from land-use i at the end of period s on land parcel p, which is a function of output price *p*, harvest costs *h,* and biophysical factors *q* for land parcel *p*, and which will determine expected output levels for that site particular to each land-use. Factors entering at the end of the current period / beginning of the next are discounted at rate δ.

2.2. Incorporating a real options framework into the bioeconomic model

2.2.1. *Real options in the landowner's decision problem*

We develop a real options model to incorporate the value of deferring a costly land allocation decision within the NPV-based spatial bio-economic modeling framework of the CFS-FBM. A key characteristic of this model is that the landowner gets to re-evaluate their land allocation decision every period. For agriculture, we consider annual re-evaluation periods that corresponds with crop production cycles. However, for forest plantations, we apply multi-year rotation lengths before a re-allocation of land back to agricultural use can be practically considered. Also, planting forest 'crops' on agricultural lands requires additional investment and, due to the multi-year rotation lengths required by these forest crops, often generates little or no income in the interim.

If land values evolve stochastically, or relative price changes, the landowner may face a situation at a future date where they want to reconsider their land-use decision. If the original land use decision was costly to implement and somewhat irreversible (at least for some period), then these constraints create an option value to maintaining land in the more flexible option. This option value can be implemented within the framework developed above as follows:

$$\Pi_{s,p}^{i} = -c_{s}^{i}(i_{s-T^{i}}) + e^{-\delta T^{i}} E\left[R_{(s+T^{i}),p}^{i}\left(p_{(s+T^{i})}^{i}, h_{(s+T^{i})}^{i}, q_{p}^{i}\right)\right] + e^{-\delta T^{i}} E[\max(\pi_{(s+T^{i}),p}^{a}, \pi_{(s+T^{i}),p}^{f})] \quad [3]$$

where the option value (or *OV*) is captured by the difference:

$$OV_{s,p}^{i} = e^{-\delta T^{i}} E\left[\max\left(\pi_{(s+T^{i}),p}^{a}, \pi_{(s+T^{i}),p}^{f}\right) - \pi_{(s+T^{i}),p}^{i}\right] \qquad [4]$$

for *i={a,f}*. T^{i} is the option's expiration time and used here to capture the rotation length for land-use i (defined by a superscript *i* hereafter), and $\Pi_{s,p}^{i}$ to capture the land value inclusive of option value.

The option value here is driven by the change in the rotation length for agricultural (i=*a*) versus forestry (*i=f*) land use, as well as the nature of the stochastic processes driving the land values in agriculture versus forestry over time. The theoretical implementation of $OV_{s,p}^{i}$ is simplified here by looking ahead from the current year for only one rotation period (that is one more year if land is in agricultural production and one multiple year forest rotation if land is in forestry use). Our estimated option value for changing land use will therefore represent a lower bound on the true option value because it does not consider the value of maintaining options to switch land-uses at times beyond the first rotation and limits the possible choices to the two choices of forestry or agricultural production.

Our use of two land use choices is conventionally implemented in other option value studies, and appears to be a reasonable assumption given that other land uses are uncommon in the study area. Note that the option values are recalculated as a sequence over the simulation period every time the land conversion decision between forestry and agricultural production is evaluated. While this restriction simplifies the calculations of the option values in our spatial application, we acknowledge that it is not strictly necessary. For example, recent studies have demonstrated more complex real options models for switching and replacement decisions as a series of repeated real options (Adkis and Paxson, 2011; Davis and Cairns, 2012; Malchow-Moeller and Thorsen, 2005).

2.2.2. Estimating real options values in the model

To estimate the option values in the landowner's decision problem, we implemented several simplifying assumptions that allow us to make these values tractable in our spatial modeling framework. First, in modeling the stochastic process underlying land values under a particular land use (i.e., forestry or agriculture), we have made a simplifying assumption that the stochastic components of annualized returns (π^i), output price (p^i), harvest costs (h^i) and plantations costs (c^i), for a particular land use type i (i.e., agriculture or forestry) all move together in perfect correlation. This assumption allows us to model land values for a given land use i as a geometric Brownian motion process:

$$d\pi^i = \mu^i \pi^i ds + \sigma^i \pi^i dz \qquad [5]$$

where i denotes the land use type (agriculture or forestry), with the specific drift rate μ^i and volatility σ^i, and dz is a Wiener process. This assumption simplifies the analysis and allows us to employ the Black-Scholes formula to derive the option values for agricultural and forestry land uses. Having agricultural land use values perfectly correlated with crop price effectively makes the difference between prices and costs of agricultural production a single stochastic variable. Note, however, that the correlations between the stochastic variables representing different land uses (i.e., agriculture vs. forestry) could be zero or negative.

Moreover, given our specific case study of hybrid poplar plantations (discussed below), the use of a European- (as opposed to an American-) style option is assumed. The adoption of a European-style option is a simplification because it requires that landowners can only re-evaluate their land-use decision (*sensu* can only execute their option) at the pre-determined rotation length (T^i), as opposed to after each period (s). For agriculture, we assume that $T^i = T^a_{s,p} = 1$ year, hence a re-evaluation of agricultural land use occurs annually. However, for forest plantations, using a European-style option means that landowners are assumed to commit and lock the land when planting trees until the harvest period $T_{s,p}^{f^*}$, which is in our case the optimal economic rotation for land parcel *p,* given the expected land value at time *s.* Multi-year forest rotation periods, $T^{f^*}{}_{s,p}$, versus a one-year agricultural production cycle, $T^{a}{}_{s,p}$, depict the loss of managerial flexibility to switch the land use before the end of the production cycle (i.e., harvesting trees vs. agricultural crops).

We recognize that restricting landowners' capacity to re-consider the land use before the end of the rotation is a fairly strong assumption. However, we undertake this approach to improve the tractability and computational efficiency of the option value calculations in a spatial setting. Moreover, we believe such an approach to be reasonable in the case of hybrid poplars because of economic and biophysical considerations that somewhat restrict the ability of landowners to change land use. The timing of harvest for hybrid poplar is constrained because younger trees are simply not merchantable in the early life of a plantation so the harvested wood won't have much commercial value and a harvest decision would entail committing to a 100% loss. Moreover, the fixed costs of establishing hybrid poplar plantations are substantial and the costs of reversing an afforestation decision (i.e. de-stumping and other land-clearing costs) are quite high, while the marginal gain in each year of plantation growth is quite high for hybrid poplar, particularly close to the optimal rotation length, once the stand is mature. For these reasons, we consider the option of abandoning a hybrid-poplar forest plantation before the optimal rotation age to be unlikely, so that the use of a European-style option and the forest rotation age as an option's expiration period is reasonable.

We implement a discrete approximation of a European spread option that gives the option holder the right to exchange one asset (in our case the "current" land use), for another asset (the " alternative" land-use) at a particular exercise or maturity date. In practice, then, the option value is determined by the expected value of the spread between the stochastic land values of the two potential land management regimes: agriculture or forest plantation and is computed as follows:

$$OV_{s,p}^{i} = \left[e^{-\gamma^i T^i}\pi_{s,p}^{i} + e^{-rT^i}\theta_j^i\right]\left[Z_j^i\phi\left[d_{j1}^i\right] - \phi\left[d_{j2}^i\right]\right] \quad [6]$$

where *i,j* denote the land use type (*i≠j, i,j* ={*a,f*}*,* where *a* is agriculture and *f* is forestry), *r* is the annual risk free interest rate, γ^i is the annual dividend or income rate for land use *i*, T^i is the time to maturity for the current land use (i.e. either $T_{s,p}^{a}$ or $T_{s,p}^{f^*}$), θ_j^i is the component of costs c_s^i specific to the cost of changing land use from current land use *i* to an alternative land use *j*, $\phi[\ ]$ is the cumulative standard normal distribution, and:

$$Z_j^i = \frac{e^{-\gamma^j T^j}\pi_{s,p}^{j}}{e^{-\gamma^i T^i}\pi_{s,p}^{i} + e^{-rT^i}\theta_j^i},$$

$$d_{j1}^i = \frac{\ln\left(Z_j^i\right) + \frac{\left(\sigma_j^i\right)^2}{2}T^i}{\sigma_j^i\sqrt{T^i}},$$

$$d_{j2}^i = d_{j1}^i - \sigma_j^i\sqrt{T^i},$$

$$\sigma_j^i = \sqrt{\sigma^{j^2} + (\sigma^i F^i)^2 - 2\rho\sigma^i\sigma^j F^i} \text{ and}$$

$$F^i = \frac{e^{-\gamma^i T^i}\pi_{s,p}^{i}}{e^{-\gamma^i T^i}\pi_{s,p}^{i} + e^{-rT^i}\theta_j^i} \quad [7].$$

Here again, *i,j={a,f}, i≠j*, and ρ is the correlation between the two land values ($\pi^a$and π^f).

2.3. Simulation procedure

Following the theory described above, we use the combined real options-NPV framework within the CFS-FBM to simulate landowner's potential afforestation decisions over a landscape *P* with many parcels *p* in *P*. The simulation procedure uses discrete, 1-year time steps over a 55-year time horizon.

Following harvest, or when faced with bare land, we assume landowners are limited to four alternative choices for each land parcel *p*: If land was most recently in agricultural production, the landowner may choose (i) to stay in agriculture, receive the payoff value for the next production cycle and have the option to convert to forestry in $T^a = 1$ year after the next production cycle. For this case, the land parcel *p* will produce a lump sum cash flow each T^a years, and the owner has the option to keep the land in agriculture. Alternatively, (ii) the landowner may choose to pay land conversion costs θ_f^a and convert the parcel to a forest plantation, thereby receiving benefits after harvesting trees at the rotation age T^f and maintaining the option to convert the afforested land to agriculture after the harvest (i.e., in T^f years). When the land parcel was most recently under forest production, the land owner may choose to (iii) replant trees after the harvest, receive benefits from the next forest rotation at the harvest age T^f, and maintain the option to convert the afforested land to agriculture after the harvest. Alternatively, the land owner may (iv) pay the land conversion costs and convert the plantation back to agriculture, receive benefits from the next agricultural production cycle and maintain the option to convert to forestry after the crop harvest in $T^a = 1$ year. The levels of the lump sum cash flows (or harvest payoffs) are assumed to evolve over time (*s*) according to geometric Brownian motions with drift rates μ^i and volatility parameters σ^i, $i=\{a,f\}$.

Given current land use *i* for land parcel *p*, after T^i years landowners re-examine their land allocation decision and select either agriculture or forestry land-use according to:

$$\max\left(\Pi^a_{s_1,p}, \Pi^f_{s_1,p}\right) = \max(\pi^a_{s_1,p} + OV^a_{s_1,p}, \pi^f_{s_1,p} + OV^f_{s_1,p}) \quad [8]$$

where, if we define s_0 as the current period, s_1 is the next evaluation period, $s_1 = s_0 + (T^i - s_0)$. Given the assumptions described in section 2.2.2., land conversions in forestry can only occur at time T^f (so that forest plantations less than age T^f have no option but to stay in forestry). This approach is essentially dictated by the Black-Scholes option type used in the model. Because the expiration times and the production cycles in forestry and agriculture are different, we compare annualized values. These annualized values reflect future (positive) drift rates, because they are based on discounted option values.

Computations are repeated in each one-year period for each land parcel, which results in a schedule of estimated land use change for each parcel on the landscape over the 55 year planning horizon. A 55-year period was chosen to ensure the possibility of allowing at least two rotation cycles for poplar plantations. We have found that for some parcels economically optimal rotation ages for poplar plantations could reach 27 years, which suggested a minimum 55-year simulation horizon. Note that at any point of the simulation, the model evaluates ahead one full – length future rotation. That is, as necessary (towards the end of the planning horizon), the evaluations look into a future rotation beyond the simulation horizon.

For each spatial location, and at every time step, we first evaluate the $\Pi^f_{s_1,p}$ and $\Pi^a_{s_1,p}$ values for a range of feasible rotation ages, T^f, between 12 and 30 years and then selected the T^f value (and the corresponding values of $\pi^f_{s_1,p}$, $OV^a_{s_1,p}$ and $OV^f_{s_1,p}$) that yield the highest value of $\Pi^f_{s_1,p}$ and $\Pi^a_{s_1,p}$. The site-specific T^f values vary between 16 and 27 years and are influenced by the site productivity and the transportation costs to the nearest forest mill. Our approach of considering a range of fixed rotations, rather than implementing flexible harvest policies, was motivated by the need to accommodate the European option model and maintain computational tractability in our spatial application.

In our model, land conversion decisions for individual parcels (map cells) did not depend on how much land is already under forestry or agricultural use. We also follow Paarsch and Rust (2004) and impose no capacity constraints (or price changes) on the resources available to harvest plantations at different locations. The price paths of agricultural land values and forest plantation values were assumed to be independent of the area of land in each use, as well as of total timber volume harvested from poplar plantations.[iii]

2.4. A case study of afforestation potential in Alberta, Canada

The geographical model described above was applied in a case study context to estimate the afforestation potential of private agricultural land in Alberta, Canada. Several recent studies in Canada (Anderson and Luckert, 2007; McKenney et al., 2004, 2006; Van Kooten et al., 1999; Yemshanov et al., 2005, 2007) have attempted to evaluate the potential of short-rotation, hybrid poplar forest plantations to compete with more traditional agricultural crops on marginal agricultural land. A motivating factor in most of these studies has been the potential for forest plantations to provide carbon sequestration benefits, but the focus on hybrid poplar relates to the higher productivity achievable by hybrid trees (versus native tree species) in Canadian conditions. This higher productivity may give firms or landowners an additional incentive to make the capital investments necessary for afforestation.

In Alberta, forest companies operate in the northern and western forested parts of the province (also known as the 'green zone'), with wood processing plants located near the border of this 'green zone' and the agricultural 'white zone' that makes up the rest of the province. This border area (also referred to as the boreal transition zone) is a region of primarily marginal agricultural land, but contains ecological and economic conditions that can be suitable for afforestation (Fig.1). Our focus in this case study is on private lands that may switch from agriculture to hybrid poplar forest plantations (or vise-versa) in this boreal transition zone of Alberta. However, the scale of competition between private forestry and agricultural land-use in this region is insufficient to generate the data required to estimate econometric land use change models and elasticities.[iv] Accordingly, this case study region provides a good test for the usefulness of our real option value-based framework to substitute for econometric methods of estimating land-use change.

2.5. Model inputs and baseline assumptions

Initial agricultural land values for each municipality contained in the study area are estimated using annual land transfer (sale) values from 1994-2006; categorized by year of sale, municipality and Canada Land Inventory (CLI) classification.[v] The CLI provides a basic ranking of geographical land units based on their biological productivity. We assume that CLI classes 1 through 5 are eligible for afforestation, based on their soil capability for agriculture.[vi] The estimated agricultural land values were assembled in a GIS map at the municipal level and overlaid onto the 2 x 2 km map cells representing individual land parcels in the spatial model. Each cell was assigned an average land value weighted by the percentage of each CLI land class contained in that cell (figure 1, panel B).

The model was initialized by assuming that the entire eligible land base is utilized for agricultural production. The feasibility of afforestation is then evaluated based on a pulpwood mill gate value of $40/m^3 at time step $t = 0$, harvest costs of $15/m^3 and basic silvicultural costs of \$1231/ha (that include site preparation, planting, cultivation and herbicide treatments (Anderson and Luckert, 2007). Conversion costs for planting trees on agricultural land are assumed to be zero, however a land clearing cost of \$354/ha is imposed when land is converted from plantation forestry back to agriculture. A real discount rate of 4% is assumed for all financial calculations in this study.

Hybrid poplar growth and yield relationships are provided in Fig. 2 (derived from Anderson and Luckert, 2007). Based on the shape of this yield curve and current afforestation practices in the Canadian Prairies (Thomas and Kaiser, 2003), the shortest rotation period is limited to 12 years. A map of hybrid poplar site suitability was then used to adjust our growth and yield estimates for spatial heterogeneity in growing conditions. The site suitability map (Fig. 1, panel A) is composed from expert knowledge and climate information (Joss et al., 2007). The eligible land base for afforestation was delineated from a land cover classification based on SPOT satellite remote sensing imagery (Latifovic et al., 2004).

To estimate the hauling and transportation costs for plantation forestry, each map cell was treated as a "block" of potential afforestation sites. Transportation costs were aggregated as a function of the transportation distance from the map cell to the nearest mill and then adjusted by a non-linear distance-dependent factor (w) as in Yemshanov et al. (2007):

$$w = (368.18 + 0.957 \times B^{1.368}) / (32.879 + B^{1.368}) \qquad [9]$$

where B is the effective distance from forest plantation to the nearest mill (km).[vii] The map (Figure 1, panel C) of "effective cost" distances, B, also includes speed limit constraints for non-major, secondary and unpaved roads to accommodate longer hauling times.

The spatial model also requires future projections of agriculture and forest plantation land values. Given that future prices (and therefore land values) are highly speculative, we evaluate a range of land use change scenarios with different ratios between the price drifts for agricultural and forest commodities, μ^f/μ^a . The drift ratio is similar to the metrics presented in Conrad (1997b) and Abildtrup and Strange (2000). The drift ratios used include the set $\frac{\mu^f}{\mu^a} = \{0.55, 1.0, 1.5\}$. These drift ratios are meant to range from a case where, given historical land values, land-owners would have little incentive to convert to forestry without additional incentives (i.e. $\frac{\mu^f}{\mu^a} = 0.55$, so the drift for forest commodity values would be 0.55 of the price drift for agricultural values), to cases where afforestation may become more appealing over time (i.e. $\frac{\mu^f}{\mu^a} = 1.5$). The drift ratio may also be interpreted as a proxy for relative changes in future markets or technology. For example, an increase in the drift ratio may occur due to ongoing investment in technological and genetic improvements to hybrid poplar relative to agricultural crops. This relative improvement in forest technology would cause the land values used for forestry to increase relative to those for agriculture.

Finally, the Black Scholes equation requires the following inputs for the case study: the expected volatilities for agriculture and forestry (σ^a and σ^f), the correlation between the returns to agriculture and forestry (*ρ),* the real interest rate *r*, and the dividend rates γ^a and γ^f. The volatility and correlation values were fitted by using the average CPI-adjusted Alberta real estate transfer values described above for historical agricultural land values, while using prices of hardwood pulpwood as a proxy for historical forestry land values; hardwood pulpwood being the product created from harvested hybrid poplar. Hardwood pulpwood prices are taken from raw materials price index (RMPI) for hardwood pulpwood from 1981-2006.[viii] This procedure yields ó$^a = 0.104$, $\sigma^f = 0.135$, and $\rho = -0.220$. The dividend rate for agriculture (γ^a) is assumed to be 0.03 (i.e. agricultural dividends equal to 3% of land values), while the dividend rate for forestry is set to $\gamma^f = 0$.

2.6. Land-use change elasticities

Land use change elasticities are computed to estimate the responsiveness of afforestation decisions to forest land value change; thereby providing a point of comparison for our real options model framework to previous results based on NPV-only criteria. We calculate elasticities for the afforestation potential of a land parcel (E_{aff}) with respect to model generated land values under forest land use (π^f) as follows:

$$E_{aff} = \frac{\Delta a}{\Delta \pi^f} \quad [10]$$

where: $\Delta a = \frac{a_{adj} - a_{baseline}}{0.5(a_{adj} + a_{baseline})}$ and $\Delta \pi^f = \frac{\pi^f_{adj} - \pi^f_{baseline}}{0.5(\pi^f_{adj} + \pi^f_{baseline})}$.

Here, $a_{baseline}$ and a_{adj} are, respectively, the land areas afforested in: (i) the scenario with the baseline forest land value, $\pi^f_{baseline}$, and (ii) a scenario with the land value adjusted by a 1% positive or negative fixed change in the baseline π^f values, called π^f_{adj}. The baseline value used for elasticity calculations is the projected area of converted land for the forecast period. We also compute elasticities with Π^f and Π^a replacing π^a and π^f (i.e. to consider the effect of including real options values in the derived elasticities).

3. RESULTS

We focus on presenting the impacts of option values on the area-based land conversion estimates and the sensitivities to our assumed price volatilities and the presence of dividends. Table 1 provides elasticity estimates of the afforestation potential of agricultural land with respect to a 1% change in the corresponding net returns to forestry from both: (i) the option value + NPV framework (Π^f); and (ii) the NPV-only framework (π^f). The land conversion elasticities calculated with real option values (Π^f) are found to be much lower than those calculated using *NPV* criteria. Furthermore, the results show that the point in time chosen to calculate the elasticity values can have a significant impact on the result. For example, in the scenarios with drift ratios (μ^f/μ^a) of 1.0 and 1.5, elasticities tend to be much higher at year 50 than at year 1 or year 10, reflecting the increasing divergence in land values over time.[ix] In general, elasticities are found to increase with the drift ratio, μ^f/μ^a. However, some exceptions occur between drift ratios of 0.55 and 1.0, and are largely caused by an abrupt increase in the absolute area of afforested land as the drift ratio increases above 0.55.

Comparisons of our elasticity estimates with those derived from econometric models of land-use change in the literature are favorable. The year one Π^f elasticities are in the range of 0.32 to 0.64 and are similar in magnitude to the elasticity estimate of 0.5 derived by Sohngen and Brown (2006) for the south central US; although higher than the estimates derived by Lubowski et al. (2006) for the contiguous US (which are approximately 0.02).[x] In contrast, the elasticity values that we estimate with *NPV* values alone tend to be 5-10 times higher than the land-use change elasticity estimates derived with option values included.

Table 1 also shows different elasticity estimates derived from positive versus negative changes in the net returns in forest land use suggesting asymmetries in the underlying land use change decisions. The influence of option value in producing this asymmetry is illustrated in a decision space diagram defined by agriculture and forest plantation land values (Fig.3). The 45-degree dashed line in Fig.3, where $\pi^a = \pi^f$, represents the land-use change threshold when decisions are based on the NPV criteria only. Accordingly, without the consideration of option value, the conversion from agriculture to forestry occurs where $\pi^f > \pi^a$ (i.e. the area above the dashed line), and *vice versa* for changes from forestry to agriculture. Land-use change decisions in the *NPV* context are therefore symmetric in nature assuming that the π^a and π^f values include the land conversion costs.

The introduction of option value in Fig. 3 shifts the relevant land conversion thresholds. The solid lines represent the conversion thresholds, in *NPV* terms, when land use decisions are made inclusive of option value (i.e. are based on Π^f). The area above the top solid line represents a region where $max[\Pi^a , \Pi^f] = \Pi^f$ and any land in agricultural use would be afforested. The area below the bottom solid line represents a region where $max[\Pi^a , \Pi^f] = \Pi^a$ and any land in use as forest plantations would convert to agriculture. In between these two solid lines is a region where land use conversions that would be undertaken based on the *NPV*-only decision rule are deferred to the next evaluation period; a result of incorporating an option value in the land-use change decision.

The boundaries of the deferral region show a deviation from the $\pi^a = \pi^f$ threshold line. This deviation is asymmetric and shows a higher conversion threshold for agriculture-to-forestry than for forestry-to-agriculture. This result occurs because conversions to forestry foreclose more future options than conversions to agriculture, as trees tie up land for a longer period than does agriculture. The deviation of these option value threshold lines from the *NPV* boundary increases for higher land values (i.e. for more productive land), reflecting the higher value of maintaining the option to convert land use in these areas. This higher option value results because the land will be more productive in the alternative, as well as the current, land use.

An important policy-relevant end result of the option value premium is that it decreases the total amount of land attractive for conversion from agriculture to forest plantations. To illustrate this, Figure 4 depicts afforestation potential over our case study region in Alberta (a total of 10.1 million ha). We show only the π^f (panel 1) and Π^f (panel 2) scenarios for the drift ratio μ^f/μ^a = 1.0, as the other scenarios revealed similar geographic patterns. The inclusion of real option values in the land-use change decisions in panel 2 reduces the area deemed suitable for afforestation by a factor of 6 over a 20-year period. Both panels, meanwhile, show a strong influence of transportation costs; with afforestation sites generally located close to mill locations (Fig. 4). The predicted land-use patterns are also defined by the relative productivity of land in the alternative uses and the relative differences in returns from agriculture *versus* forest plantations.

Figure 5 compares the amount of land afforested over time, with and without option values, for the three drift ratio scenarios. For all three drift ratios there are large differences between the π^f and Π^f scenarios, indicating that the importance of option values in land use decisions increases with the drift ratio. Different combinations of the drift ratio and option values also affect how patterns of afforestation vary over time. For instance, at the lowest drift ratio the π^f scenario shows some forested land reverting back to agriculture after two forest rotations (at approximately 35-40 years). The inclusion of option values reduces this reversion of land back to agriculture since it makes land conversion thresholds higher and more inelastic with respect to changes in land values over time.

To better illustrate the magnitude of these projected differences in land conversion, Table 2 compares the total area of afforested land over the study area, with and without the inclusion of option value. In the case with the lowest drift ratio (i.e. μ^f/μ^a = 0.55), the *NPV* scenario predicts afforestation of 0.083M ha through 20 years, and 0.066M ha after 55 years (the reduction in afforested land after 55 years is due to the reversion of some afforested area back to agriculture, as described above). The inclusion of an option value premium reduces this afforestation potential by a factor of 3.6 over 20 years (to 0.024M ha), and by a factor of 1.9 over 55 years (to 0.035M ha). Cases with higher drift ratios (i.e $\mu^f/\mu^a = 1.0$) show greater land conversion potential (up to 0.192M ha in the *NPV*-only scenario), but the impact of the option value premium is similar and decreases the total area attractive for afforestation by 2.6-7.4 times (Table 2).

Figure 5 shows how assumed dividend rates (i.e. annual income, by land-use) may impact land use and potential afforestation in this model. The base model assumes that land used in forestry generates zero income until harvest, whereas land used in agriculture generates annual income equal to 3% of its land value. But forestry too could potentially generate dividends. For example, Alpac, a forest company in Alberta, is paying annual rents to landowners for planting trees on private land. Fig.5 shows the increase in afforestation potential when forestry is assumed to generate dividends at a rate of 1%. For all drift ratios, the inclusion of dividends eliminates a large portion of the difference between option value and *NPV* decision rules. Measures or policies designed to allow afforested lands to generate positive annual income may therefore significantly influence private afforestation decisions.

Another key factor that influences option value is the volatility of land value (i.e. the stochastic component of underlying land values). The simulation results reported thus far use historic measures of volatility (i.e. $\sigma^a = 0.104$ and $\sigma^f = 0.135$), however the volatility of agricultural land values could increase in the future with climate change, or decrease with genetic improvements to crops such as increased cold tolerance. Figure 6 shows the amount of land afforested over time for the three drift ratios and $\pm$ 10% changes in agricultural volatility. In the case with the lowest drift ratio (i.e. where $\mu^f/\mu^a = 0.55$) there is little difference in land conversion over scenarios with different volatility parameters, as forestry is not an attractive option. But at higher drift ratios, the inclusion of an option value causes predicted afforestation rates to increase with increased agricultural volatility.

4. DISCUSSION AND CONCLUDING COMMENTS

Models of land use change that estimate opportunity costs based on conventional NPV analyses are thought to be incomplete representations of land use change behavior; a finding that is highlighted through comparisons with econometric results of actual land use. Econometric approaches may represent (implicitly or explicitly) other economic factors known to influence land use choices (such as the cost of potential irreversibility in land-use change, or non-market benefits), however a reliance on historic information makes these approaches dependent on the quality and completeness of available data. In particular, econometric results are not always feasible to generate when historical data are thin or missing. Hence, there is a need for other approaches when historical data are lacking. Results from our combined real options-NPV spatial model confirm the criticism of the approaches based on simple NPV analyses, showing large differences in potential land use changes and elasticity estimates. The simple NPV approach suggests a much higher area of land attractive to afforestation than the model incorporating option values.

The principles of our real options model generally agree with other types of real option models developed to quantify decision-making irreversibilities in land use change, such as sequential real options models by Thorsen (1999) and Malchow-Moeller et al. (2004), and the choices between mutually exclusive options by Geltner et al. (1996) and Thorsen and Malchow-Moeller (2003). Associating a value with the option to postpone investment decisions was found to provide land-use change estimates more in line with behavioral data from afforestation projects, and brings our land use change elasticity estimates into the range of those found in the econometric literature. The preference to stay in agriculture and postpone the decision to convert to forestry also depicts the present situation with afforestation in Alberta, where farmers have expressed a reticence to convert land to forest plantations unless expected returns are significantly higher than the present-day returns from agriculture (Smith *et al.* 2005). These results suggest the importance of including option value as a component in the opportunity cost of land use change, and reflect the relative lack of flexibility that may attend investments in forest plantations.

Furthermore, the case study illustrates the impact on land use decisions of specific price and cost factors, such as increases in the relative value of forest versus agriculture land over time (i.e. the drift ratio, μ^f/μ^a), the provision of annual income (i.e. dividends) and changes in the volatility of the land values. The lack of annual income from forests in particular is found to significantly decrease the attractiveness of afforestation investments. The results of these sensitivity tests in our model framework could be useful to inform decision-makers who are considering policies to promote afforestation, such as bioenergy or carbon sequestration incentives programs.

In our study, the model was parameterized with best available data and was in general agreement (within the same order of magnitude) of land conversion elasticities reported in the literature (Lubowski et al., 2006; Sohngen and Brown, 2006), thereby providing some confidence in the results for policy interpretations. The model could also be used to explore other scenarios, parameterized according to other expectations, thus providing results that could be used in a more normative context.

Despite the apparent advantages of incorporating option prices within land use models, the application of this approach has a number of limitations. Long forest rotations make results sensitive to the choice of the discount rate. Similarly, as a forward-looking algorithm, real options may be sensitive to the choice of the price trend and irregularities in future price paths. The omission of the flexibility to harvest planted trees before the planned date, dictated by the use of a European option, represents another shortcoming. Adding the possibility to change rotation lengths would potentially increase the attractiveness of forest plantations, because more flexibility in the timing of harvest operations could generate additional benefits, in that land owners could wait for favorable prices. The assumption of perfect correlation of prices and costs in forestry is another simplification in our model, which was also dictated by the nature of the European options (which requires that asset prices follow a Wiener process). Both of these assumptions could be relaxed if the model could be structured with an American option, which can be exercised before the expiration date. Though such an approach would significantly increase the computational burden is spatially explicit models, further research could investigate means of making such algorithms tractable.

The quality and precision of available spatial economic data represents another concern. While the site suitability and biological productivity information used in this model are delineated with a high potential spatial precision (2-km), price and cost assumptions are often limited by the size of administrative units and require interpolation and downscaling to match the spatial resolution of the biophysical data. This introduces spatial errors that may influence predicted land conversion dynamics.

Our model also ignores the possibility that the land uses could differentially contribute to a diversified portfolio. For example, if forestry were more desirable than agriculture because if its contribution to a mixed portfolio, then forest plantations could appear more readily across the landscape. Future research could consider adding these types of effects to the model simulations. Further research is also needed to extend the analysis and the option value model to include multiple land-use choices. While we do not consider the combined real options-NPV method implemented here as a complete substitute for econometric estimates, we find the inclusion of real option values to be useful for predicting land-use change in situations where historical information is sparse or absent.

5. ACKNOWLEDGEMENTS

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Table 1. Elasticity of the change in afforested land area for a change in forestry land value (E_{aff})

Time period*:	Year 1			Year 10			Year 50		
Drift ratio, μ^f/μ^a:	1.5	1.0	0.55	1.5	1.0	0.55	1.5	1.0	0.55
Scenarios without option value									
π^f (+1% change)	3.98	2.18	5.21	5.57	2.25	5.21	>10	2.52	3.05
π^f(- 1% change)	7.24	3.62	0.71	4.53	3.62	3.71	>10	2.69	6.07
Scenarios with option value									
Π^f(+1% change)	0.37	0.34	-**	0.72	0.21	-**	1.62	1.58	0.19
Π^f(- 1% change)	0.64	0.32	-**	0.74	0.37	-**	2.01	1.94	0.22

[*] Elasticities are calculated with changes occurring over 1 year at the year specified.

[**] The change in afforested area was below the minimum spatial resolution of the study (400ha).

Table 2. Aggregate land use conversion potential in afforestation scenarios ($\times 10^6$ ha)

μ^f/μ^a scenario:	0.5 (baseline)		1.0	
Land use Conversion[1]:	Ag.->For.		Ag.->For.	
Option value scenario[2]:	NPV-OV	NPV only	NPV-OV	NPV only
Total conversion, $\times 10^6$ ha				
1st year	0.022	0.083	0.026	0.190
Over 20 years	0.024	0.083	0.032	0.192
Over 55 years	0.035	0.066	0.074	0.192

[1] "Ag.->For." – Conversion of agricultural land to forest plantations;

[2] "NPV-OV" – Land conversion metric (Π^a and Π^f) includes the option value premium;

"NPV only" – Land conversion metric (π^a and π^f) is inclusive of *NPV* only.

Figure captions:

Fig.1. Spatial input data: A – Hybrid poplar site suitability maps (growth rate multiplier of the yield values depicted in Fig. 2); B – Net agricultural returns (\$/ha/year, annualized for a 4% discount rate); C – Poplar wood tree-to-gate harvest and transportation costs (\$/m^3). Agricultural lands with poor site suitability for hybrid poplar plantations were omitted from the analysis (shown blank).

Fig.2. Hybrid poplar yield curve for the most productive sites.

Fig.3. Decision space diagram in the dimensions of π^a and π^f. Dashed line – land use conversion threshold in the scenario without option values (i.e., where $\pi^a = \pi^f$). Note that the π^a and π^f values include the land conversion costs (see Eq. 2), hence the NPV-based $\pi^a - \pi^f$ decision boundary appears to be symmetric. Solid lines – land use conversion thresholds in the scenario with option values included, delineating the range of values where any land use-change that would be undertaken based on an NPV-only decision rule is instead deferred until the next evaluation period.

Fig.4. Geographic (or spatial) portrayal of afforestation potential across the case study region of Alberta, Canada. Left-hand side shows the scenario without inclusion of option value, while right-hand side shows the scenario that includes option values in land-use change decisions. Both panels assume a drift ratio of $\mu^f/\mu^a = 1.0$. Callout boxes show examples of land conversion patterns at high spatial resolution.

Fig. 5. Predictions of afforested land area (million ha) over time. Figures show the effect of including option value in land-use decision analysis over the baseline (0.55) versus alternative drift ratio scenarios, while also varying the dividend rate for forestry between 0 and 1%. Agriculture remains at the 3% base model dividend rate.

Fig.6. Predictions of afforested land area (million ha) over time. Figures show the effect of varying the volatility of agricultural land values over three drift ratios: $\mu^f/\mu^a = 0.55$, 1.0 and 1.5. All scenarios include option values in the land-use decision.

Figures :

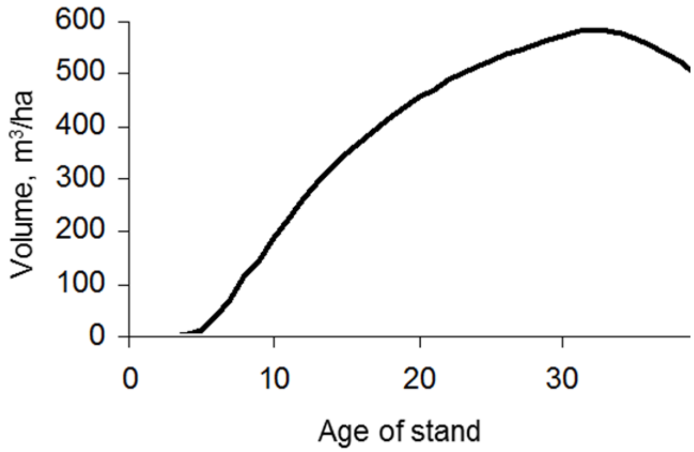


Fig.1

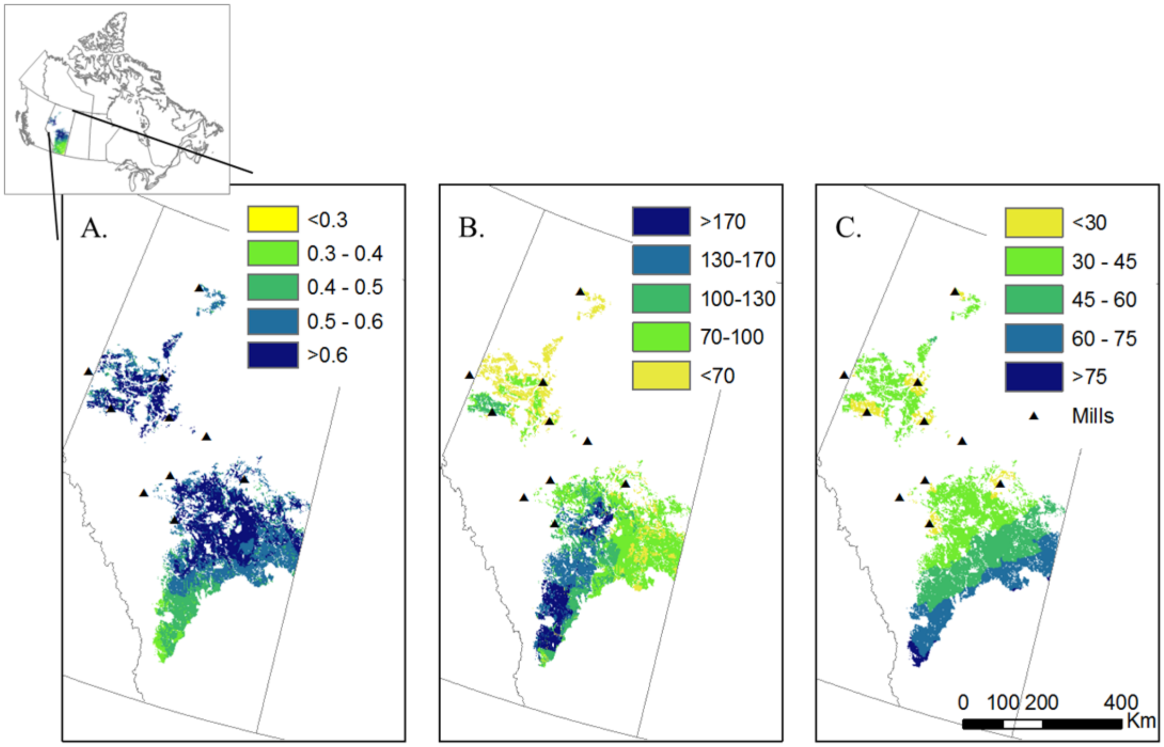

A.
<0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
>0.6
B.
>170
130-170
100-130
70-100
<70
C.
<30
30 - 45
45 - 60
60 - 75
>75
Mills
0 100 200 400
Km

Fig.2.

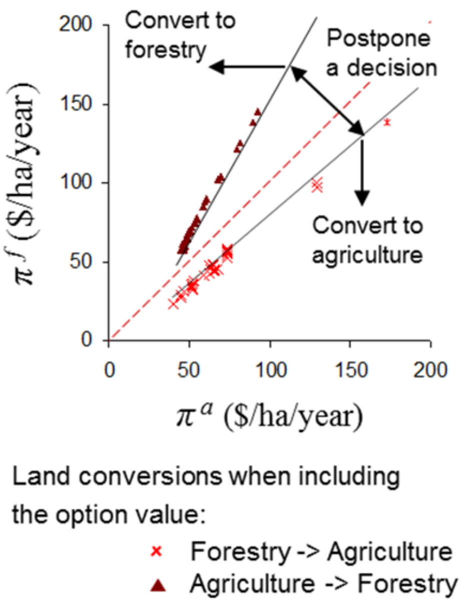

Convert to forestry
Postpone a decision
Convert to agriculture
200
150
100
50
0
0
50
100
150
200
π^f ($/ha/year)
π^a ($/ha/year)
Land conversions when including the option value:
Forestry -> Agriculture
Agriculture -> Forestry

Fig.3.

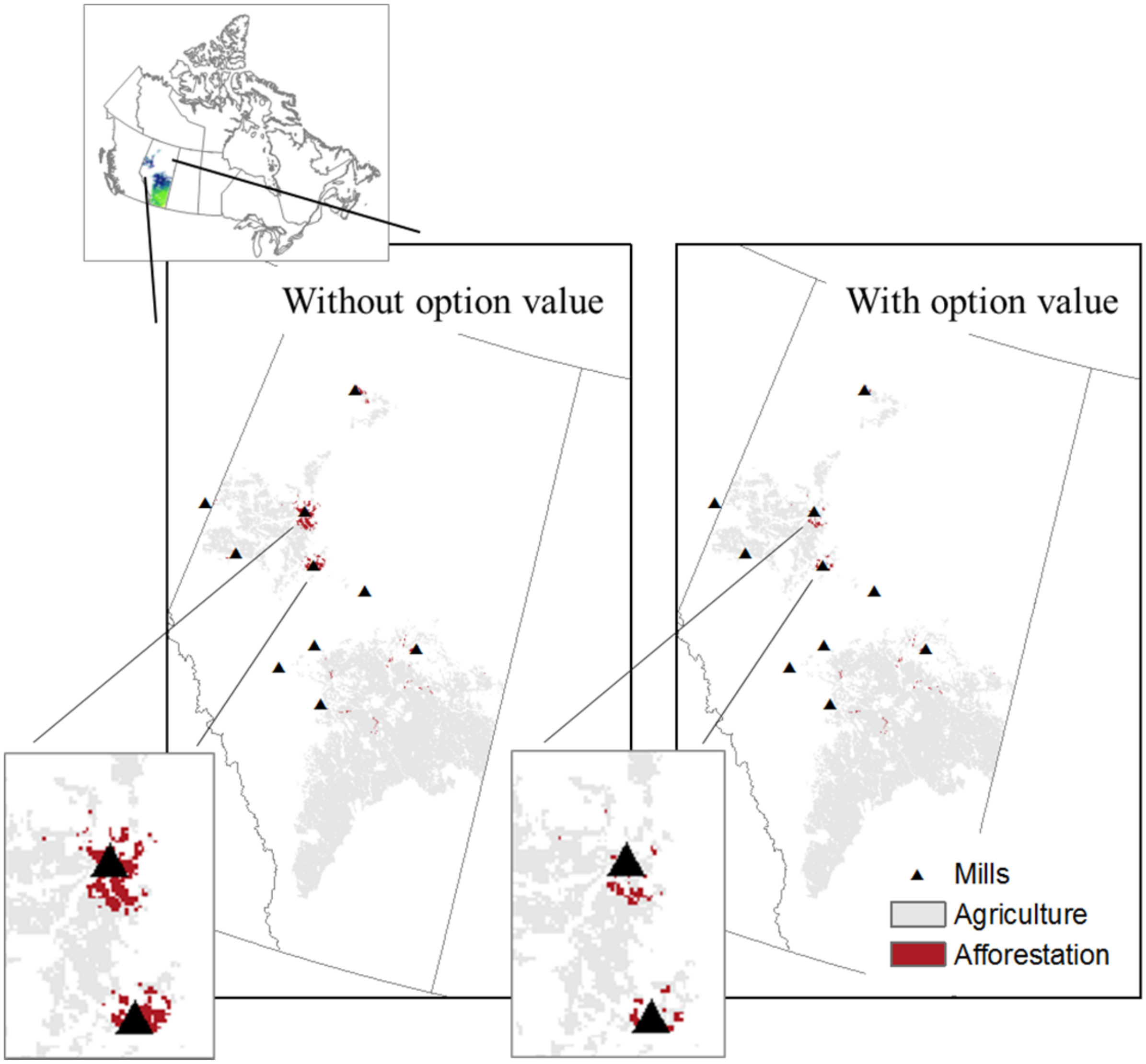
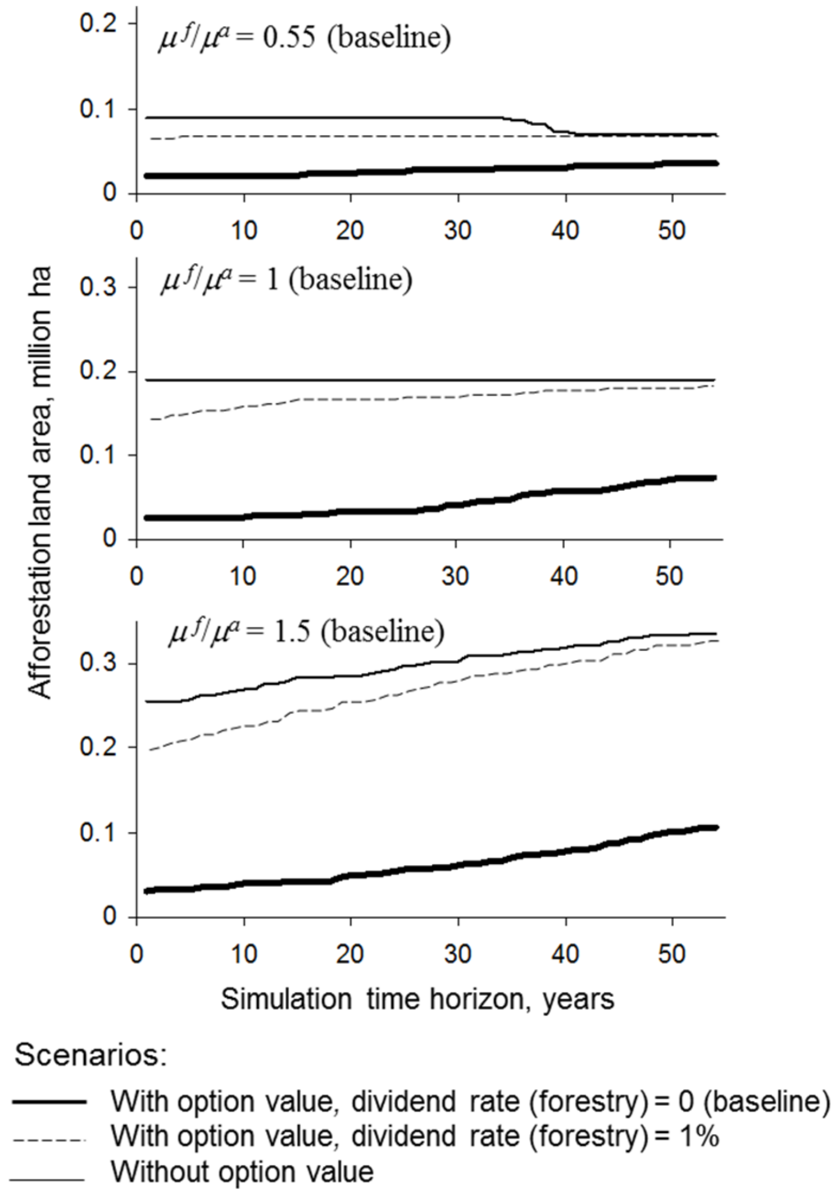

Without option value
With option value
Mills
Agriculture
Afforestation

Fig.4.



$\mu^f/\mu^a = 0.55$ (baseline)
$\mu^f/\mu^a = 1$ (baseline)
$\mu^f/\mu^a = 1.5$ (baseline)
Afforestation land area, million ha
Simulation time horizon, years
Scenarios:
With option value, dividend rate (forestry) = 0 (baseline)
With option value, dividend rate (forestry) = 1%
Without option value

Fig.5.

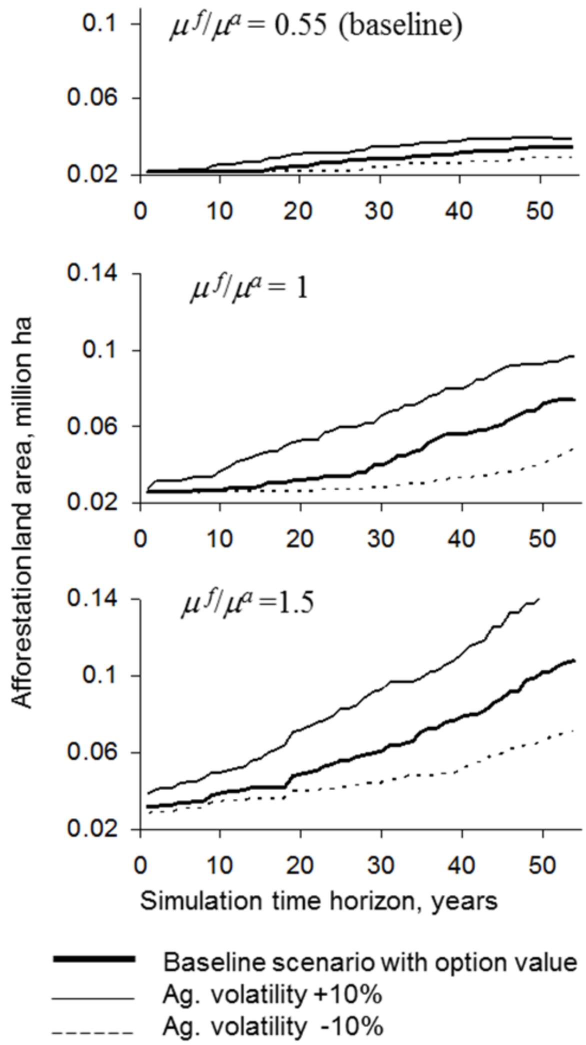

μ^f/μ^a = 0.55 (baseline)
μ^f/μ^a = 1
μ^f/μ^a =1.5
Afforestation land area, million ha
Simulation time horizon, years
0.1
0.06
0.02
0.14
0
10
20
30
40
50
Baseline scenario with option value
Ag. volatility +10%
Ag. volatility -10%

Fig.6.

Footnotes:

[i] Lubowski, et al. (2006) draw their dataset from the U.S. National Resources Inventory (NRI).

[ii] Both Conrad (1997a) and Mason (2001) have illustrated similar effects. Conrad (1997a) finds that it is optimal to wait until the expected net gains reach a strictly positive cutoff value before altering behaviour to delay or avoid global warming, while Mason (2001) shows that for a given level of reserves, the critical price that would cause an inactive mine to be opened exceeds the price that would induce an active mine to be closed.

[iii] For an example of a model of the U.S. forest and agricultural sectors with endogenous prices, see Alig et al. (1997). The small magnitudes of land use change that we model in this case study suggest that assuming exogenous prices is a reasonable assumption.

[iv] For instance, Natural Resources Canada specifies that only 3% of Alberta's forested land is privately owned (http://canadaforests.nrcan.gc.ca/statsprofile/resources/ca: accessed March 7, 2011). Furthermore, much of the land base afforested in Alberta can be accredited to the Poplar Farm Program (PFP) undertaken by Alberta-Pacific Forest Industries Inc. (Al-Pac), and is limited to a specific region in central Alberta (Hall et al., 2004).

[v] Land transfer values were obtained from Alberta Agriculture and Rural Development [online: http://www.agric.gov.ab.ca/app21/infopage?cat1=Statistics&cat2=Real+Estate+Values]. These values are corrected to real values using the CPI. Spatial data for CLI classes was obtained from Agriculture and Agri-Food Canada [online: http://geogratis.cgdi.gc.ca/CLI/frames.html].

[vi] Class 1 areas have no significant limitations in use for crops, while class 5 areas included marginal lands with a possibility for improvement practices. The following lands are not included as they were deemed unfeasible for afforestation: class 6 (marginal lands with no capability for improvement practices), class 7 (soils with no capability for arable culture or permanent pasture), and organic soils.

[vii] This adjustment accounts for time delays associated with biomass loading/unloading and lower average trucking speeds that are typical for short hauling distances (Gingras and Favreau, 1996).

[viii] The RMPI for hardwood pulpwood is obtained from Statistics Canada's CANSIM database [online: http://cansim2.statcan.ca/cgi-win/cnsmcgi.exe?Lang=E&CANSIMFile=CII\CII_1_E.htm&RootDir=CII/ : accessed 15th April 2008]. Annual projections are based on January RMPI values.

[ix] Note that elasticities are calculated as the % change in afforested area over 1 year at the year specified.

[x] The afforestation elasticities based on the models in Lubowski et al. (2006) and Sohngen and Brown (2006) were obtained from personal communication with B. Sohngen and R. Lubowski.