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A real options-net present value approach to assessing land use change: A case study of afforestation in Canada

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ABSTRACT

Geographically explicit land use change models based on net present value have been criticized for not reflecting the breadth of economic considerations relevant to private land use decisions. An alternative approach is to econometrically estimate land allocations from historical transactions, but this approach requires extensive historical econometric data sets, which may not be available, and may be difficult to model spatially. We show that a geographically explicit net present value approach inclusive of an option value to defer land conversion can be a viable and insightful alternative to econometric approaches. The model is applied to Alberta, Canada where historical land use change data are not available. The elasticity estimates of converting agricultural land to afforestation, 0.21 to 0.37, are similar to other North American estimates from econometric studies.

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 et al., 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 et al., 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.[5] 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

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

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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-Mueller (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).[6]

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 Bioeconomic 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:

$$LU_{s,p} = \max\left(\pi^{a}_{s,p}, \pi^{f}_{s,p}\right) \tag{1}$$

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:

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

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

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[6] 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 behavior 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.

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