WORKING PAPER
2005-09

Resource Economics and Policy Analysis (REPA) Research Group

Department of Economics
University of Victoria

Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Carbon Forest Sinks?

Sabina L. Shaikh, Lili Sun and G.C. van Kooten

July 2005

REPA Working Papers:

2003-01 – Compensation for Wildlife Damage: Habitat Conversion, Species Preservation and Local Welfare (Rondeau & Bulte)
2003-02 – Demand for Wildlife Hunting in British Columbia (Sun, van Kooten, & Voss)
2003-03 – Does Inclusion of Landowners' Non-Market Values Lower Costs of Creating Carbon Forest Sinks? (Shaikh, Suchánek, Sun, and van Kooten)
2003-04 – Smoke and Mirrors: The Kyoto Protocol and Beyond (van Kooten)
2003-05 – Creating Carbon Offsets in Agriculture through No-Till Cultivation: A Meta-Analysis of Costs and Carbon Benefits (Manley, van Kooten, Moeltner, and Johnson)
2003-06 – Climate Change and Forest Ecosystem Sinks: Economic Analysis (van Kooten and Eagle)
2003-07 – Resolving Range Conflict in Nevada? The Potential for Compensation via Monetary Payouts and Grazing Alternatives (Hobby and van Kooten)
2003-08 – Social Dilemmas and Public Range Management: Results from the Nevada Ranch Survey (van Kooten, Thomsen, Hobby, and Eagle)
2004-01 – How Costly are Carbon Offsets? A Meta-Analysis of Forest Carbon Sinks (van Kooten, Eagle, Manley, and Smolak)
2004-02 – Managing Forests for Multiple Tradeoffs: Compromising on Timber, Carbon and Biodiversity Objectives (Krcmar, van Kooten, and Vertinsky)
2004-03 – Tests of the EKC Hypothesis using CO2 Panel Data (Shi)
2004-04 – Are Log Markets Competitive? Empirical Evidence and Implications for Canada-U.S. Trade in Softwood Lumber (Niquidet and van Kooten)
2004-05 – Conservation Payments under Risk: A Stochastic Dominance Approach (Benítez, Kuosmanen, Olschewski and van Kooten)
2004-06 – Modeling Alternative Zoning Strategies in Forest Management (Krcmar, Vertinsky, and van Kooten)
2004-07 – Another Look at the Income Elasticity of Non-Point Source Air Pollutants: A Semiparametric Approach (Roy and van Kooten)
2004-08 – Anthropogenic and Natural Determinants of the Population of a Sensitive Species: Sage Grouse in Nevada (van Kooten, Eagle, and Eiswerth)
2004-09 – Demand for Wildlife Hunting in British Columbia (Sun, van Kooten, and Voss)
2004-10 – Viability of Carbon Offset Generating Projects in Boreal Ontario (Biggs and Laaksonen-Craig)
2004-11 – Economics of Forest and Agricultural Carbon Sinks (van Kooten)
2004-12 – Economic Dynamics of Tree Planting for Carbon Uptake on Marginal Agricultural Lands (van Kooten) (Copy of paper published in the Canadian Journal of Agricultural Economics 48(March): 51-65.)
2004-13 – Decoupling Farm Payments: Experience in the US, Canada, and Europe (Ogg & van Kooten)
2004–14 – Afforestation Generated Kyoto Compliant Carbon Offsets: A Case Study in Northeastern Ontario (Jeff Biggs)
2005–01 – Utility-scale Wind Power: Impacts of Increased Penetration (Pitt, van Kooten, Love and Djilali)
2005–02 – Integrating Wind Power in Electricity Grids: An Economic Analysis (Liu, van Kooten and Pitt)

2005–03 – Resolving Canada-U.S. Trade Disputes in Agriculture and Forestry: Lessons from Lumber (Biggs, Laaksonen-Craig, Niquidet and van Kooten)
2005–04 – Can Forest Management Strategies Sustain The Development Needs Of The Little Red River Cree First Nation? (Krcmar, Nelson, van Kooten, Vertinsky and Webb)
2005–05 – Economics of Forest and Agricultural Carbon Sinks (van Kooten)
2005–06 – Divergence Between WTA & WTP Revisited: Livestock Grazing on Public Range (Sun, van Kooten and Voss)
2005–07 – Dynamic Programming and Learning Models for Management of a Nonnative Species (Eiswerth, van Kooten, Lines and Eagle)
2005–08 – Canada-US Softwood Lumber Trade Revisited: Examining the Role of Substitution Bias in the Context of a Spatial Price Equilibrium Framework (Mogus, Stennes and van Kooten)
2005–09– Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Carbon Forest Sinks?* (Shaikh, Sun and van Kooten) *Updated version of Working Paper 2003-03

For copies of this or other REPA working papers contact:

REPA Research Group
Department of Economics
University of Victoria PO Box 1700 STN CSC Victoria, BC V8W 2Y2 CANADA
Ph: 250.472.4415
Fax: 250.721.6214
http://repa.econ.uvic.ca

Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Carbon Forest Sinks?

Sabina L. Shaikh[a], Lili Sun[b] , G. Cornelis van Kooten[b]

[a]RCF Economic and Financial Consulting, Inc., Chicago, IL
[b]Department of Economics, University of Victoria

ABSTRACT

This research examines the effects of various factors on farmer participation in agricultural tree plantations for economic, environmental, social and carbon-uptake purposes, and potential costs of sequestering carbon through afforestation in western Canada. Using data from a survey of landowners, a discrete choice random utility model is used to determine the probability of landowners' participation and corresponding mean willingness to accept (WTA) compensation for a tree-planting program. WTA includes positive and negative benefits to landowners from planting trees, benefits not captured by foregone returns from agricultural activities on marginal land. Estimates of WTA are less than foregone returns, but even so average costs of creating carbon credits still exceed their projected value under a CO_2-emissions trading scheme.

Key words: Willingness to accept compensation for tree planting; afforestation; climate change

Acknowledgements: The authors want to thank Pavel Suchánek for research support and funding from a BIOCAP Canada/SSHRC grant.

1. INTRODUCTION

As a result of the U.S.'s withdrawal from the Kyoto process, the EU relented to a much broader definition of and role for land use, land-use change and forestry (LULUCF) activities in lieu of greenhouse gas emissions in meeting targets during Kyoto's first commitment period (2008-12). At COP7 in November 2001 at Marrakech, the annual cap on carbon (C) uptake in sinks for 2008-12 was set at 219 Mt C (151 Mt C if the U.S. is left out). Thus, terrestrial sinks could conceivably account for more than 80% of the 250 Mt C annual reduction from 1990 levels required of Annex B countries, although the proportion is much lower when compared to projected business-as-usual emission levels. It is not clear, however, whether carbon sink offsets are economically competitive with emissions reduction (van Kooten et al. 2004). Efficient land-use management in agriculture and forestry requires evaluation in terms of the cost-effectiveness of carbon uptake.

One option for achieving significant carbon offsets is to plant trees on marginal agricultural land. In addition to providing carbon-uptake and potential commercial timber benefits, tree planting provides non-market benefits from reduced soil erosion, improved water quality, increased wildlife habitat, riparian buffer zones and aesthetic appeal. In 2002, the U.S. Farm Bill extended the Conservation Reserve Program (CRP) with a hardwood tree initiative that would restore up to 500,000 acres of floodplains by planting bottomland hardwood trees on private lands.[1] The initiative preserves the CRP's initial goals of reducing soil erosion and

[1] The Conservation Reserve Program was established in 1985 and has been an ongoing project to reduce soil erosion and improve land quality through voluntary participation of land idling.

improving wildlife habitat, while extending the program to the potential sequestration of 100 million metric tons of greenhouse gases (USDA 2003). As the CRP indicates, society might subsidize afforestation regardless of concerns about climate change, because of soil conservation, wildlife and other externality benefits. However, the concern here is with carbon uptake.

Since forgone returns from agricultural activities are an unreliable measure of the willingness of landowners to plant trees (e.g., see Stavins 1999), the purpose of the current study is to examine the compensation landowners in western Canada might require for converting pasture and cropland to forestry.[2] Determining compensation is not straightforward because: (1) there is uncertainty about the costs of tree planting, actual yields and stumpage values due to geographical differences in proximity to saw mills or pulp mills; (2) some returns to tree planting accrue in the distant future, causing disruptions in income flows that could increase compensation demanded; (3) farmers may feel that their ability to participate in current and future government agricultural programs is threatened by tree planting because capacity to produce agricultural commodities is reduced; and (4) landowners have varying preferences towards managed forests versus agricultural ecosystems.[3] Non-market values and risk attitudes play a significant role in farming decisions, so compensation set equal to agricultural rents (including any price support or subsidy payments) may not be appropriate for convincing landowners to change their land use to forestry.

---

[2] I t is important to recognize that current tree planting is unlikely to have much effect in terms of attaining Kyoto targets for 2008-12. Incremental growth at that time will be too small, although the result of ongoing negotiations regarding monitoring may enable suppliers of carbon sink credits to use expected average annual growth over the entire rotation rather than current MAI. Current tree planting may, however, be used in subsequent commitment periods.

[3] Stavins (1999) provides a slightly different list of reasons, which include concerns about irreversibility and liquidity constraints.

The compensation required will be higher if landowners realize non-market benefits from agriculture and/or worry about the lack of guaranteed payments between the end of a contract period and the time trees are harvested. They could also be lower if annual forestry payments reduce landowners' risks (even if such payments stop some years before trees mature) and/or forestry provides non-market (e.g., aesthetic) benefits. Information from a contingent valuation survey is valuable in this context, because it is able to incorporate non-market values and risk attitudes, as well as unobservable transactions costs, into the compensation amount. Rather than rely on returns to agricultural activities, which are an unreliable guide to the willingness of landowners to convert farmland to forestry, we employ data from a survey of western Canadian farmers to provide estimates of the possible costs of creating carbon offsets on marginal agricultural land. The survey explicitly asked landowners about their willingness to accept (WTA) compensation for participation in tree-planting programs. The purpose is to compare the costs of carbon uptake when compensation demanded is used instead of the opportunity cost of land to determine if tree planting is a cost-effective means of achieving Kyoto-type targets.

The paper is organized as follows. A general overview of the theory in the context of tree planting is presented in the next section, followed by a discussion of the data and an explanation of the empirical model. Using estimates of compensation levels and opportunity costs of land, the cost-effectiveness of potential tree planting programs is examined. The paper concludes with a discussion of policy implications and considerations for further research.

2. MODEL FOR ANALYZING DECISIONS TO CONVERT FARMLAND TO FORESTRY

In this study, a discrete-choice random utility maximization (RUM) framework is used to model the decision of a landowner to convert farmland to forestry. The landowner will accept a bid to afforest (marginal) agricultural land so as long as the compensation offered is at least as much as the opportunity cost of not producing plus any positive or negative non-market/risk benefits that he/she gets from planting trees. This decision can be modeled as follows: Landowner *i* will accept a tree-planting project ($a = 1$) as long as $v_{i,1}(m+\Delta m, \mathbf{s}) + \varepsilon_{i,1} > v_{i,0}(m, \mathbf{s}) + \varepsilon_{i,0}$, where Δm is the compensation or bid (B) offered minus forgone expected annual net returns in agriculture (OC). Since utility is a random variable, the probability that a farmer's choice to accept the bid can be written (suppressing subscript i) as (Hanemann 1984; Greene 2000):

(1) $$\Pr(a=1) = \Pr\{v_1(m+\Delta m, \mathbf{s})+\varepsilon_1 > v_0(m, \mathbf{s})+\varepsilon_0\} = \Pr\{(\varepsilon_1 - \varepsilon_0) > -[v_1(m+\Delta m, \mathbf{s}) - v_0(m, \mathbf{s})]\}.$$

Replacing $[v_1(m+\Delta m, \mathbf{s}) - v_0(m, \mathbf{s})]/\sigma$ with Δv and $(\varepsilon_1 - \varepsilon_0)/\sigma$ with ε, where $\varepsilon \sim N(0,1)$ is i.i.d. because ε_1 and ε_0 are i.i.d., yields the probit model:

(2) $$\Pr(a=1) = \Pr(\varepsilon > -\Delta v) = F_\varepsilon(\Delta v),$$

where F_ε is the normal cumulative distribution function (cdf).

Timber benefits accrue in the distant future and their realization depends on what landowners do after the expiration of the contingency contract, with contracts usually of ten years duration. For example, landowners might sell the land and realize the value of the standing timber plus carbon benefits, or they might choose to hold the land until harvest perhaps renting or leasing the carbon offset credits to a third party (e.g., large industrial emitter) in the meantime. The costs of possibly converting land back to agriculture at the time of harvest will at least partially offset the timber returns. These costs consist of stump removal and root raking plus the foregone returns of lost agricultural (or forestry and carbon) production for period of one to two years. Timber returns also occur relatively far in the future, thus creating a considerable risk premium further offsetting any timber benefits. The alternative to converting the land back to agriculture is keeping it in forestry, which requires a farmer's long-term commitment to growing trees and learning about forestry practices and timber marketing (see Plantinga 1997 for further discussion). As a result, we do not include timber benefits in the Δm measure. Rather, we expect landowners take into account such benefits in formulating their responses to a question eliciting a willingness to accept compensation for a tree-planting program. Positive expected forest rents are one factor that will lower WTA.

The decision to accept the proposed compensation is based on the returns from the least productive parcel of land, with the least productive acres assumed to be the ones a landowner would commit to a tree planting program. Thus, the landowner will compare $v_1(m+B–OC, \mathbf{s})$ against $v_0(m, \mathbf{s})$, where B is the bid and OC is the opportunity cost of foregone agricultural production on a per acre basis and $\Delta m = B - OC$. While the opportunity cost represents foregone agricultural net returns from accepting a tree planting program, the total compensation required by the farmer may be increased by other non-market values associated with keeping the land in agriculture (e.g., the landowner may prefer an agricultural landscape or feels a commitment to an earlier generation that cleared the land) and/or reduced by non-market (say, aesthetic) values associated with forestry. Compensation demanded is also affected by landowners' perceptions about the reduced risk of fixed annual payments (at least over the contract period), increased risks associated with forest and carbon markets (assuming these develop) after the initial contract period, and so on.

Following Hanemann's (1984) linear-in-parameters utility specification, so that welfare calculations are derived in a manner compatible with utility maximization, we re-write (2) as:

$$(3) \qquad E[a|X] = \Pr(a{=}1) = F_{\varepsilon}(\Delta v) = \int_{-\infty}^{+\infty} \phi(\Delta v) = \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{-\Delta v}{2}} d\Delta v\,,$$

where $E[a|X]$ is the conditional mean probability, X is a vector of exogenous variables, F_{ε} is the standard normal cdf and ϕ is the corresponding probability density function. The log-likelihood function is given generally by:

$$(4) \qquad \log L(\Delta v) = \sum_{i=1}^{n} \left\{ a \log\left[\int_{-\infty}^{(\Delta v)} h(z_1) dz_1 \right] + (1-a) \log\left[\int_{-\Delta v}^{(\infty)} h(z_1) dz_1 \right] \right\},$$

where $h(\cdot)$ represents a standard normal distribution function.

Landowners' minimum WTA compensation, denoted by B^*, is determined as the amount of money needed to keep the farmer indifferent between accepting the bid and retaining marginal land in agriculture. One can express this indifference by setting the probability of accepting a bid in (1) equal to 0.5 and solving for B^* – the median willingness to accept compensation.

3. SURVEY OF CANADIAN FARMERS

A questionnaire was mailed in July 2000 to 2,000 randomly selected Canadian farmers from the grain belt region of northeastern British Columbia, Alberta, Saskatchewan and Manitoba. Farmers with less than 160 acres of land were omitted from the survey sample since small landowners were unlikely to contribute significant amounts of land. Dairy farmers were also excluded from the sample for their presumed high opportunity cost of tree planting due to value-added production. A total of 379 surveys were returned undelivered, due to the lack of available updates of the mailing list purchased from Watts Brokerage Listing. Reminder cards were sent out three weeks after the first mailing. The effective response rate (corrected for returned/undelivered surveys) was 13%, higher than the 12% rates reported by the Environics Research Group (2000) in their study of stewardship of Canadian farmers and by Bell et al (1994).[4]

The survey included a brief, personalized cover letter explaining the purpose of the questionnaire and a definition of carbon offset credits. In addition to willingness to accept compensation for tree planting, the actual survey also elicited detailed information on a farmer's agricultural operations including activities on marginal fields, farmers' opinions about and awareness of climate change issues and carbon credits, and personal characteristics and demographics (Suchánek 2001). Personal and demographic information can be compared with similar data from Canada's 2001 Census of Agriculture.

Direct comparisons between Census and survey data are difficult because the survey used a much finer grid for age and net worth data than reported in the Census of Agriculture. The survey employed ten age and net worth categories, while the Census reports three age and five net worth categories. Education is reported in the Census as the proportion of individuals with education levels according to the following four categories: "less than grade 9", "grade 9 to 13" (Ontario used grade 13), "post-secondary, non-university", and "university". The survey asked respondents to indicate the number of years of post-secondary education, with categories ranging from 0 to 7+ years. The average age of respondents in the survey is 56.5 years, while it is 52 years in the Census; the average net worth of survey respondents is $587,000, whereas the

[4] This low response rate is not at all atypical of farm surveys as the Environics survey of Canadian farmers and Bell et al. survey of Tennessee farmers indicate. Importantly, response rates for executives of small firms are notoriously low (see Friedman and Singh 1989), and farms must be viewed as small firms, and not as individuals commonly surveyed using CVM. But response rates for individuals may even be low depending on the topic. Riddel and Shaw (2003), for example, report a response rate of 24% for those who previously agreed to participate in a telephone survey about nuclear waste, implying an effective response rate perhaps half that.

Census average for the Prairie Provinces (excluding BC) is $628,000. Survey respondents completed an average 1.44 years of post-secondary education, while the comparable average education level of prairie farmers in the 2001 Census was about one year of post-secondary education (assuming that "post-secondary, non-university" equals 2 years and "university" equals 4 years). The differences between survey and Census net worth, age and education are small and can easily be attributed to the differences in the reporting categories employed.

The first series of questions in the survey was meant to reduce information biases by familiarizing respondents with the topic and issues under investigation before asking them about their willingness to plant trees. Landowners were presented a hypothetical tree-planting program that covers all costs of tree planting while compensating for lost agricultural production. A compensation amount was offered to convert their least productive land to forest under a 10-year contract. The hypothetical program offered landowners was considered as attractive as the hardwood tree initiative of the CRP. Initial payment amounts for early CRP programs were determined through test programs and auctions with landowners. The bid compensation amounts for this study were selected on the basis of results from a pilot study, and range from $1 to $60 per acre per year (see Suchánek 2001).[5] The distribution of these bids is skewed towards the lower bound of the range in order to provide more efficient estimates of WTA (Cooper 1993). The contingent contract indicates that farmers have no right to harvest the trees before the contract expires, but trees become their property at the end of the contract period. The contract provides no compensation for the conversion of land back to agriculture.

4. VARIABLE DESCRIPTION

The explanatory variables of greatest interest are the level of the bid and the opportunity cost of the (least productive) field that would be planted to trees if the bid is accepted. Together these form the actual compensation that a landowner might expect. The calculation of opportunity cost deserves further attention. Farmers were asked to provide information for up to four of their least productive fields. Land uses were combined into three categories: pasture, hay and grain, with the latter including wheat, canola, barley, rye, oats, flax, lentils, peas and summer fallow. Net returns to each land use vary according to soil zone and region. Survey data on costs of production and returns by region and agricultural activity are available for Alberta. We constructed weighted averages of net returns for agricultural activities on marginal farmland (weighted by number of farmers providing information to extension agents) for five regions in Alberta (Table 1) and apply these to the landowners in our survey. Notice that cropping may not always be the most profitable activity on marginal land, but farmers will nonetheless crop the land because, under Canada's grain marketing system, they receive quota for cropland but not for land in perennial hay or pasture. We assign an opportunity cost for tree planting on the basis of the region in which a respondent is located and the land use on their marginal field.[6]

Landowners could very well obtain positive non-market plus "intangible" benefits from

---

[5] Agricultural producers identified their least productive fields and the use of those fields in an earlier section of the survey. They were then told of the role of tree planting in mitigating climate change and the terms of a potential contract. Finally, the farmer is asked to respond 'yes' or 'no' to the following question: "Suppose a block tree-planting program is available, and at least one of your fields is identified as a potential site for tree plantations. Would you be willing to accept *annual* compensation of $___ per acre for a 10-year contract?"

[6] All respondents in British Columbia are assigned to the Peace Region, while soil maps are used to assign all other landowners to one of the remaining four regions in Table 1. An alternative means of calculating foregone returns to agriculture is described in Suchánek (2001), but it only distinguishes between the three marginal land uses, thus providing little variation. Nonetheless, estimation results turn out to be similar regardless of which opportunity costs are used.

planting trees on marginal land, where the latter might include benefits from having an assured and invariant annual payment (reduced risk), reduced frustration from harvesting hay in difficult-to-get at areas, aesthetic benefits from forest landscapes, and so forth. To test the effect of these benefits on the decision to accept a tree-planting program, the choice to accept or reject the offered bid is regressed on both the bid and the opportunity cost of land.

In addition, a number of control variables were employed as regressors. Two provincial indicators are used to account for differences in jurisdictional factors across provinces (with policy in northeastern B.C. generally following that in Alberta). Soil zone dummy variables are used to take into account weather, terrain, soil fertility and other productivity differences. One would expect farmers in the black soil zone to require greater compensation than those in the dark brown and brown soil zones. The reason is that the black soil zone demarcates the transition between the boreal forest and grain belt. While there is a greater capacity to grow trees in this zone, landowners have spent significant effort clearing trees and would likely be the most hesitant to replant (van Kooten et al. 2002). The brown soil zone is characterized by drier conditions, so drought tolerant species will need to be planted; farmers are more likely to view trees more positively for their soil conservation benefits (reducing wind erosion).

A visual scale variable is used to incorporate farmer opinions about the aesthetic benefits of tree cover, which is likely to influence acceptance positively. The value of the visual variable ranges on an integer scale from 1, if the respondent considers increased tree cover in the region to enhance the visual appeal of the landscape, to 5 if she considers additional trees to be visually unappealing.

As the number of acres of farmland covered by trees increases, we postulate that the likelihood of accepting the bid amount will increase for several reasons. Extant tree cover could indicate some preference for forest, but it could also indicate that soils in the region are better suited to forest than agriculture, although we control for the latter by including soil zone dummy variables. Owners of existing forests may also be more likely to accept a particular bid because an increase forest area leads to economies of scale in timber production. However, landowners with higher proportions of land in forest may have a lower marginal utility from non-market forest amenities, which would serve to reduce their likelihood of accepting a bid amount.

Likewise, whether or not a respondent had previous experience with a tree-planting contract is thought to have a positive effect on the probability of accepting the bid to plant trees.

Respondents were asked to indicate whether they would adapt to climate change by leaving agriculture altogether. We postulate that those who expressed a greater likelihood to leave agriculture as a response to climate change would be more likely to accept the bid amount. These are probably farmers who are already struggling to stay in the sector, perhaps because they are not the 'best' farmers, or they had a few bad years that they attribute to weather conditions. Such farmers may see forestry as a means to leave the sector without losing their land, or they may be interested in greater income stability, which a tree-planting contract could offer.

Further, a farmer's age would likely influence participation positively, as contracts reduce workloads while ensuring a steady income. Increased education, on the other hand, could influence the likelihood of accepting the bid amount negatively, because those with a higher education are more likely to view tree plantations as a restriction on future land-use flexibility. More educated landowners are likely more knowledgeable about the disputes concerning the Canadian Wheat Board marketing system and opportunities afforded should it be abandoned in the future. They may also be more knowledgeable about the WTO process and the impact future trade agreements will have on future grain markets and prices.

Rather than planting trees, a farmer who expects to bequeath the farm to an heir may be better off to maximize annual returns and invest the proceeds in the capital market. However, agricultural landowners tend to invest in land, with which they are familiar. This increases farm size and results in increasing returns to scale, but also exposes the landowner to greater risks, some of which can be diversified by planting more trees and creating carbon offset credits. Further, the form in which land is passed on to an heir may be important: A diversified farm with forests that provide ecosystem amenities that benefit agricultural production is a form of investment that provides an heir with greater opportunities in the future. If this is the case and standing timber is considered a form of financial and non-financial wealth, those who expect to bequeath the farm are more likely to participate in tree planting. Contrariwise, tree-planting contracts reduce the long-term flexibility of land use and this might be considered to reduce the future options available to an heir. Which of these effects has the greatest influence on the probability of accepting a contract offer to plant trees can only be determined empirically.

Finally, we employ a measure of net worth to capture a farmer's wealth and size and scale of farm operations. Net worth is measured as a categorical variable, with ten categories starting with $100,000 and less, and increasing by $100,000 to a maximum of $1million. Again, it is not clear what effect wealth will have on the likelihood of accepting a bid to plant trees. As in the previous paragraph, larger and wealthier farmers may be exposed to more risk and, to reduce such risk, they are willing to move some land into forestry. Forests may also be seen as an investment that enhances the sustainability of agriculture and long-term yields. On the other hand, wealthier farmers may be better positioned to take advantage of changes in grain marketing institutions (e.g., trucking grain into the U.S. if the Canadian grain marketing system changes), seeing tree-planting contracts as reducing flexibility to pursue such opportunities.

Summary statistics for the explanatory variables are provided in the last column of Table 2. Not all returned surveys were used in the probit estimation. The design of the survey did not permit those respondents unwilling to accept any compensation to answer the contingent valuation questions. While these responses could be construed as a ‘no’ response for any bid amount, they were not included in this analysis as we are primarily interested in those willing to convert their land. Further research explores these responses as part of the relevant sample. As a result of this and some missing data, 103 observations were used to estimate WTA.

5. RESULTS

A general and a restricted regression model were estimated and the results provided in Table 2. The general model includes all of the explanatory variables available from the survey instrument and potentially able to explain the willingness of respondents to accept the offered bid. The restricted model is derived in iterative fashion by eliminating the least significant variable in each stage, continuing until the likelihood ratio χ^2 statistic falls below a critical significance level (see Table 2), in which case the restricted model is preferred to the general one. This is confirmed by McFadden’s (1974) Adjusted R^2 goodness of fit measure, which is also provided in Table 2 and calculated as

$$\overline{R}^2_{McFadden} = \left[1 - \frac{L_w - K}{L_\Omega}\right],$$

where L_Ω is the log-likelihood in the null case (where all coefficients other than the constant are assumed to be zero), L_w is the unrestricted log-likelihood, and K equals to the number of parameters in the model.

Surprisingly, the opportunity cost variable, whose construct was described in the preceding section, has no statistical impact on the probability of accepting the hypothetical tree-planting program. Perhaps the range of opportunity costs in Table 1 was insufficient, but more likely the respondents did not consider the potential loss of direct income from their marginal fields to be an important consideration in choosing to plant trees on those fields. Rather, it might be the contribution of marginal fields to the total enterprise (the indirect income effect, perhaps operating through Canada's grain quota system) that was important to those who chose not to take up the offered bid, or lack of contribution for those who did.

The marginal effects of the explanatory variables are also provided in Table 2. For a continuous variable *x*, the marginal effect is calculated using Greene 2000 (p.815, Eq. 19-9), with the slope evaluated at the sample mean $\bar{x}$. The marginal effect for a dummy variable (*dum*) is calculated using:

(5) $$\frac{\partial E[y \mid dum]}{\partial dum} = \Pr[Y = 1 \mid \overline{X}, dum = 1] - \Pr[Y = 1 \mid \overline{X}, dum = 0],$$

where the matrix $\overline{X}$ represents all the other variables in the probit model evaluated at their sample means.

Except for the intercept term, four coefficient estimates are significant at the 1% significance level and one at the 10% level of significance (Table 2). As expected, per acre compensation has a significant positive effect on the probability that a respondent accepts the bid amount. A one-dollar increase in the difference between the offered bid and forgone agricultural returns implies an increase of between one and nearly two percent in the probability of accepting the bid.

The variable that has the greatest positive impact on the probability of accepting a tree-planting program is whether land is located in the brown as opposed to the black soil zone (which is the reference case in the regression, along with Saskatchewan). Trees occur naturally and are common in the black (most northerly) and dark brown soil zones, but are less common in the (most southerly) brown soil zone. It is not surprising, therefore, that landowners in the brown soil zone, who have spent less time removing trees, are more likely to accept the bid amount. As shown by van Kooten et al. (2002), farmers in the black soil zone even appear negative towards tree planting because trees are seen as an obstacle to farm operations, while in the drier brown soil zone they act as shelterbelts and watersheds. It may be the ecosystem functions that cause landowners in the brown soil zone to be more receptive to planting of trees on marginal lands. The probability that landowners in the brown soil zone accept a bid to plant trees is some 50% higher at the margin.

The more trees a farmer already has as a proportion of all owned land, the more likely she is to accept the opportunity to plant more trees, providing support for the notion that respondents have some preference for forest. While it might also indicate that the farmer is already producing timber and more forest area leads to economies of scale in timber production, this is unlikely the situation given that so few landowners practice commercial forestry in the region (although this has been changing rapidly in the past several years). However, the effect of an additional acre of tree cover produces only a small (less than 0.5 percent) increase in the likelihood that the respondent accepts the bid to plant more area to trees.

Finally, the coefficient on age is statistically significant at the 5% significance level. Older agricultural producers are more likely to accept a tree-planting program that provides more secure and consistent annual payments, as hypothesized. An increase in age category increases the probability of accepting the offered compensation by about 1½ percent.

The proxy income variable, net worth, is negative and statistically significant at the 10% level. This result suggests that wealthier farmers see tree-planting contracts as reducing their flexibility to pursue future revenue opportunities as opposed to a means to reduce risk or improve the sustainability of agricultural production. At the margin, a farmer with $1 million additional wealth is 33% less likely to accept the offered bid.

The visual variable is negative and, although statistically insignificant, an important factor explaining the likelihood a respondent would accept the offered compensation (as it could not be removed from the restricted model). This implies that, for a farmer who perceives further increases in local tree cover as visually unappealing, the probability of accepting a bid to plant trees is lower than for a farmer who is fond of trees. The marginal effect on the probability to accept for a one-step increase on the scale of the visual variable is approximately ten percent. So the difference in probabilities of accepting a bid to plant trees between a farmer who very much enjoys the visual aesthetics of trees and one who prefers a more open landscape can be as high as 20%.

Provincial dummy variables turned out to be statistically insignificant, possibly because soil zone captures some of this impact, but also because agricultural programs tend to be similar across the Canadian Prairies, despite the different political jurisdictions and separate agricultural ministries. Whether the landowner will pass the farm to an heir does not appear to be a significant variable, suggesting that continuation of the family farm is unimportant in explaining the decision to accept a tree-planting program – the benefit of passing along added wealth in the form of standing timber may be offset by the loss of flexibility in the way offspring can use land. Further, neither previous experience with a tree-planting program nor education affects the likelihood of accepting the proposed bid.

By setting $\Pr(a=1)=0.5$ and solving, it is possible to calculate the expected median compensation level for each respondent in the sample. We calculate median WTA for each respondent and provide the mean, standard deviation, minimum and maximum values in Table 3. The average compensation required to get farmers to plant blocks of trees is $33.42 per acre, or $33.59/ac if estimated parameter values are random and Monte Carlo simulation is used. The estimated maximum compensation required, on the other hand, could be as high as approximately $75 per acre (or higher). It is important to keep in mind, however, that this pertains to the least productive acres and that compensation to plant large blocks of trees might well be much higher as increasingly better agricultural land is converted to tree cover. However, WTA compensation is often below the foregone earnings of the land, which most economists would use as the appropriate measure for estimating costs of carbon uptake.

6. COST-EFFECTIVENESS OF TREE PLANTING ON AGRICULTURAL LANDS

Using data from Table 3, it is possible to determine whether it would be cost-effective to pay farmers in western Canada to plant trees to mitigate climate change. To do so, we employ a 40-year time horizon using the growth functions illustrated in Figure 1.[7] The growth functions represent a fast-growing species (hybrid poplar) and a mix of native species (see van Kooten et al. 1999, 1995). Native species are generally more attractive from a visual and ecological perspective. Carbon in wood biomass amounts to 0.187 metric tons of carbon (tC) per m^3 for hybrid poplar and 0.203 tC/m^3 for the slower growing native species. In addition, a factor of 1.57 is assumed to account for total above ground biomass, while soil carbon is assumed to increase at a rate of 0.96 tC per ha per year when marginal agricultural land is converted to forest (van Kooten et al. 1999).

Unlike a reduction in CO_2 emissions, which results in a permanent decrease in the rise of atmospheric CO_2, carbon uptake in sinks is not permanent (land can easily be converted back to agriculture releasing stored carbon). To take into account the ephemeral nature of tree planting, the IPCC (2000) recommends using ton-years, with the conversion factor ranging from one permanent ton being equivalent to 50 to 150 ton-years of temporary storage. Many observers have condemned the ton-year concept on various grounds, and it has been rejected by most countries, primarily because it disadvantages carbon sinks relative to emissions avoidance (Dutschke 2002, p.395).

A second method that has been proposed is the use of temporary carbon emission reduction credits, which under an EU proposal would last for a period of five years. A country claiming such credits during Kyoto's first commitment period would be held responsible for them in ensuing commitment periods.

A third proposal for dealing with the ephemeral nature of biological carbon sinks is due to Marland et al. (2001), and Sedjo and Marland (2003). They suggest that the temporary nature of carbon uptake in sinks can be addressed via a rental market for credits, where the rental rate (r) is simply the price of a permanent emission credit (P) multiplied by the discount rate (δ), which equals the established financial rate of interest adjusted for the risks inherent to carbon uptake (e.g., fire risk, slower than expected tree growth, etc.). Thus, $r = P \times \delta$, which is the well-known bond formula. If emissions trade for \$15 per t CO_2, say, and the risk-adjusted discount rate is 10%, then the annual rental for a metric ton of CO_2 in a terrestrial sink would be \$1.50.

---

[7] We recognize that, in the WTA question, tree-planting contracts were specified to run for 10 years, not 40 years. Yet, we assume the longer time horizon, implicitly assuming contracts are renewed under the same conditions, in order to estimate the costs of creating carbon credits. Alternatively, it can be assumed that landowners incur the same cost as given by WTA for keeping the land in forest until harvest at 40 years.

Like the ton-year concept, this approach may make terrestrial sink projects less attractive than they might be under some other political solution.

Since we do not know the value at which CO_2 emissions trade, we employ the ton-year concept, using a conservative conversion factor of 50 ton-years of temporary to one ton of permanent removal of atmospheric CO_2. Costs of carbon uptake are calculated using estimated planting costs of $1,050 per hectare and costs half that amount (see Krcmar et al. 2001),[8] and annual payments to landowners (in lieu of opportunity costs) from Table 3. Costs are discounted at 4%, while physical carbon is discounted at rates of 0%, 2% and 4%.[9] Krcmar et al. (2003) estimate stumpage rates in Alberta (using Government of Alberta methodology) of $8.52 per cubic meter for coniferous wood used in lumber production and \$0.50/m^3 for deciduous timber used for OSB. Since these are conservative as they are rates intended to capture the resource rent, we also assume higher net stumpage value (returns after harvest costs) of \$20/m^3 and \$30/m^3 for conifers (natives) and \$10/m^3 and \$20/m^3 for poplar (van Kooten et al. 1999).

In Table 4, we provide estimates of the costs of carbon uptake in Canadian dollars per metric ton of CO_2 for low, medium and high stumpage values, three different rates for discounting future CO_2 removals from the atmosphere (above and below ground biomass are included in calculations of carbon uptake), two tree planting options, and alternative plantation establishment costs. In addition, we compare results where the landowner is paid according to willingness to accept compensation and an opportunity cost of land of $54.78 per acre, with the latter determined

---

[8] Cost data are from a 1997 study by the Agricultural Utilization Research Institute, University of Minnesota, Crookston (http://www.hybridpoplar.org/EMCosts.htm, 3 August 2003), and are converted from acres and USD to Canadian dollars per hectare.

[9] Weighting of physical flows of a resource as to when they are available is well established in the natural resource economics literature (Ciriacy-Wantrup 1968). On the discounting of physical carbon, see van Kooten et al. (2004, pp.241-42) for a discussion.

as a weighted average of land in pasture (40%), hay (40%) and grain (20%) further averaged over regions. The costs of carbon uptake by afforestation in western Canada range from net benefits from tree planting to a cost of nearly \$70 per t CO_2 for fast-growing hybrid species, to some \$30.50–\$135.00 per t CO_2 for slow-growing native species, and then only if compensation is based on landowners' WTA. If landowners are compensated according to estimated foregone net returns to extant agricultural activities, costs rise to \$34.33–\$84.09 per t CO_2 for hybrid species under a low (but perhaps most realistic) stumpage value scenario, to \$5.71–\$30.10 per t CO_2 for the most optimistic stumpage value scenario.

Emission reduction permits are expected to trade in the range of \$15 to \$30 per t CO_2.[10] In that case, the results suggest that landowners in western Canada are unlikely to make a major contribution to Canada's Kyoto targets even if marginal agricultural lands are planted to fast-growing hybrid species. If stumpage prices for poplar are similar to those of conifers or higher, planting costs are not "too high", and landowners are compensated according to their willingness to accept compensation as opposed to the opportunity cost of land, then some planting of hybrid poplar will be competitive with emissions reductions for mitigating climate change. Clearly, there is no room to plant native species as these will not be able to compete with emissions reduction strategies. Nonetheless, our cost estimates for native species are not outside the range of estimates of the costs of carbon uptake in forest sinks found in the literature (van Kooten et al. 2004).

7. CONCLUSIONS

While farmers are unwilling to plant blocks of trees on their land without financial incentives, these incentives may be less than the net returns to current agricultural activities on

[10] The Government of Canada has capped what large final emitters will have to pay at \$15 pet t CO_2, while emission reductions were trading in Europe at just under \$30/t CO_2 in June 2005.

marginal agricultural land (compare Tables 1 and 3). This is because some farmers may receive benefits from growing trees that do not show up in market transactions. These benefits relate to potential reductions in risk from assured annual payments, environmental spillover benefits from forests that may enhance sustainable agricultural production, aesthetic benefits, and so on. Thus, if governments or large final emitters seeking offset carbon credits through biological sinks wish to minimize outlays, they should consider compensating landowners according to their WTA instead of observed net returns to extant land use. This could save between one-third and two-thirds of the costs of implementing an afforestation program, or result in more carbon sequestered for the same cost, an important consideration when programs have a budget constraint. However, it will require identifying those landowners who would be willing to participate in tree-planting programs, which could be done through a bidding process.

This research also demonstrates that, even when landowners have some preference for forestry, the cost of providing carbon offset credits by planting native species of trees on marginal agricultural land in western Canada is likely higher than socially desirable: estimates of the costs of creating carbon credits by planting trees are more than likely to exceed the price projected under CO_2 emissions trading schemes. This is generally but not always true even if farmers' WTA compensation is below foregone returns to agricultural activities, because they receive other benefits (environmental amenities, reduced risk, potential earnings from sale of timber) from planting trees.

Finally, further research needs to examine other important factors that influence farmer decisions and, in turn, the amounts of land available for tree planting in Canada. Critical in this regard is the attitude of landowners and environmental groups to large-scale planting of fast-growing hybrid species, an object of future contingent valuation research. Also critical are the mechanisms and institutions used to compensate landowners, such as whether farmers receive direct payments from government, a private corporation or an environmental NGO, whether they can sell emission offset in open markets and/or whether they form cooperatives to market carbon credits or tree plantations.

8. REFERENCES

Bell, D.C., K.R. Roberts, C.B. English, and M.W. Park. 1994. A Logit Analysis of Participation in Tennessee's Forest Stewardship Program, *J. of Agric. and App. Econ.* 26:463-472.

Ciriacy-Wantrup, S.V. 1968. *Resource Conservation. Economics and Policies*. 3rd ed. University of California Agricultural Experiment Station, Berkeley, CA.

Cooper, J. 1993. Optimum Bid Selection for Dichotomous Choice Contingent Valuation Surveys, *J. Environ. Econ. & Manage.* 24: 25-40.

Dutschke, Michael. 2002. Fractions of Permanence – Squaring the Cycle of Sink Carbon Accounting, *Mitigation and Adaptation Strategies for Global Change* 7: 381-402.

Environics Research Group. 2000. Survey of Farmers, Ranchers and Rural Landowners Attitudes and Behaviours Regarding Land Stewardship. Wildlife Habitat Canada [On-line report]. http://www.whc.org/whc/WHCDocuments.nsf/Documents?OpenFrameSet.

Friedman, S.D. and H. Singh. 1989. CEO Succession and Stockholder Reaction. The Influence of Organizational Context and Event Content, *Acad. of Manage. J.* 32: 718-744.

Greene,W.H. 2000. *Econometric Analysis*. 4th ed. Prentice Hall, Englewood Cliffs, NJ.

Hanemann, W.M., 1984. Welfare Evaluation in Contingent Valuation Experiments with Discrete Responses, *Am. J. Agric. Econ.* 66: 332-41.

Intergovernmental Panel on Climate Change (IPCC). 2000. *Land Use, Land-use Change, and Forestry*. Cambridge University Press, New York.

Krcmar, E., B. Stennes, G.C. van Kooten and I. Vertinsky. 2001. Carbon Sequestration and Land Management under Uncertainty, *European J. Operational Res.* 135(December): 616-29.

Krcmar, E., H. Nelson, G.C. van Kooten, and I. Vertinsky. 2003. Can Forest Management Strategies Sustain the Development Needs of the Little Red River Cree First Nations? FEPA Working Paper 10-03, Univ. of British Columbia, Vancouver, B.C., Canada. 22p.

Marland, G., K. Fruit, and R. Sedjo. 2001. Accounting for Sequestered Carbon: The Question of Permanence, *Environ. Sci. & Policy* 4(6): 259-68.

McFadden, D. 1973. *Conditional Logit Analysis of Qualitative Choice Behaviour*. P. 105-142 in Frontiers in econometrics, Zarambka, P. (ed.), Academic Press, New York.

Riddel, M. and W.D. Shaw, 2003. Option Wealth and Bequest Values: The Value of Protecting Future Generations from the Health Risks of Nuclear Waste Storage, *Land Econ.* 79(November): 537-548.

Sedjo, R.A. and G. Marland. 2003. Inter-trading Permanent Emissions Credits and Rented Temporary Carbon Emissions Offsets: Some Issues and Alternatives, *Climate Policy* 3(December):435-444.

Stavins, R.N. 1999. The Costs of Carbon Sequestration: A Revealed Preference Approach, *Am. Econ. Rev.* 89(September):994-1009.

Suchánek, P. 2001. Farmers' Willingness to Plant Trees on Marginal Agricultural Land in Canada's Grain Belt. M.Sc. thesis, Univ. of British Columbia, Vancouver, B.C., Canada. 92 p.

Plantinga, A.J. 1997. The Cost of Carbon Sequestration in Forests: A Positive Analysis, *Critical Rev. in Environ. Sci. & Techn.* 27: S269-S277.

United States Department of Agriculture (USDA). 2003. USDA announces sign-up for hardwood tree initiative to restore up to 500,000 acres of river floodplains. Press Release Number 0402-03, Office of Communications, Washington, DC.

van Kooten, G.C., S.L. Shaikh, and P. Suchánek. 2002. Mitigating Climate Change by Planting Trees: The Transaction Costs Trap, *Land Econ.* 78(November): 559-572.

van Kooten, G.C., C.S. Binkley, and G. Delcourt. 1995. Effect of Carbon Taxes and Subsidies on Optimal Forest Rotation Age and Supply of Carbon Services, *Am. J. Agric. Econ.* 77(May): 365-774.

van Kooten, G.C., A.J. Eagle, J. Manley, and T. Smolak. 2004. How Costly are Carbon Offsets? A Meta-Analysis of Carbon Forest Sinks, *Environ. Sci. & Policy* 7(4 August): 239-51.

van Kooten, G.C., E. Krcmar-Nozic, B. Stennes, and R. van Gorkom. 1999. Economics of Fossil Fuel Substitution and Wood Product Sinks when Trees are Planted to Sequester Carbon on Agricultural Lands in Western Canada, *Can. J. For. Res.* 29(11): 1669-78.

Table 1: Net Returns to Agricultural Activities on Marginal Agricultural Lands, by Region or Soil Zone ($ per acre)[a]

	Land Use		
Soil Zone	Crop	Hay	Pasture
Brown Soil Zone	20.54	43.46	37.39
Dark Brown Soil Zone	32.63	68.96	52.81
Black Soil Zone	45.36	83.12	86.00
Peace Region	34.54	88.17	26.40
Grey-Wooded Soil Zone	35.11	63.67	Not available

[a] Opportunity costs are calculated based on the Data provided by Alberta Agriculture, Food and Rural Development.

Table 2: Probit Estimation Results (103 observations)[a]

Explanatory Variable	General Estimated coefficient	Restricted Estimated coefficient	Restricted Marginal effect	Mean
Constant	-3.363*** (1.283)	-3.262*** (1.096)	—	
Compensation offered	0.048*** (0.009)	0.046*** (0.009)	0.017***	25.409
Opportunity Cost	0.005 (0.010)	—	—	48.408
Alberta (=1; =0 otherwise)	-0.224 (0.371)	—	—	0.308
Manitoba (=1; =0 otherwise)	-0.149 (0.529)	—	—	0.126
Brown soil zone (=1; =0 otherwise)	1.454** (0.586)	1.407*** (0.500)	0.511***	0.165
Dark Brown soil zone(=1;=0 otherwise)	0.145 (0.393)	—	—	0.258
Forest landscape visually unappealing	-0.235 (0.167)	-0.266 (0.163)	-0.101	2.151
Acres of farmland covered with trees	0.007*** (0.003)	0.007*** (0.002)	0.003***	39.202
Respondent would leave agriculture if climate change became a reality (=1; =0 otherwise)	0.127 (0.493)	—	—	0.25
Respondent previously participated in a tree-planting program (=1; =0 otherwise)	-0.128 (0.339)	—	—	0.618
Number of years of post-secondary education	-0.088 (0.101)	—	—	1.436
Age (median category variable from 33 to 68 years with 5-year intervals)	0.044*** (0.016)	0.042*** (0.016)	0.016***	56.547
Respondent expects a heir to continue farming (=1; =0 otherwise)	-0.063 (0.344)	—	—	0.715
Net worth [b]	-1.002** (0.522)	-0.867* (0.501)	-0.329*	0.587
# of observations	103	103		
Log likelihood	-43.993	-45.043		
Likelihood ratio χ^2(df)		2.10(8)		
McFadden Adjusted R^2	0.161	0.260		

[a] Numbers below coefficient estimates are the Huber/White/sandwich robust standard errors. *** indicates statistical significance at the 1% level or better; ** indicates significance at 5% level or better; * indicates significance at 10% level or better.

[b] The net worth variable is in million dollars.

Table 3: Estimated Median Willingness to Accept a Tree-planting Program ($/acre)[a]

	Median	Standard Deviation	Minimum	Maximum
Estimated parameter values fixed; WTA based on farmers' covariates	$33.42	$18.49	–$23.84	$74.06
Estimated parameter values random; representative farmer covariates (Monte Carlo simulation: *n*= 10,000)	$33.59	$2.25	$25.45	$41.42

[a] Estimated using the restricted model in Table 2.

Table 4: Estimated Costs of Carbon Uptake from Tree-planting in Western Canada (C$ per t CO_2)

Item	Low Stumpage ($8.52/$m^3$ natives; $0.50/$m^3$ poplar)			Medium Stumpage ($20/$m^3$ natives; $10/$m^3$ poplar)			High Stumpage ($30/$m^3$ natives; $20/$m^3$ poplar)		
C discount rate[b]	0%	2%	4%	0%	2%	4%	0%	2%	4%
WTA = $33.50 per ha per year									
Planting cost of $1050 per ha									
Slow growth	58.59	90.64	134.96	50.18	77.63	115.58	42.85	66.30	98.71
Rapid growth	36.40	51.24	68.68	22.46	31.62	42.38	7.79	10.96	14.69
Planting cost of $525 per ha									
Slow growth	46.24	71.53	106.50	37.83	58.57	87.13	30.50	47.19	70.26
Rapid growth	26.16	36.82	49.35	12.22	17.19	23.05	++	++	++
Opportunity cost = $54.78 per ha per year									
Planting cost of $1050 per ha									
Slow growth	78.28	121.11	180.30	69.87	108.10	160.94	62.54	96.76	144.07
Rapid growth	44.57	62.73	84.09	30.63	43.11	57.79	15.96	22.46	30.10
Planting cost of $525 per ha									
Slow growth	65.93	102.00	151.86	57.52	88.99	132.49	50.19	77.65	115.61
Rapid growth	34.33	48.31	64.76	20.38	28.69	38.46	5.71	8.04	10.77

[a] For hybrid-poplar, trees are harvested after 20 years and again after 40 years, with the ton-years of carbon adjusted accordingly. ++ indicates benefits of tree planting so there are no carbon uptake costs.

[b] Discounting is combined with the ton-years conversion factor as follows: If 1 tC is stored during the first year of growth, it is assumed to remain stored for 40 years (for natives) and is thus counted as 40 ton-years C. In the second year, storing 1 tC is counted as 39 ton-years C, but it is discounted by one period (if the discount rate > 0%). The same is true for subsequent years.

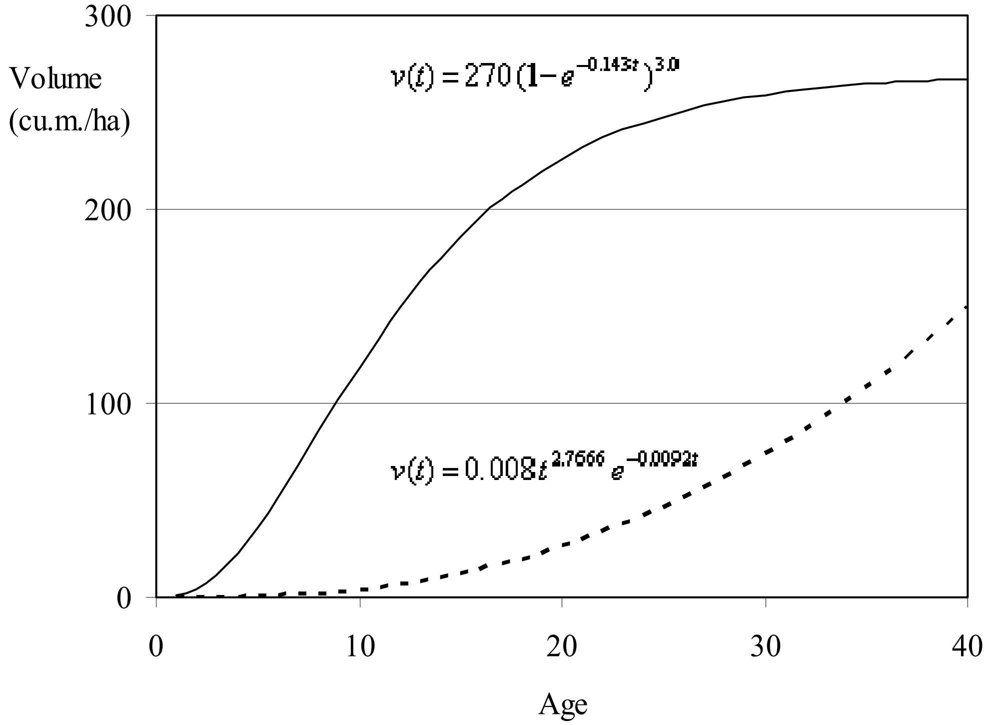

Figure 1: Tree Growth Functions