Forest Policy and Economics 97 (2018) 41–50

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

# Use of revealed preference data to estimate the costs of forest carbon sequestration in Canada

Rose Murphy[a,*], Dominique M. Gross[b], Mark Jaccard[a]

[a] School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia V5A 1S6, Canada
[b] School of Public Policy, Simon Fraser University, 515 West Hastings Street, Vancouver, British Columbia V6B 5K3, Canada

ARTICLE INFO

*Keywords:*
Afforestation
Carbon sequestration
Carbon sequestration cost
Econometric method
Offset
Additionality

ABSTRACT

Estimates of the costs of forest carbon sequestration can guide policy makers in determining the level of effort to place on achieving this form of greenhouse gas emissions mitigation. The Canadian literature on the costs of forest carbon sequestration is dominated by what is known as the bottom-up engineering method. Generally speaking, this approach relies on values observed in markets to estimate land opportunity costs. An alternative is the econometric method, which can capture other potential influences on the behavior of landowners, as revealed by historical data. To our knowledge, there are currently no studies that apply the econometric method to Canada; this may be because detailed land-use data over time is not available. We identified a database compiled by the Canadian Forest Service and used it to estimate an econometric model of afforestation in Ontario. Simulations were conducted from the estimated equation under a range of conditions. The results suggest that carbon sequestration at a given cost could be much lower than indicated by Canadian bottom-up studies. The simulations also demonstrate that, if afforestation is encouraged by awarding offset credits, low carbon prices could result in an unacceptably high share of those credits going to non-additional projects – ones that would have been carried out anyway.

## 1. Introduction

A forest can act as a carbon sink, absorbing carbon dioxide ($CO_2$) from the atmosphere through the process of photosynthesis. Actions that include afforestation, reforestation, and changes in forest management practices therefore have the potential to mitigate anthropogenic greenhouse gas (GHG) emissions. Estimated costs associated with each incremental unit of carbon sequestration in a particular jurisdiction – summarized as a marginal cost curve – can be referred to in considering the degree to which such actions should be pursued through government policy. Moreover, this information can be used to anticipate the uptake of actions by landowners and other decision makers (and resulting carbon sequestration levels) in response to policy alternatives.

Richards and Stokes (2004), Stavins and Richards (2005), and Van Kooten and Sohngen (2007) review studies of the costs of forest carbon sequestration undertaken since the late 1980s. They find a wide range of estimates, even among studies with the same geographic scope. The reviews indicate that direct comparison of results is problematic because of inconsistent use of terminology, wide ranging assumptions with respect to key parameter values, and different methodological approaches. In particular, three methods have been applied to estimating land opportunity costs, which are the most important factor influencing carbon sequestration costs: bottom-up engineering, sectoral optimization, and econometric analysis. The majority of studies use the bottom-up engineering approach.

The three methods of estimating land opportunity costs may be described as follows. In the bottom-up approach, these costs are estimated exogenously, for example from data on land rental or land purchase prices, or information on the expected returns from agriculture. Sectoral optimization models represent interactions between the forest and agricultural sectors, and are therefore able to address the problem of leakage that may be associated with forest-based carbon sequestration programs. Leakage can occur if enough land is converted from farms to forests, resulting in higher agricultural land prices and increased deforestation of land that is not included in the program. With the econometric method, land costs are estimated based on observed land-use choices over time, given changing agricultural and forest product prices. As such, the resulting cost estimates implicitly take into account the revealed preferences of landowners.

Bottom-up engineering analyses may not portray landowner behavior in a realistic manner. Stavins (1999, p. 995) offers four possible

* Corresponding author.
*E-mail addresses:* remurphy@sfu.ca (R. Murphy), dgross@sfu.ca (D.M. Gross), jaccard@sfu.ca (M. Jaccard).

https://doi.org/10.1016/j.forpol.2018.06.008
Received 20 December 2017; Received in revised form 18 May 2018; Accepted 21 June 2018
1389-9341/ 

reasons for this: "(1) land-use changes can involve irreversible investments in the face of uncertainty (Parks, 1995), and so option values may be important (Robert S. Pindyck, 1991); (2) there may be non-pecuniary returns to landowners from forest uses of land (Plantinga, 1995), as well as from agricultural uses; (3) liquidity constraints or simple 'decision-making inertia' may mean that economic incentives will affect landowners only with some delay; and (4) there may be private, market benefits or costs of alternative land uses (or of changes from one use to another) of which an analyst is unaware." In addition to the reasons provided by Stavins (1999), agricultural landowners may lack the knowledge and skills required to make appropriate forest management decisions – obtaining them would therefore represent an additional cost of afforestation (Plantinga et al., 1999).

Econometric studies that help to address these concerns have been carried out for the US (e.g. Lubowski et al., 2006; Newell and Stavins, 2000; Plantinga et al., 1999; Stavins, 1999); however, there is a lack of this type of research for Canada. The Canadian literature on forest carbon sequestration costs is dominated by bottom-up engineering analyses (e.g. McKenney et al., 2004; Van Kooten et al., 1992, 2000; Yemshanov et al., 2005). One possible reason for this discrepancy is a lack of information on how land use has changed over time in Canada. The models used by Newell and Stavins (2000), Plantinga et al. (1999), and Stavins (1999) incorporate land-use data from periodic surveys conducted by the US Forest Service, while that of Lubowski et al. (2006) relies on repeated land-use observations from the US Department of Agriculture's National Resources Inventory. Canada has compiled periodic forest inventories; however, the CanFI system that was used up until 2001 is not conducive with tracking changes over time (Canada's National Forest Inventory).

The findings of US econometric studies may have limited applicability to Canada due to qualitative differences in landowner behavior with respect to tree planting in the two countries. Combined with the gap in the Canadian literature, this would suggest a deficiency in the information available to evaluate actions and policies. In a 2006 report, the Canadian Forest Service notes that Canada has historically lacked a culture of farm forestry. This is in contrast to the US, where a large percentage of timberland is held by non-industrial private forest landowners (Beach et al., 2005). The Forest Service report explains the influence of Canadian land-use and taxation policies, which promote agriculture at the expense of forest plantations. As described by DeMarsh (1999, in Canadian Forest Service, 2006), cultural biases are also important in the Canadian context; it can be difficult for rural landowners whose ancestors worked to clear the land for agriculture to see the value of planting trees on it once again.

In this paper, we develop a simple econometric model of afforestation on private land in the Canadian province of Ontario. The source that allows us to estimate this model is a backcast database of afforestation activity between 1990 and 2002 obtained from the Canadian Forest Service. We apply the estimated equation in a series of simulations to develop marginal cost curves for carbon sequestration under different conditions. We are not aware of another study that takes this approach to estimating the costs of forest carbon sequestration in Canada.

Forest carbon sequestration is generally encouraged by awarding offset credits to projects that meet established criteria. The Regional Greenhouse Gas Initiative (RGGI) of Northeast and Mid-Atlantic US States and the California Cap-and-Trade Program (linked with Quebec) both allow offset credits from forestry projects to be used for compliance purposes (ICAP, 2016).[1] Because of the prominence of offsets as a policy option to promote forest carbon sequestration, our simulation procedure is designed with a hypothetical afforestation offsets program in mind.

Van Kooten and Sohngen (2007) consider the issue of additionality in the context of forest carbon sequestration offsets. Carbon sequestration for which offset credits are awarded must be additional to what would have occurred in the absence of the incentives created by the offset provision. If a significant amount of credits go to free-riders who were going to plant trees anyway, the integrity of the system governing emissions may be threatened. In the case of an emissions cap and trade program, the cap is effectively exceeded when non-additional projects are credited. It is difficult to demonstrate additionality because it is impossible to have knowledge of the counterfactual scenario that would have been observed if the offset provision had not been in place. Protocols for quantifying forest carbon offsets often establish additionality for afforestation or reforestation projects not required by law based on the length of time since the land was forested or whether the project is financially viable in the absence of any potential revenues from the sale of credits (see, for example, Air Resources Board, 2015). Both of these criteria are problematic. An advantage of the econometric approach to estimating forest carbon sequestration costs is that the resulting model can be used to simulate landowner behavior in the absence of offset revenues, shedding light on the counterfactual. Hence, in this study, we generate a base case simulation that allows us to estimate the percentage of carbon sequestration from afforestation that is additional over a range of offset prices.

## 2. Econometric model of afforestation in Ontario

### 2.1. Theoretical background and empirical specification

#### 2.1.1. Theoretical background

The econometric studies of the costs of forest carbon sequestration cited in the introduction employ models of land use. However, the data required to estimate such models is not currently available for Canada. The theoretical model for this study is therefore drawn from the literature on non-industrial private forest management, which includes timber harvesting, timber stand improvement, and reforestation. Of these three types of management, reforestation is the one that is most similar to afforestation. Beach et al. (2005) review and synthesize the empirical literature on non-industrial private forest management, and provide a useful analytical framework for landowner behavior based on utility-maximization theory. The theoretical model assumes that landowners make management decisions to generate optimal combinations of forest products income and non-market amenities, in such a way as to maximize their utility. These management decisions involve selecting levels of harvesting, reforestation, and timber stand improvement. The factors that influence these choices are divided into four sets: market drivers (MD), policy variables (PV), owner characteristics (OC), and plot/resource conditions (PR). The reduced form determinants of reforestation (REF) are therefore the inputs to the function:

$$REF = f(MD, PV, OC, PR). \tag{1}$$

A number of specific variables for each of the four primary categories have been used to explain reforestation behavior.

#### 2.1.2. Variables and data

The dependent variable is total area afforested ($A_{it}$) in hectares (ha) on non-industrial private land, by census division and year.[2] This information was obtained from a backcast database developed by the Canadian Forest Service under the Government of Canada's Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS)

[1] The percentage of a regulated source's compliance obligation that can be met through offsets is limited to 3.3% in the RGGI and 8% in the California program (ICAP, 2016).

[2] Census divisions are as defined in the 2001 census agricultural regions and census divisions map for Ontario (Statistics Canada, 2002). There were 49 census divisions in Ontario as of 2001. Our methodology for coding the dependent variable by census division is described in Appendix A.