Forest Policy and Economics 63 (2016) 43–51

Contents lists available at ScienceDirect

Forest Policy and Economics

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

Economic impacts of climate change considering individual, additive, and simultaneous changes in forest and agriculture sectors in Canada: A dynamic, multi-regional CGE model analysis

Thomas O. Ochuodho [a,*], Van A. Lantz [b], Edward Olale [c]

[a] Department of Forest Resources and Environmental Conservation, 310 West Campus Drive, Virginia Tech, Blacksburg, VA 24061, USA
[b] Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, NB E3B 5A3, Canada
[c] New Brunswick Department of Agriculture, 850 Lincoln Road, Fredericton, NB E3B 9H8, Canada

ARTICLE INFO

Article history:
Received 29 January 2015
Received in revised form 11 December 2015
Accepted 12 December 2015
Available online 29 December 2015

Keywords:
Computable general equilibrium
Climate change impacts
Additive impacts
Simultaneous impacts

ABSTRACT

Computable general equilibrium (CGE) model analyses of economic impacts from climate change have often focused on individual impacted sectors such as forest. However, such an approach may not provide accurate economic impact estimates since climate change will affect multiple sectors simultaneously. Furthermore, imprecise aggregate economic impact estimates may result if one were to add together individual sector impact estimates. We used CGE models to compare economic impacts of individual, additive, and simultaneous climate-induced changes in Canadian and other regions' forest and agriculture sectors over the 2006–2051 period. We found negative additive impact biases in a majority of regions for five of our economic variables including GDP, income, imports, terms of trade, capital, and total output. Positive additive impact biases were found in a majority of regions for four economic variables including welfare, consumption, export, and labor. These findings emphasize the importance of considering impacted sectors simultaneously when using CGE models to evaluate the economic impacts of climate change.

1. Introduction

Forestry and agriculture play important roles in Canada's economy. At the national level in 2012, the agriculture sector produced over $50 billion in output, accounting for 6.7% of Canada's GDP and directly contributed one in eight jobs at over 2 million people (AAFC, 2015, 2012). The forest sector contributed a further $54 billion to national output, directly employed over 230 thousand people, and was the country's largest net exporter with a balance of trade of over $16 billion (NRCan, 2015).

These two important sectors to Canadian economy have potential susceptibility to changes in climate and climate variability. It is projected that climate change will continue to produce a strong direct impact on both Canadian crops (Cline, 2007) and forests (Kirilenko and Sedjo, 2007). For instance, agricultural crops productivity in Canada are expected to increase in the range of 1% to 115% by 2080, depending on the region and variety considered (e.g., Cabas et al., 2010; Almaraz et al., 2008; Bootsma et al., 2005; Weber and Hauer, 2003). On the other hand, timber supplies in Canada could change in the range of −30.8% to 1.6% by 2080, depending on the climate change scenario and region considered (Ochuodho et al., 2012).

In order to facilitate more informed climate change mitigation and adaptation strategies and policies in both sectors, both at the national level and more importantly also in the Provinces, there is urgent need to better understand the potential impacts of climate change in aggregate, by sector, by region, and over time. Estimating climate change along these dimensions is critical because there are sectoral interactions of climate change impacts (Fankhauser and Tol, 1996), climate change impacts vary by regions (Weber and Hauer, 2003) and it also varies over time (McKenney et al., 2006).

As already indicated, the most appropriate approach to estimating climate change impacts in these two sectors would be one that combines the three dimensions of sectoral interactions, by region and over time. However, such analysis is currently not available in literature. A few studies have estimated the economic impacts of climate change on forest and agriculture sectors in Canada, focusing on either sector at the exclusion of the other. Zhai et al. (2009) estimated a 0.2% GDP loss and 0.2% welfare (equivalent variation) gain for Canada by 2080 from climate change impacts in the agriculture sector. Ronneberger et al. (2009), on the other hand, reported a GDP gain of just under 0.005% for Canada by 2050 from climate-induced changes in the agriculture sector. More recently, Ochuodho and Lantz (2015), estimated climate change impacts in Canadian agriculture sector across the Provinces with GDP gains ranging from 0.37 to 6.34% by 2051. In the forest sector, Ochuodho et al. (2012) estimated a 0.5% to 8% GDP loss for Canada by 2080 from climate change, with substantial regional variation across the

---

* Corresponding author.
E-mail addresses: ochuodho@vt.edu (T.O. Ochuodho), vlantz@unb.ca (V.A. Lantz), Edward.Olale@gnb.ca (E. Olale).

http://dx.doi.org/10.1016/j.forpol.2015.12.005
1389-9341/

country. Ochuodho and Lantz (2014) estimated GDP impacts ranging from −10% to 5% in forest sector across the Canadian Provinces by 2051.

A focus on estimating economic impacts of climate change in a specific sector in isolation, as are the cases in the literature cited above, neglects the interaction effects between sectors, and may therefore lead to "imprecise" estimates. Furthermore, if one were to simply add together the individual sector impact estimates from different economic model simulations, "biased" economic impact estimates would emerge (Eboli et al., 2010). To properly account for such interactions, climate-impacted sectors should be assessed simultaneously within the economic modeling framework (Fankhauser and Tol, 1996; Tol et al., 2000; Tol, 2005; Eboli et al., 2010).

Recently, there have been a number of studies conducted that assess economic impacts of simultaneously-impacted sectors from climate change (e.g., Eboli et al., 2010; Bigano et al., 2008; Berrittella et al., 2006; Bosello et al., 2004; Jorgenson et al., 2004; Kemfert, 2002). However, to-date, only two of these studies have compared economic impact estimates produced by additive vs. simultaneous sector impact analyses. Bigano et al. (2008) found that the additive (disjoint) analysis produced substantially different impacts than the simultaneous (joint) analysis. Similar findings emerged from a study by Eboli et al. (2010) from economic impacts in five climate-impacted sectors (agriculture, energy, human health, tourism).

The purpose of this study was to shed light on the extent of "bias" associated with additive (as opposed to simultaneous) sector impact analysis. To do this, we compared economic impact estimates produced by CGE models that consider individual, additive, and simultaneous climate-induced changes in Canadian and other regions' forest and agriculture sectors. We employed dynamic, multi-regional global CGE models of 13 regions. Canada was disaggregated into 11 provinces and territories and other regions include the United States (US) and the Rest of the World (RW).[1]

The remainder of this article is structured as follows. The second section details the development of the multi-regional CGE models, their specifications and their calibrations. In the third section, we present the results. We then provide discussion and some conclusions in the final section.

2. Methods

2.1. CGE model specification

Our CGE models were based on traditional neoclassical economic theory. We developed three, multi-regional, recursive dynamic CGE models for Canadian Provinces and territories, US, and RW regions. The first model (*Model 1*), similar to recent work by Ochuodho and Lantz (2015), focused on the agriculture sector by incorporating agricultural land services as a primary factor of production, the second (*Model 2*) (Ochuodho and Lantz, 2014), focused on the forestry and logging sector by incorporating stumpage as a primary factor of production. The last model (*Model 3*) focused on both sectors simultaneously by incorporating both of the above-mentioned factors of production. We specified these three models instead of using only one model (i.e., *Model 3*) for all analyses so that, as explained below, we could provide individual and additive estimates in a way that would be typically employed in the literature.[2]

The models were deterministic in nature with assumptions of small-open-economies (price takers) and constant returns to scale technology for each region.[3] The models were formulated as sets of simultaneous linear and non-linear equations, which define: (i) the behavior of economic agents; (ii) market conditions; (iii) macroeconomic balances; (iv) intertemporal components; and (v) steady-state economic growth path. Detailed general representation of the models equations are provided by Ochuodho and Lantz (2015, 2014).

Model 1 had three factors of production, including labor, capital and agricultural land services. *Model 2* also had three factors of production, including labor, capital and stumpage. *Model 3*, on the other hand, had four factors of production, including labor, capital, agricultural land services and stumpage.

In all three models, production was specified in a two-level nest where at the top level, a composite of value-added and a composite of intermediate inputs are substitutable in a CES function. At the bottom level, the primary input factors were assumed to substitute through a CES composite value-added function under single primary factor nest (Winchester et al., 2006; Rutherford and Paltsev, 2000). Intermediate inputs on the other hand, were determined by fixed-shares through a Leontief function (Fig. 1).

Each region had a representative household who receives income from supplying factors of production (Prasada et al., 2010). Supplies of input factors were assumed to be fixed within a given time-period. While labor and capital were mobile across sectors, land services were specific to the agriculture sector (Ochuodho and Lantz, 2015; Zhai et al., 2009) and stumpage was specific to the forestry and logging sector (Chang et al., 2012; Ochuodho and Lantz, 2014), hence these two factors were not mobile across other sectors.[4]

The optimal allocation between consumption of commodities by households was determined through maximization of a Stone–Geary Utility function (a Linear Expenditure System (LES) function) subject to a disposable income constraint (Stone, 1954).[5]

We introduced unemployment by specifying the Phillips curve in the models. This explained the wage–unemployment relationship in the models using factor prices and supplies, and a Laspeyres consumer price index (CPI).

Demand for commodities equaled supply to achieve equilibrium in the commodities market. Aggregate demand for each commodity comprised household consumption spending (consumption, investment and intermediate) on domestic and imported goods. Aggregate supply included both domestic production and imported goods (Fig. 2).

---

[1] Some regional aggregation could significantly reduce the complexity of the model without any loss in generality. However, each provincial government needs climate change impacts specific to their jurisdiction in formulating climate change mitigation and adaptation strategies. This is part of the reason of having all the 11 Canadian regions individually rather than aggregating them somehow. Also, both forest and agriculture sectors' contributions to regional economies vary significantly across the regions. Modeling individual regions reflect this variation in regional impacts. In previous work, the regions have been aggregated in single-region CGE models in forest sector (Ochuodho et al., 2012). Also, we have a different manuscript under review focusing on impacts of regional aggregation in economic impacts in a multiregional CGE modeling setup.

[2] We could have used *Model 3* to assess the economic impacts from climate-induced changes in each individual sector instead of using *Model 1* and *Model 2*. However, this would have required us to fix the input of the sector that was not the focus of attention (i.e., hold it constant over time). Typical analyses of climate-induced impacts in an individual sector do not consider fixing other sector inputs such as stumpage or agricultural land services since this would impose an additional constraint in the model. Therefore, we used *Models 1* and *2* to focus on the individual impacts.

[3] Assumptions of small-open-economies are necessary for modeling purposes even though this may not be true particularly for US. It assumes that each region in the model is a price-taker unlike in large open economies, the actions of which do affect world prices and other economic parameters.

[4] While there may be land mobility between agriculture and forest sector in the long run, this is not practical to switch on annual basis. Agricultural crops are mostly annual while timber grown on forest lands have optimal economic harvest rotation period going up to over 60 years depending on species, end product, latitude, etc. In Canada, 60% of forests are under public (Provincial Crown land) lands. Private forests make up 6% of Canada's 402 million ha of forested land and 13% of the managed forest, according to Canadian Association of Forest Owners. The remaining portions are Territorial and federally owned. These private forests are owned by private timber growing companies, whose sole business is timber growing only.

[5] The Stone–Geary Utility function is derived from modified CES family of functions (such as Cobb–Douglas) to yield the associated Linear Expenditure System (LES) demand function by introducing a minimum (subsistence) consumption of each commodity. The household is still assumed to make the optimal allocation between consumption of commodities by maximizing this LES utility function. Stone–Geary Utility function therefore incorporates supernumerary or residual income of the household, which represents the available or residual income after the household has satisfied its minimum consumption.