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How a carbon tax will affect an emission-intensive economy: A case study of the Province of Saskatchewan, Canada

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ABSTRACT

A carbon tax has been proposed or applied in many countries and regions around the world to reduce greenhouse gas (GHG) emissions. In this study, a Computable General Equilibrium (CGE) model for the Province of Saskatchewan is first developed to examine and analyze a series of direct and indirect socio-economic impacts of a carbon tax. The energy sector is further disaggregated based on the production structure and energy use pattern to obtain robust results. Different carbon tax rates are simulated to quantify the inter-relationships of the carbon tax, GHG emission reduction, and economic growth. In-depth examinations are also conducted to investigate some other macroeconomic impacts and responses from specific economic sectors. The results show that the GDP change is mainly caused by consumption reduction and import increases, due to the income decline and relatively low tariff rates. Changes in coal and petroleum product production and processes result in the greatest GHG emissions among all sectors. This suggests that clean coal and petroleum technologies may be the crucial issues for realizing both national and provincial environmental and economic objectives. It is expected that the results will provide a solid basis for supporting the application of an effective Pan-Canadian carbon pricing strategy.

1. Introduction

Recently, global climate change has emerged as one of the most challenging environmental issues and has gained considerable attention worldwide [1–3]. The greenhouse gases (GHG) in the Earth's atmosphere are destabilizing established climate patterns and damaging the ecosystems on which all living beings depend [4–6]. Thus, tremendous efforts are badly needed to avoid the increasing risks of climate change on the environment, human health, and the economy [7,8].

A carbon tax can create a powerful incentive to reduce carbon emissions by means of conservation, substitution and innovation [9,10]. This measure has been proposed or applied in many countries and regions around the world, including Australia, Sweden, and Alberta [11–13]. However, theoretical principles indicate that a carbon tax may be detrimental to economic growth [14,15]. Hence, it is necessary to systematically study the multiple effects of a carbon tax on the socio-economic system so that an effective and economic strategy for GHG emission reduction can be determined.

A computable General Equilibrium (CGE) model provides a consistent framework to analyze the economic impacts of a policy, including the direct and indirect effects of policy changes [16–18]. Thus, the CGE model has been widely used to investigate the impacts of a carbon tax on socio-economic systems during the past several decades [19]. Since a carbon tax has both macro and micro (economic) impacts, previous studies about carbon tax were conducted from different scopes, including global [20,21], national [22–25], regional [15,26], and industrial [27–29].

Different CGE models have been developed and applied to various countries or regions to inform carbon tax policy-making. Bruvoll and Fæhn quantified the effects of endogenous carbon tax policy in Norway, where an ambitious climate policy has been implemented. The results indicated that the environmental benefits declined and the economic costs increased when a global rather

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than a national perspective was employed [30]. Orlov and Grethe investigated the economic effects of carbon taxes on the Russian economy under the assumptions of perfect competition and a Cournot oligopoly in output markets [31]. Meng et al. employed a CGE model with an environmentally extended social accounting matrix to simulate the effects of a carbon tax of $23 per ton of carbon dioxide, as proposed by the Australian government, on the environment and the economy [32]. Liu and Lu used a dynamic CGE model to test the impact of a carbon tax in China, wherein several revenue recycling schemes were adopted [33]. Frey assessed the impacts of different carbon tax levels on Ukrainian economy using a CGE model [34]. The results confirmed that the effects of current tax levels were negligible. A state-level CGE model that reflected the roles of raw energies in supplying electricity was developed using Colorado as a case study [35]. The findings suggested that without the Production Tax Credit, the state policy of mandating renewable power generation was too costly to in-state stakeholders. Beck et al. disaggregated households into deciles by annual income and investigated the distributional implications of a revenue-neutral carbon tax policy in British Columbia [36]. A 30-Chinese–province dynamic CGE model has been developed to forecast the possible impact of a carbon tax on both provincial carbon reduction and economic loss [37].

Focused on different issues, CGE models adopt a range of factors as the primary production factors. For example, forest land services were considered as one of the production factors when analyzing the regional economic impacts of climate change and adaptation in the forest industries [38]. Since most of the carbon emissions were caused by energy consumption, energy has been usually considered as a production factor in CGE models that are used to evaluate carbon tax effects. The Input-Output table, as one of the most important data inputs for the CGE model, should be aggregated and disaggregated to better reflect the carbon tax effects on different energy sectors and their related industries [39–41]. Lin and Jiang [42] and Liu and Li [43] disaggregated the power sector into five sub-sectors, including clean power from nuclear power, hydroelectric power, and renewable power. Cai and Arora disaggregated the electricity sector into its generation sector and O&M sector and distribution sector in a CGE model to simulate the U.S. Clean Power Plan [44]. However, most of the previous studies have focused on the disaggregation of the electricity sector [45], while few studies were specialized in the disaggregation of the raw fossil fuel energy sectors [46,47].

Canada targets to achieve an economy-wide emissions objective by reducing its GHG emissions 30% below 2005 levels by 2030 [48]. As planned, in 2018, a national carbon price will be imposed on all of Canada. The initial price will be a minimum of C$10 per tonne of CO_2 and it will be increased annually by C$10/tonne to reach C$50 in 2022 [1]. Moreover, Canada has some special characteristics in terms of its production structure and energy use patterns. In 2016, the Canadian economy was estimated to have nearly equivalent net exports of minerals and fuels (i.e., 16% of GDP) and automobiles (i.e., 16.4% of GDP) [49]. Mineral and fuel production tend to be concentrated in Western Canada provinces (i.e., Alberta, and Saskatchewan, and to some extent British Columbia), while Canadian manufacturing exports tend to come from Central Canada (i.e., Quebec and Ontario). Manufacturing economies can adjust to carbon pricing and taxation by passing on costs to customers, but revenues in natural resource based economies are determined by global commodity markets.

The Province of Saskatchewan's economy largely relies on resource extraction. The total value of mineral sales (i.e., oil, potash, and uranium) was $12.8 billion in 2016. The potash production increased to 10.9 million tonnes with over half of Saskatchewan's potash exports going to Brazil, Indonesia, China, and India [50]. High oil prices motivated accelerated drilling activities within the province before 2014. In 2016, Saskatchewan produced 26.7 million cubic meters of oil, which is affected by the oil industry itself [50]. Agriculture is another pillar industry in Saskatchewan. According to the 2016 Census of Agriculture, Saskatchewan accounted for more than two-fifths of Canada's total field crop acreage with 36.7 million acres [51]. In Saskatchewan's energy system, crude oil plays an important role, while the production of natural gas liquids is relatively low. Coal also accounts for a significant portion of Saskatchewan's energy utilization, with most of the production is used for electricity generation in the Province [52]. Renewable energy, such as hydropower, wind power, is also used for electricity generation, but is currently available at higher unit costs [52].

As a result, the existing CGE models are inapplicable for the study area of the Province of Saskatchewan. Taking all of these challenges into consideration, the situation in Canada is complex and has serious technical and political considerations. Elected officials are eager to acquire scientific bases for decisions at multiple administrative and/or jurisdictional levels in terms of policies and strategies for carbon-emission reduction. Stakeholders in various industries are also seeking the most economical pathways under new policies and strategies. A vast number of conflicting objectives, interactive effects and compounded risks may co-exist within various sectors in the country. Therefore, an in-depth and comprehensive study with regard to the carbon tax impacts on the socio-economic system of Canada is desired to offer significant benefits for climate change policy-making.

The objective of this study is to examine and analyze a series of direct and indirect socio-economic impacts of a carbon tax on the Province of Saskatchewan, which is a representative Canadian province that has low population density, a large territory, and considerable fossil fuel energy reserves. It is expected that the results will provide a solid basis for supporting the application of a carbon tax in Canada. In detail, a CGE model for the Province of Saskatchewan will be first developed from a typical Canadian province perspective. The energy sector will be further disaggregated based on the production structure and energy use pattern to obtain robust results. Different carbon tax rates will be simulated to quantify the inter-relationships of a carbon tax, GHG emission reduction, and economic growth. In-depth examinations will be conducted to investigate some other macroeconomic impacts and responses from specific economic sectors.

2. Theoretical framework for the SK-CGE model

A static CGE model for Saskatchewan has been first developed to describe the new equilibrium after an exogenous shock affects the province's economic system. The SK-CGE model can reflect the reactions of the economy at one point in time. Through results comparisons between with and without the policy shock, the impacts of different policies can be obtained. Through the disaggregation of energy sectors, the developed model provides a full representation of the structure of production and consumption in the economy that makes it possible to analyze the aggregate and detailed implications of GHG mitigation policies. Facing the complex conditions in Canada, both federal government and provincial government are eager to know the potential impacts of a carbon tax on the economy. Therefore, the static CGE model, which avoids tremendous prediction on other exogenous variables and is much easier to construct and solve, is especially crucial to provide scientific basis for the forthcoming policy development.

2.1. Production module

The production module describes the ways in which capital,