

Economic Evaluation of Climate Change Impacts on Road Transportation in Atlantic Canada

Yuri Yevdokimov

Department of Economics and Civil Engineering, University of New Brunswick, Canada

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Abstract Climate change impacts such as an increase in mean temperature, change in precipitation patterns and sea level rise are affecting regional road transportation network in Atlantic Canada. Those impacts cause direct and indirect economic consequences for the network and regional economy. In our study, we constructed a dynamic computable general equilibrium model (CGEM) to trace these consequences over time. Basic principles of the designed CGEM are discussed and the model's architecture is presented. The model's elements are estimated, and the obtained CGEM is tested with exogenously imposed shocks. The dynamics of regional temperature, precipitation and sea level are analyzed on the basis of comprehensive time series analysis. This dynamics will later be imposed on the designed CGEM as external productivity shocks. Some preliminary cumulative economic consequences are evaluated in monetary terms to obtain benchmarks for the mitigation measures associated with future development of the regional road transportation network.

Keywords Climate Change, Regional Transportation Network, General Equilibrium Model, Time Series Analysis, Productivity Shocks

1. Introduction

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change [1-3] emphasized that previous assessments have already shown through multiple lines of evidence that the climate is changing across our planet, largely as a result of human activities. The most compelling evidence of climate change derives from observations of the atmosphere, land, oceans and cryosphere.

According to AR5, the main climatic drivers in North America are temperature warming and drying trends, extreme temperature events, extreme precipitation events, damaging cyclones and rising sea level. Therefore, in this study three fundamental climate change impacts, namely

increasing temperature, changing precipitation patterns and rising sea level have been analyzed with respect to their potential economic consequences for the Regional Road Transportation Network (RRTN) in Atlantic Canada.

Our RRTN for this study was defined according to guidelines of the New Brunswick Department of Transportation presented in "Charting the Course: Atlantic Canada Transportation Strategy, 2008-2018", and provincial Economic Development and Innovations Plan. Five regional transportation hubs – Fredericton, Moncton, St. John, Northern New Brunswick and Halifax – were chosen on the basis of the above mentioned documents.

Our study was dedicated to the following three tasks:

- Design of the model's architecture to incorporate microeconomic factors, regional macroeconomic factors and climate change impacts on the basis of systems dynamics
- Estimation of the model's elements on the basis of dynamic analysis
- Analysis of the evolutionary dynamics of climate change variables – temperature, precipitation and sea level – associated with five regional hubs

In order to perform all these tasks, comprehensive economic and transportation databases have been developed. Below the results of our study are presented according to the above mentioned tasks.

2. Model's Architecture

Our analysis of the existing literature on economic evaluation of climate change impacts in various segments of an economic system, led us to the conclusion that dynamic general equilibrium model (GEM) is the best framework for our analysis. Study by Nordhaus and Yang [4] is a seminal work in this regard followed by more recent studies by Rezai, Taylor and Mechler [5], Jaglom [6], and Nannen, van den Bergh, and Eiben [7]. These studies helped us formulate basic principles for our model:

- Both microeconomic and macroeconomic aspects of the RRTN should be incorporated simultaneously

- Modified Computable General Equilibrium Model (CGEM) is our fundamental tool since it allows us to directly incorporate micro- and macroeconomic dynamics as well as dynamics of climate change impacts
- Modeling has to address the following two goals: (i) design of the appropriate model architecture to include microeconomic and macroeconomic dynamics affecting our RRTN; (ii) modeling of the dynamics of climate change variables.

Once both goals presented above are achieved, dynamics of the climate change variables should be imposed on the dynamics of the basic CGEM to trace economic consequences of the climate change impacts. Below our model's architecture is described in detail.

Regional road transportation module is the centerpiece of our CGEM, and it represents the highest level 1 in our architecture. It consists of a system of dynamic equations for price and volume of regional transportation (traffic). Within the module, this system produces equilibrium price of regional transportation for the entire RRTN based on major economic determinants explained in detail in the next section.

Next level 2 consists of *five regional hubs* defined previously – Fredericton, Moncton, St. John, Northern New Brunswick and Halifax. At each hub, the above price of transportation is taken as an input to define the value added produced by the hub based on this price, geographical and industrial characteristics as well as the required volume of transportation (traffic).

Each hub is further disaggregated with respect to major *industrial consumers of transportation* in that sub-region which defines our level 3 – the lowest one. At this level, the value added produced by each major industry is defined on the basis of microeconomic and regional macroeconomic characteristics and then is sent to level 2.

At level 2, aggregate value added by each industry is summed up at the corresponding hub, the hub's traffic to support this aggregate value added is defined and both values are sent back to level 1 to determine next period equilibrium price of transportation for the entire RRTN. This process repeats itself to produce time paths of our major economic and transportation variables associated with the RRTN over time given current and expected micro- and macroeconomic conditions.

In line with the CGEM framework described in the literature, eventually we obtain a time path of the system under study which is a set of short-run equilibria of that system. Microeconomic forces are internal in our model since they are based on the supply/demand dynamics of the regional industries/sectors while macroeconomic forces are based on external dynamics given exogenously. On top of that, dynamics of climate change variables should be imposed as well. In other words, given initial conditions, our model replicates evolution of the RRTN, driven by internal microeconomic forces plus external

macroeconomic forces and climate change impacts.

According to the philosophy of the dynamic CGEM, all model's elements should be estimated on the basis of statistical analysis and historical data outside the model. Below we present this procedure in detail beginning with the RRTN dynamics and followed by the climate change dynamics.

3. Estimation of the Model's Elements

Regional transportation data was provided by the New Brunswick Department of Transportation and Nova Scotia Transportation and Infrastructure Renewal. The traffic count for major roads in our RRTN was taken daily and then averaged on an annual basis. Economic data was provided by Transport Canada and Statistics Canada specifically from Canadian economic database CANSIM. Obtained data covers period of 1990-2013.

Regional road transportation module represent a dynamic version of supply-demand system with equilibrium price and traffic level for the entire RRTN as endogenous variables and general price level, regional GDP, oil price, value added by the largest consumers of regional transportation and population as exogenous variables. Choice of these variables was based on microeconomic determinants of demand and supply as well as some common regional macroeconomic variables. For example, traffic level and price of transportation are pure microeconomic variables; oil price is a proxy for transportation costs while value added is a proxy for income. On the other hand, general price level in the region, GDP and population capture common macroeconomic characteristics.

Initial structural demand-supply system is:

$$T_t^D = a_0 + a_1 T_{t-1}^D + a_2 P_t^T + a_3 P_{t-1}^T + a_4 CPI_t + a_5 GDP_t + a_6 VA_t + a_7 POP_t + e_t^D$$

$$T_t^S = b_0 + b_1 T_{t-1}^S + b_2 P_t^T + b_3 P_{t-1}^T + b_4 CPI_t + b_5 OIL_t + b_6 VA_t + b_7 POP_t + e_t^S$$

where T_t^D and T_t^S are volume of transportation (traffic) demanded and supplied respectively at time t ; P_t^T is the price index for regional transportation; CPI_t is the consumer price index; GDP_t is regional GDP; OIL_t is oil price, VA_t is the value added by the largest regional consumers of transportation; POP_t is regional population; e_t^D and e_t^S are demand and supply shocks respectively.

Solved for equilibrium values of T_t^* and P_t^{T*} , initial structural system produces the following system of reduced form equations:

$$T_t^* = a_{01} + a_{11} T_{t-1} + a_{12} P_{t-1}^T + a_{13} CPI_t + a_{14} GDP_t + a_{25} OIL_t + a_{26} VA_t + a_{27} POP_t + u_{2t}$$

$$P_t^{T*} = a_{02} + a_{21}T_{t-1} + a_{22}P_{t-1}^T + a_{23}CPI_t + a_{24}GDP_t + a_{25}OIL_t + a_{26}VA_t + a_{27}POP_t + u_{2t}$$

in which u_{1t} and u_{2t} are composite shocks.

In econometrics, such systems are usually estimated on the basis of Vector Autoregression (VAR). This procedure is described in all details in Enders [8], and we followed his methodology. Our VAR was estimated in Eviews 8, and below we present our results:

$$T_t^* = 0.086 + 0.78IT_{t-1} + 0.188P_{t-1}^T + 0.049CPI_t + 0.069GDP_t - 0.056OIL_t - 0.054VA_t + 0.255POP_t$$

$$P_t^{T*} = -6.148 - 0.145T_{t-1} + 0.304P_{t-1}^T + 1.166CPI_t - 0.559GDP_t + 0.089OIL_t - 0.012VA_t + 2.748POP_t$$

with adjusted *R*-squared of 0.96 and statistically significant coefficients. These results show that dynamics of the demand-supply system was captured well.

At each regional hub, largest consumers of transportation were identified. It turns out that the following industries are the largest consumers according to our statistical analysis: (i) forestry and logging, (ii) wholesale trade, (iii) retail trade, and (iv) manufacturing. Consequently, each hub was disaggregated to include microeconomic dynamics of these industries.

In an economic sense, each industry at a corresponding hub can be presented by dynamic demand-supply system. Similar to the previous module explanation, if these demand-supply systems are solved for equilibrium values of price and quantity produced by each industry, in terms of time series analysis we end up with Panel Vector Autoregression (PVAR) at each hub in the following form:

$$VA_{it}^* = a_{01} + a_{11}VA_{i(t-1)} + a_{12}P_{i(t-1)} + a_{13}CPI_t + a_{14}GDP_t + a_{15}OIL_t + a_{16}P_t^T + a_{17}POP_t + a_{18}D_i + u_{1t}$$

$$P_{it}^* = a_{02} + a_{21}VA_{i(t-1)} + a_{22}P_{i(t-1)} + a_{23}CPI_t + a_{24}GDP_t + a_{25}OIL_t + a_{26}P_t^T + a_{27}POP_t + a_{28}D_i + u_{2t}$$

where VA_i is value added produced by the *i*-th industry, P_i is the production price index of the *i*-th industry, D_i is industry dummy: 1 for forestry and logging, 2 for wholesale trade, 3 for retail trade, 4 for manufacturing; all other variables were already explained. In this specification it is assumed that at each hub microeconomic dynamics is similar but each industry contributes its own value added based on its own price index, common regional characteristics and overall price of transportation for the whole RRTN.

At this point in time, we managed to construct the required data sets for Fredericton and Halifax transportation hubs with four industries mentioned above. First, we tested for unit roots in our series. For this purpose, the Dickey-Fuller test was applied to each series individually.

Dickey-Fuller unit root test showed that all our economic time series exhibit unit root process - random walk with drift - and therefore, they all are difference-stationary. Further, following our methodology, we examined our variables with panel unit root tests checking for common and individual unit roots. The results of Levin, Lin & Chu [9] test showed that two economic series are stationary: transportation price index and provincial GDP. However, according to Im, Pesaran and Shin [10] panel unit root test, unit root is present in all our economic variables.

Since we are interested in long-run dynamics, we did not difference our variables to preserve long-memory and instead we used logarithmic transformations. In addition, in this case, significance of the overall system dynamic is more important than significance of each individual variable. Below we present our results:

Fredericton hub

$$VA_{it}^* = -2.806 + 0.995VA_{i(t-1)} - 0.138P_{i(t-1)} + 0.109CPI_t + 0.344GDP_t - 0.099OIL_t + 0.006P_t^T + 0.531POP_t + 0.004D_i$$

$$P_{it}^* = -3.631 - 0.005VA_{i(t-1)} + 0.779P_{i(t-1)} + 0.09CPI_t - 0.024GDP_t + 0.004OIL_t - 0.038P_t^T + 1.417POP_t + 0.002D_i$$

with adjusted *R*-squared of 0.80 and statistically significant coefficients.

Halifax hub

$$VA_{it}^* = -14.808 + 0.990VA_{i(t-1)} - 0.073P_{i(t-1)} + 0.569CPI_t + 0.142GDP_t - 0.066OIL_t + 0.462P_t^T + 4.787POP_t + 0.007D_i$$

$$P_{it}^* = -6.648 - 0.004VA_{i(t-1)} + 0.781P_{i(t-1)} - 0.281CPI_t + 0.197GDP_t - 0.018OIL_t - 0.082P_t^T + 2.234POP_t + 0.003D_i$$

with adjusted *R*-squared of 0.81 and statistically significant coefficients. These results show that the overall dynamics of the demand-supply systems was captured rather well.

We have tested our model in the following way. In our previous study [11], we evaluated annual impact from climate change on traffic produced in RRTN. Expected value of the annual loss in traffic due to climate change in Atlantic Canada expressed through increasing temperature, changing precipitation and rising sea level was defined as 1.5%. Therefore, we imposed this negative shock to trace its consequences for the regional economy and RRTN over time. According to our simulation based on the designed CGEM, immediate impact of a 1.5% loss in regional traffic leads to a 1.8% loss in the regional value added or \$0.959 billion in dollars of 2007. Over time this impact accumulates and by the tenth year annual loss in regional value added becomes 8.2% or \$4.367 billion. Long run value of the loss is 19.4% or \$10.332 billion. In terms of traffic produced in RRTN, short-run loss in traffic is 2.9%; cumulative loss is 13.5% by year 10 and 31.8% in the long run.

All these values are defined under assumption that no mitigation measures are taken. On the one hand, these numbers point to significant climate change impact on regional economy but on the other hand they can serve as benchmarks for investment in mitigation measures. Of course, in order to derive marginal impacts from rising temperature, changing precipitation and rising sea level, it is necessary to study dynamics of these climate variables first and then impose it directly on our CGEM. We have already done some preliminary evaluation of dynamics of climate variables which is presented below.

4. Evolutionary Dynamics of Climate Variables

As stated before, three fundamental climate variables – temperature, precipitation and sea level - have been chosen for our analysis of climate change dynamics. Our analysis of evolutionary dynamic of these variables is based on stationary linear models widely used in time series econometrics: autoregressive moving-average (ARMA) and generalized autoregressive conditional heteroskedastic (GARCH) models.

We assumed that dynamic path of a climate variable can be described by a dynamic process in the form of a linear stochastic difference equation. Accordingly, our estimation procedure involved the following steps: (i) identification and estimation of the baseline ARMA model; (ii) series of parameter instability tests; (iii) identification and estimation of appropriate error term structure for ARMA model with particular focus on ARCH and GARCH specifications; (iv) selection of the best fitting model followed by in-sample (one-step-ahead) and out-of-sample (dynamic) forecast, and series decomposition. Below we present our major findings.

4.1. Temperature

We used monthly mean of daily temperature time series data obtained from the second generation of adjusted and homogenized Canadian climate dataset (AHCCD). AHCCD was constructed by the Meteorological Service of Canada specifically for the use in climate change research and trend analysis. It is based on historical temperature records from National Climate Data and Information Archive of Environment Canada. One advantage of the AHCCD is that it contains longer time series data, which was obtained by combining, homogenizing and adjusting observations from co-located meteorological stations. AHCCD covers 338 locations across Canada including 46 locations in Atlantic Canada. A complete overview of the dataset including statistical adjustment algorithms and data correction methods is presented in Vincent et al.. We chose stations located close to our five regional hubs.

Based on the above presented steps, we concluded that irrespective of the season of the year, mean monthly temperature will be increasing on average by $+0.0011755^{\circ}\text{C}$

during 1872-2101. Estimated cumulative increase in mean monthly temperature will amount to $+3.25^{\circ}\text{C}$ by 2101 if compared with initial temperature level of 1872 or to $+1.43^{\circ}\text{C}$ if compared with 2000. According to our estimates, cumulative increase in mean monthly temperature amounts to $+1.95^{\circ}\text{C}$ between 1872 and 2010. These values correspond to the estimates reported in AR5. All details of this analysis can be found in MA Report by Oleg Zaitsev [12] at the University of New Brunswick.

So, our statistical analysis of the temperature dynamics supports a stylized fact that climate will be getting warmer in Atlantic Canada by the end of the 21st century. Most importantly it gives us numerical value of the speed of the increasing temperature.

4.2. Precipitation

Our precipitation data is taken from the second generation Adjusted Precipitation for Canada (APC2) dataset. Data is annual, obtained from daily values for rainfall in millimeters (mm) and snowfall in centimeters (cm). As previously, we took the data from meteorological stations that are close to our five regional transportation hubs.

According to our methodology described at the beginning of this section, we can conclude the following. There are currently stable positive trends in rainfall in Fredericton and Moncton: annual increase in rainfall is 2.2 mm in Moncton and 0.98 mm in Fredericton. Forecasted value of rainfall in Moncton for 2050 year is 1,054 mm while forecasted value of rainfall in Fredericton for 2050 year is 959.7 mm. Statistically significant trends in snowfall are present in data for Miramichi, Moncton, Saint John, and Fredericton. Three of them are negative. All significant snowfall trends have structural breaks around 1950s. Forecasted value of snowfall in Miramichi for 2050 year is 277 cm; forecasted value of snowfall in Moncton is 485 cm; forecasted value of snowfall in Saint John is 300 cm; forecasted value of snowfall in Fredericton is 184cm.

Almost all rainfall time series have abnormally high variation over 1970s and 1980s. Edmundston rainfall series has clear pattern of increasing variation. Miramichi and Halifax rainfall series variation do not show clear patterns. Fredericton rainfall time series has higher than average variation after mid-1990s. Moncton and Saint John rainfall series exhibit upward shift in variation in 1950s which stays at higher level since then.

In snowfall time series, variation is more controversial. Miramichi, Moncton, and Halifax snowfall series exhibit a declining variation. Miramichi time series has declining variation since 1950s, Moncton series variation has declined since 1980s, Halifax time series has sharp decline in variation in 1970s with low level afterwards. Edmundston, Fredericton, and Saint John snowfall series have increasing variation. Edmundston series variation has grown since 1980s; Saint John and Fredericton series have sharp increase in variation in 1960s, which stayed at high level afterwards.

For most of our regional transportation hubs, rain has higher share in total precipitation. Except Halifax and Moncton, where patterns are not clear, other regional hubs exhibit high and increasing variation in the second part of 20th century. Increasing variation means less predictable weather coupled with an increase in probability of extreme precipitation events.

4.3. Sea Level

In general, analysis of sea level rise is a complex process subject to various factors including vertical land motion, glacier isostatic adjustment, regional oceanographic effects, extreme water levels and others. Since a very complicated geophysical process underlies a sea level rise, its explanation is beyond our analysis. In this study, as with our temperature and precipitation analysis, we have tried to capture dynamics of sea level rise using linear stochastic time series models.

The data provided by Canadian Hydrographic Service (a division of the Science Branch of the Department of Fisheries and Oceans Canada) was chosen as our main source. Monthly mean sea level data for three tide-gauge stations were downloaded from the Atlantic Zone Monitoring Program (AZMP). All stations were chosen according to geographical location of the regional transportation hubs identified in our study as RRTN. Rimouski was chosen for Northern New Brunswick hub. Sea level is measured by tide-gauges relatively to land. Shediac Bay station was chosen for Moncton transportation hub. The data was obtained from Permanent Service for Mean Sea Level, UK (PSMSL).

Based on our methodology, we were able to make out of sample forecast for future sea level in Atlantic Canada with respect to our regional transportation hubs. Projected sea levels for 2101 are:

- for Halifax: 1.39 m compared to 2001 level of 1.04 m;
- for Saint John: 4.65 m compared to 2001 level of 4.51 m;
- for Shediac Bay: 0.72 m compared to 2001 level of 0.70 m;
- for Rimouski: 2.65 m compared to 2001 level of 2.24 m.

As a matter of fact, obtained results are consistent with estimates presented in Updated Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections Based on AR5.

We also found accelerating volatility in the last decade in sea level data which leads us to a conclusion that frequency of extreme events associated with sea level rise is increasing, and we should take it into account in our future forecast.

As mentioned previously, change in sea level is natural and complex process influenced by a number of factors including unobserved ones. Nevertheless, based on our

results we can consider our assumption of linear trend process useful as it allows us to forecast future sea levels with some confidence.

5. Conclusions

A major result of our study is design of a suitable methodology to trace economic consequences of climate change impacts on regional road transportation network (RRTN). The designed methodology is based on systems approach namely the so-called systems dynamics. In order to implement basic principles of systems dynamics it was necessary to define our system first. We defined it as a hierarchical, three-level model with some specific architecture. Technically it is a modified version of the computable general equilibrium model (CGEM). However, traditional CGEMs are either macroeconomic models with aggregate markets or microeconomic models when economy is viewed as a collection of markets for goods and services (one good/service - one market) which are simultaneously in equilibrium. Our model is somewhere in between these two types of CGEM since we are modeling RRTN and therefore, microeconomic and macroeconomic components were incorporated into quasi-spatial model of a transportation network.

All CGEMs are first estimated on the basis of statistical analysis and then are used for simulation purposes. In our study, we have been collecting regional economic and transportation data in order to estimate our model's elements statistically. The designed model's architecture requires a lot of specific datasets which is very time consuming. This is non-stop continuing process which we have been doing since 2012, and we managed to construct our own database. This database allowed us to do some preliminary statistical estimation based on advanced time series techniques. However, this process requires much more time and data, and we hope to continue it in our future work.

In parallel, we have analyzed dynamics of our major climate change variables – regional temperature, precipitation and sea level. This analysis was also based on advanced time series techniques, and we obtained some interesting results associated with five regional transportation hubs in our RRTN. As a matter of fact, we were able to capture long-run trends in these climate variables at each hub, and we plan to use these results further in our CGEM during simulation phase of our study.

So, in general at this point in time we have our model's architecture with some pieces already in place and with some others to be developed and estimated. We have climate change dynamics in terms of temperature, precipitation and sea level. Next step is to combine the two, expand our database and add some other climate change impacts and first of all frequency and magnitude of large weather events. In parallel, we are going to design user-friendly interface which will allow policy makers to easily use our CGEM without knowing all the model's details. This is our future agenda.

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