Water Markets as a Coping Mechanism for Climate-induced Water Changes on the Canadian Economy: A Computable General Equilibrium Approach

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ABSTRACT

Water markets represent a policy tool that aims at finding efficient water allocations among competing users by promoting reallocations from low-value to high-value uses. In Canada, water markets have been discussed and implemented at the provincial level; however, at the national level a study about the economic benefits of its implementation is still lacking. This paper fills this void by implementing a water market in Canada and examine how water endowment shocks would affect the economy under the assumptions of general equilibrium theory. Our results show a water market does damp the economic loss in case of reductions in water endowment, but it also cuts back on the economic expansion that would follow from an increase on it. These results provide new insights on the subject and we hope will provide a novel look and reinvigorate informed discussions on the use of water markets in Canada as a potential tool to cope with climate-induced water supply changes.

KEYWORDS

computable general equilibrium; water market; climate change; Canada

1. INTRODUCTION

1.1 Overview

Water is essential for life and necessary for the well-being of the biosphere. Development and long-term sustainability of human societies imply having access to water in adequate quantities and acceptable quality. For this reason, foreseeable climate changes are a factor that must be pondered as they may alter the water cycle on a region and, consequently, bring about changes on availability, or even quality, of this resource.

Even though Canada is abundant on water resources, assessing the effect of potential changes in water availability on the economy is crucial for the design of adaptation or mitigation strategies by researchers or policy makers, and ultimately to inform society and spark behavioral changes if needed.

The interplay between water resources and economic impacts in Canada has been studied at the regional level for the Great Lakes (Garcia-Hernandez & Brouwer, 2020; Garcia-Hernandez, Brouwer, & Pinto, 2022) or the Saskatchewan river basin (Eamen, Brouwer, & Razavi, 2020). Yet, a model focused on the role of water resources for the Canadian economy as a whole is wanting. This paper fills this void.

1.2 Literature review

Water market simulations have been fruitful for exploring market-efficient water allocations or gauging the adaptation of economies to water shocks. For example, (Solís & Zhu, 2015) use a CGE model to explore water markets as a way to cope with potential future water disruptions in a region of Spain. In (Koopman, Kuik, Tol, & Brouwer, 2017) authors followed a similar approach for the Netherlands economy where they test the inclusion of different industries into the water market trade. The effect of imposing water taxes on a water market and its overall consequences on the economy has been explored for South Africa (van Heerden, Blignaut, & Horridge, 2008). Overall, these studies show mixed results as benefits of implementing water markets (measured by welfare or GDP increase) depend on additional factors, such as which the industries are included in the trade or the allocation of the proceeds from water trading. The success of water markets also depends on the constraints imposed by infrastructure and transaction costs (McCann & Garrick, 2014)

There are few water-related CGE models developed for the Canadian economy. A similar model to the one presented here is found in (Rivers & Groves, 2013), where authors explore the welfare change on the Canadian economy if price were used to allocate water resources to industries. Authors found either a welfare loss or gain depending on whether the proceedings of water payments go directly to households or to offset taxes, respectively. Other CGE models have also been used to study flooding events in (Gertz, Davies, & Black, 2019), where authors study the recovery response of Vancouver, British Columbia to cope with this natural event.

1.3 Novelty, relevance, and contributions

The model presented here, to the best of our knowledge, is the first CGE model constructed to study water markets on the Canadian economy as a whole. Though water markets have been discussed in Canada, and even introduced before at the provincial level (Bjornlund, Zuo, Wheeler, & Xu, 2014) with not much participation success, we hope the insights of this paper would provide a novel look on the subject and reinvigorate informed discussions. Besides the insights generated by the scenarios on the paper, the contributions of the present work are the development of a CGE model for Canada, as well as a procedure to create social accounting matrices from statistical data.

2. CGE MODEL

2.1 Overview

The CGE model closely follows the formulation presented in (Lofgren, Harris, & Robinson, 2002), having four sets of block equations: a price block, a production block, economic agents block, and a system block. The industry and commodity structure are shown in Figure 1. Water use is included as a primary input for the industries that belong to the general sectors of agriculture, mining, utilities and manufacturing (a total of 29). For the remaining industries, water use is assumed to be in the form of commodity. Figure A.2 shows the breakup of these industries.

The water sector (Water, sewage and other systems) and water-specific commodities (Water delivered by water works and irrigation; Sewage and dirty water disposal) are explicitly singled-out in the model. Irrigated and non-irrigated (rainfed) crop production are treated as separate industries.

Transaction costs and investment on water markets, though an important limiting factor, are inherently dependent upon local conditions on infrastructure and water legislation. For this reason, authors believe these aspects can be treated better on regional studies or on a spatially disaggregated model. The current model assumes that water trade is not hampered by infrastructure constraints, and thus the results provide the best-case scenario.

Computationally, the CGE model is formulated as a square system (same number of variables as equations), where the user defines the values of the exogenous variables (factor endowments and CPI) and exogenous parameters (elasticity substitutions and weights for price indices). A solution to the CGE is an x such that the following equations are met:

$$\left.\begin{aligned} &f(x, s \mid \theta_{exo}, \theta_{end}) = 0 \\ &x \geq x_{min} \end{aligned}\right\} \tag{1}$$

where $f(\cdot)$ represents the system of equations of the CGE; x, x_{min} the model variables and their lower bound respectively; s the exogenous (user-defined) variables; and $\theta_{exo}, \theta_{end}$ the exogenous and endogenous parameters of the model.

The calibration of parameters follows a two-step process: first, an optimization subroutine obtains the prices and quantities that match the values of the SAM (shown in Appendix A); next, these variables are used to calculate the endogenous parameters (θ_{end}). Finally, the exogenous variables and parameters (s, θ_{exo}) are specified by the user and the simulation is executed to obtain x.

The model was implemented on GAMS® via its Python API and solved using the CONOPT® solver. Due to its extension, the model is presented in full on the Supplementary Information; however, the main aspects of the model are shown in the next sections.

2.2 Industry structure

The industry production structure has three levels. The top level is a constant elasticity of substitution (CES) or Leontief production function. Industries using a CES production function determine their production solving the following optimization problem which maximizes income over production cost:

$$\max_{QVA_i,\ QINTA_i} PA_i\, QA_i - PVA_i\, QVA_i - PINTA_i\, QINTA_i\,, \qquad \forall i \in ICES \tag{2.1}$$

s.t

$$QA_i = \alpha_i^I \left[\delta_i^I \, QVA_i^{-\rho_i^I} + (1-\delta_i^I)\, QINTA_i^{-\rho_i^I}\right]^{-\frac{1}{\rho_i^I}}, \qquad \forall i \in ICES \tag{2.2}$$

which yields the following first-order condition for optimality:

$$(1-\delta_i^I)\, PVA_i \, QVA_i^{1+\rho_i^I} = \delta_i^I \, PINTA_i \, QINTA_i^{1+\rho_i^I}, \qquad \forall i \in ICES \tag{2.3}$$

where $ICES$ is the set of industries with CES production function; PA_i, QA_i the price and quantity of industry i; PVA_i, QVA_i those for value-added; $PINTA_i, QINTA_i$ those for the composite intermediate consumption. Parameters $\alpha_i^I, \delta_i^I, \rho_i^I$ characterize the CES function; only the latter is user-defined and determines the elasticity of substitution. Only equations (2.2,2.3) are included into the model. For industries using a Leontief production function, the associated equations, which are included in the model, are the following

$$\left.\begin{aligned} QVA_i &= iva_i \, QA_i \\ QINTA_i &= inta_i \, QA_i \end{aligned}\right\} \quad \forall i \in ILEO \tag{3}$$

where $ILEO$ is the set of industries with Leontief production function; $iva_i, inta_i$ are the shares of value-added and intermediate consumption with respect to the industry output.

The second level is a Leontief function for intermediate industry consumption, and a CES function for the first level of the value-added function. In this level, capital and water are treated as a single factor dubbed "CapWat"; the other factors are labor, land, and natural resources. The value-added production is determined by solving the following optimization problem, which maximizes value-added income over production costs:

$$\max_{QCW_i,\ QF_{f,i \mid f \in FL1}} PVA_i \, QVA_i - PCW_i \, QCW_i - \sum_{f \in FM \cap FL1} WFM_f \, QF_{f,i} - \sum_{f \in FNM \cap FL1} WFS_{f,i} \, QF_{f,i}, \qquad \forall i \in I \tag{4.1}$$

s.t

$$QVA_i = \alpha_i^{va1} \left(\sum_{f \in FL1} \delta_{f,i}^{va1} \, QF_{f,i}^{-\rho_i^{va1}} + \delta_{CapWat,i}^{va1} \, QCW_i^{-\rho_i^{va1}} \right)^{-\frac{1}{\rho_i^{va1}}}, \qquad \forall i \in I \tag{4.2}$$

which yields the following first-order conditions for optimality:

$$(\alpha_i^{va1})^{\rho_i^{va1}}\ WFM_f\ QF_{f,i}{}^{(\rho_i^{va1}+1)} = PVA_i\ QVA_i{}^{(\rho_i^{va1}+1)}\ \delta_{f,i}^{va1}, \qquad \forall i \in I, f \in \{FM \cap FL1\} \tag{4.3}$$

$$(\alpha_i^{va1})^{\rho_i^{va1}}\ WFS_{f,i}\ QF_{f,i}{}^{(\rho_i^{va1}+1)} = PVA_i\ QVA_i{}^{(\rho_i^{va1}+1)}\delta_{f,i}^{va1}, \qquad \forall i \in I, f \in \{FNM \cap FL1\} \tag{4.4}$$

$$(\alpha_i^{va1})^{\rho_i^{va1}}\ PCW_i\ QCW_i{}^{(\rho_i^{va1}+1)} = PVA_i\ QVA_i{}^{(\rho_i^{va1}+1)}\delta_{CapWat,i}^{va1}, \qquad \forall i \in I \tag{4.5}$$

where FL1,FM,FNM are the sets of factors that belong to the first value-added function, mobile factors, and non-mobile factors; $PCW_i\ QCW_i$ the price and quantity of the composite CapWat; $QF_{f,i}$ the quantities of factor *f* allocated to industry *i*; $WFM_f, WFS_{f,i}$ the wages or price of the mobile and non-mobile factors. Parameters $\alpha_i^{va1}, \delta_{f,i}^{va1}, \delta_{CapWat,i}^{va1}, \rho_i^{va1}$ characterize the CES function. Only equations (4.2-4.5) are included in the model.

Finally, the third production level is a CES function between capital and water inputs which describes the substitution effect between them. The associated optimization problem maximizes the income from the composite CapWat over its cost:

$$\max_{QCW_i,\ QF_{f,i\,|\,f\in FL2}} PCW_i\ QCW_i - \sum_{f\in FM\cap FL2} WFM_f\ QF_{f,i} - \sum_{f\in FNM\cap FL2} WFS_{f,i}\ QF_{f,i}\,, \qquad \forall i \in I \tag{5.1}$$

s.t

$$QCW_i = \alpha_i^{va2}\left(\sum_{f\in FL2} \delta_{f,i}^{va2}\ QF_{f,i}{}^{-\rho_i^{va2}}\right)^{-\frac{1}{\rho_i^{va2}}}, \qquad \forall i \in I. \tag{5.2}$$

The first-order conditions for optimality yield:

$$(\alpha_i^{va2})^{\rho_i^{va2}}\ WFM_f\ QF2_{f,i}{}^{(\rho_i^{va2}+1)} = PCW_i\ QCW_i{}^{(\rho_i^{va2}+1)}\ \delta_i^{va2}, \qquad \forall i \in I, f \in \{FM \cap FL2\} \tag{5.3}$$

$$(\alpha_i^{va2})^{\rho_i^{va2}}\ WFS_{f,i}\ QF2_{f,i}{}^{(\rho_i^{va2}+1)} = PCW_i\ QCW_i{}^{(\rho_i^{va2}+1)}\ \delta_i^{va2}, \qquad \forall i \in I, f \in \{FNM \cap FL2\} \tag{5.4}$$

where $FL2$ is the set of factors that belong to the second value-added function (namely, "capital" and "water"). Here again, the parameters $\alpha_i^{va1}, \delta_{f,i}^{va1}, \rho_i^{va1}$ determine the production function in (5.2). Only equations (5.2-5.4) are included in the model.

The overall industry production structure is shown in Figure 2 (A). Following (Solís & Zhu, 2015) the constant elasticity of substitution is set to 0.7 for the first level of the value-added function and 0.2 for the second level.

2.3 Commodity structure

Commodities are produced by industries using a fixed yield coefficient. Commodities of the same type are aggregated into a domestic supply following a CES function as follows

$$QX_c = \alpha_c^{ac} \left(\sum_{i \in I} \delta_{i,c}^{ac}\, QXAC_{i,c}{}^{-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}}}, \qquad \forall c \in CX \tag{6.1}$$

$$\alpha_c^{ac(\rho_i^{ac})}\, PXAC_{i,c}\, QXAC_{i,c}{}^{(\rho_i^{ac}+1)} = PX_c\, QX_c{}^{(\rho_i^{ac}+1)}\, \delta_{i,c}^{ac}, \qquad \forall i \in I, c \in CX \tag{6.2}$$

where CX is the set of commodities with domestic output; PX_c, QX_c the price and quantity of domestic output; $PXAC_{i,c}, QXAC_{i,c}$ those for the domestic output of commodity c by industry i. Parameters $\alpha_c^{ac}, \delta_{i,c}^{ac}, \rho_c^{ac}$ determine the composite domestic commodity output function. Equation (6.2) is the first-order condition for optimality.

The decision between allocating domestic supply to satisfy domestic or foreign consumption is determined using a constant elasticity of transformation (CET) function. Therefore, producers of domestic commodities determine the market to sell to based on:

$$QX_c = \alpha_c^t \left[\delta_c^t\, QE_c{}^{\rho_c^t} + (1 - \delta_c^t)\, QD_c{}^{\rho_c^t} \right]^{\frac{1}{\rho_c^t}}, \qquad \forall c \in (CD \cap CE) \tag{7.1}$$

$$\delta_c^t\, PDS_c\, QD_c{}^{(1-\rho_c^t)} = (1 - \delta_c^t)\, PE_c\, QE_c{}^{(1-\rho_c^t)}, \qquad \forall c \in (CD \cap CE) \tag{7.2}$$

where CD and CE are the set of domestic commodities and exported commodities; PDS_c, QD_c the domestic supply price and quantity of domestically produced and consumed commodities; PE_c, QE_c the price and quantity of exports.

Domestic consumers decide between buying from local or foreign suppliers based on a CES function. This is implemented by the following equations:

$$QQ_c = \alpha_c^q \left[\delta_c^q \, QM_c^{\;-\rho_c^q} + \left(1-\delta_c^q\right) QD_c^{\;-\rho_c^q}\right]^{-\frac{1}{\rho_c^q}}, \qquad \forall c \in (CD \cap CM) \tag{8.1}$$

$$\left(1-\delta_c^q\right) PM_c \, QM_c^{\;1+\rho_c^q} = \delta_c^q \, PDD_c \, QD_c^{\;1+\rho_c^q}, \qquad \forall c \in (CD \cap CM) \tag{8.2}$$

where CM, PM_c, QM_c are the set, price, and quantity of imported commodities, respectively. Equation (8.2) is the first-order condition for optimality.

The commodity structure is shown in Figure 2 (B). The constant elasticities of substitution for commodities follow those used on the GTAP (T. W. Hertel, McDougall, Narayanan, & Aguiar, 1997).

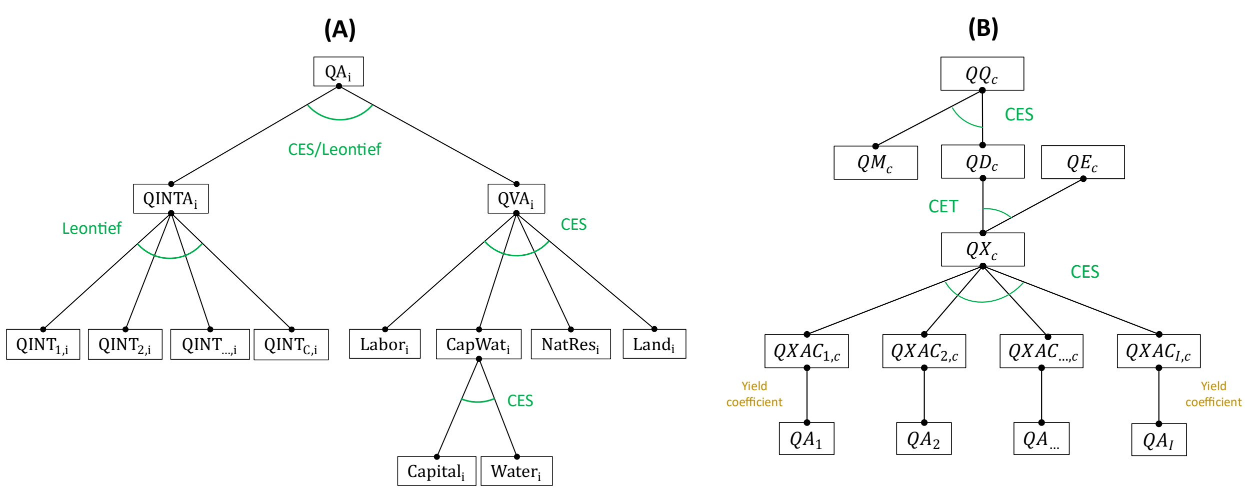

Figure 1. Industry (A) and commodity (B) production structure

2.4 Economic agents

There are four economic agents in the model: households (HH), non-profit institutions serving households (NPSH), corporations (CORP), and government (GOV). Each agent both a current and capital account. The use of agent capital accounts diverges from the model by (Lofgren et al., 2002) but follows the structure of income distribution used by the Canadian System of Macroeconomic Accounts.

The current income of agents is the sum of payments from the factors of production, taxes (for GOV only), and current transfers from other agents and the RoW. The government agent allocates transfers to other non-foreign agents based on the CPI while the other agent do it based on a fixed proportion of their total current income. Likewise, the RoW is assumed to transfer a fixed amount in foreign currency to domestic agents.

Expenditure is divided into consumption, current transfers to agents and RoW, and the remaining amount representing savings and investment is transferred to the respective agents’ capital account. Consumption and transfers are fixed proportions, therefore transfers to the capital accounts are endogenously determined by the model.

Disposable income is a fixed proportion of current income. For HH, the allocation of disposable income among commodities is divided into a subsistence and marginal consumption. The subsistence consumption is a minimum commodity amount that must be met, and the marginal consumption is based on the remaining budget after all subsistence purchasing is met. Transfers are fixed proportions of income for non-government agents, and a fixed amount based on the CPI for GOV.

The capital accounts of agents receive income from their respective current account, capital transfers from other agents and RoW, and from domestic borrowing. These capital flows are allocated to gross fixed capital formation, change in inventories, capital transfers to agents and RoW, and domestic lending. Capital transfers among agents are also a fixed proportion of the capital income for non-government agents, and a constant amount based on the CPI for GOV. Gross fixed capital formation and inventories are kept in the same proportion as in the baseline.

Finally, financial flows are balanced by setting domestic borrowing plus RoW lending equal to domestic lending plus RoW borrowing. Closure of the capital accounts is set by letting domestic borrowing and RoW lending to be determined endogenously by the model. Domestic lending is set to keep the same proportion of capital income as that of the baseline for agents, and the same transfer with respect to the composite exchange rate (EXR) for RoW borrowing.

Since the CGE is a square system whose column summation equals its row summation, then one row or column is redundant. Therefore, a dummy variable is created and set it equal to one equation of the system. The equation selected is the financial flows balance as shown on the Supplementary Information.

3. DATA

3.1 Social Accounting Matrix

Social Accounting Matrices (SAM) are square matrices that contain the transactions between economic accounts of an economy during a period of time, typically a year. These transactions are recorded in monetary terms between pairs of accounts. Columns represent expenditures and rows income of the accounts, therefore the column- and row-wise summation must give the same value.

The development of the SAM for the Canadian economy follows a two-step procedure. First, a detailed SAM is constructed at the most detailed level available using the following data sources:

- supply and use tables at the detail level (Statistics Canada, 2020h);
- current and capital accounts for
    - households (HH) (Statistics Canada, 2020a, 2020b);
    - non-profit institutions serving households (NPSH) (Statistics Canada, 2020c);
    - corporations (Statistics Canada, 2020d, 2020e);
    - general governments (Statistics Canada, 2020f);
    - non-residents (Statistics Canada, 2020g); and
- financial flows accounts (Statistics Canada, 2020i).

The resulting matrix contains 857 accounts in total, and follows a structure similar to the one presented in (Mainar-Causapé, Ferrari, & McDonald, 2018) and the three levels of income distribution for economic agents in (Siddiqi & Salem, 2012). The discrepancies between column- and row-wise summations were balanced using linear programming (see Appendix A).

The second step was to aggregate the detailed SAM and create the factor accounts for water intake, land, and natural resources. The account aggregation followed the North America Industry Classification System (NAICS) level 2 (Statistics Canada, 2021a) for industries and the Input-Output Commodity Classification level 1 (Statistics Canada, 2019) for commodities. The water systems industry and water use commodities were explicitly singled out and kept separate. The creation of new factor accounts is shown in the next sections.

The aggregated SAM has the following macro-accounts and number of accounts:

1.	C	Commodities	64
2.	M	Transaction costs margins	3
3.	I	Industries	48
4.	T	Taxes	3
5.	F	Factors	5
6.	A	Economic agents	4
7.	CAP	Capital accounts of agents	6
8.	FF	Financial flows	1
9.	RoW	Rest of the world	1

3.2 Water as Primary Input

Water is included as primary input for industries that are intensive water users, i.e., industries belonging to agriculture, mining, power generation, water distribution, and manufacturing. The water use is taken from the physical water flow table (Statistics Canada, 2021d), which contains the water use by industry and year at the country level. Since the industry aggregation of the water use data is higher than that of the detailed SAM, water use is allocated to sub-industries based on output. Payments for water use for mining, power generation and manufacturing are taken from (Statistics Canada, 2021c, 2021b). Since no information is available for the agriculture payments to water use, the mean value from the prices per meter cubic from the other sectors is taken to have a value that balances the low price paid by power generation and the relatively high price by manufacturing. The value obtained for agriculture (0.07 CAD/cubic meter) is within the bracket of agriculture water prices in the US that goes from 0.005 to 0.1 [US/cubic meter] (Winchelns, 2010). These expenditures are taken as payments to the water primary factor, which are extracted from the payments to capital. The water rates are shown in Table 1 and the water user industries in Figure A2 in Appendix.

Table 1. Water intake rates

[CAD/cubic meter]	
Power generation	0.00581
Mining	0.05106
Manufacturing	0.16737
Agriculture*	0.07475

*estimated

3.3 Land or Natural Resources

Payments to land or natural resources are calculated using the formula for industry-specific primary inputs from (T. Hertel, Tsigas, Narayanan, & McDougall, 2016), where the share of value-added for industry-specific factor is given by

$$\theta_R = \frac{\theta_{VA}\,\sigma_{VA}}{\theta_{VA}\,\eta_S + \sigma_{VA}} \tag{9}$$

where θ_R, θ_{VA} are the shares of the industry-specific resource and value-added, σ_{VA} the elasticity of substitution of value-added, and η_S the elasticity of supply of the resource factor. This step was performed on the detailed SAM.

3.4 Import Taxes and transaction costs

Import taxes and transactions are not explicitly singled-out on the supply and use tables. Since import taxes most often vary depending on the province, commodity and quantity bought, it was decided to use a marginal rate of 50% the consumption commodity tax, i.e., imported commodities would pay 1.5 the domestic tax rate. Likewise, for transaction costs it was assumed that imports trigger 50% more costs than domestic transaction costs.

4. SCENARIOS

The main scenario (A) assumes a water market is implemented as the mechanism to allocate water intake to economic activities and explores the response on the Canadian economy of water supply shocks due to potential climate changes. Therefore, water input is mobile across industries in this scenario.

The alternative scenario (B) estimates the economic costs of having targeted water shocks to selected water-intensive industries, but without having a water market implemented, i.e., water input is industry-specific and not sharable among industries. The selected industries are the following:

- B.1 Crop production.
- B.2 Paper manufacturing.
- B.3 Mining & quarrying.
- B.4 Water sectors.

In both scenarios, the rest of the production assume labor is mobile; and capital, land, and natural resources are industry-specific.

5. RESULTS

Results from scenario A show the Canadian economy has a small relative response to water supply changes. The largest affected industry is primary metal manufacturing with an output change in the range of [-3.7%, 2.2%], which is a small variation compared to the change in water availability. The total output of the economy has a small response between [-0.09%, 0.05%] (see Figure 2), while that of GDP is between [-0.022%,0.037%]. Results in the same order of magnitude have been found before for the Canadian economy (Rivers & Groves, 2013) though authors in there explore only reductions and not increases to water endowment.

Another insight from this scenario is the linkage between water availability and trade balance, which indicates that when water becomes scarce and its price increases, the production of domestic water-intensive commodities becomes costlier. These commodities then must be satisfied on foreign markets, which amplifies the trade deficit on the economy. This linkage also works in the opposite direction when water supply is increased, though the effect is less pronounced as seen in Figure 2.

In terms of income, that of HH shows a positive correlation with water supply (Figure A3 in Appendix). This is because a decrease in water supply, forces industries to employ more labor, which in turn makes labor less productive and have a lower price. The effect is the opposite when water supply is increased.

The income of corporations (Figure A3 in Appendix) shows a negative correlation with water supply. This is likely due to capital being non-mobile and associated with water in the capital-water production function. Therefore, a variation water input is only met with capital price changes (since capital supply is fixed) which has the effect that a decrease in water supply increases the relative contribution of capital to production, which overall increases capital income. Since capital income benefits primarily to corporations, hence the inverse relation.

The income of governments and NPSH exhibits a more complex behavior, mainly due to both being the recipients of large income transfers from HH and corporations (jointly accounting for 27% and 38% of their income respectively) that affect them in opposite direction as stated above.

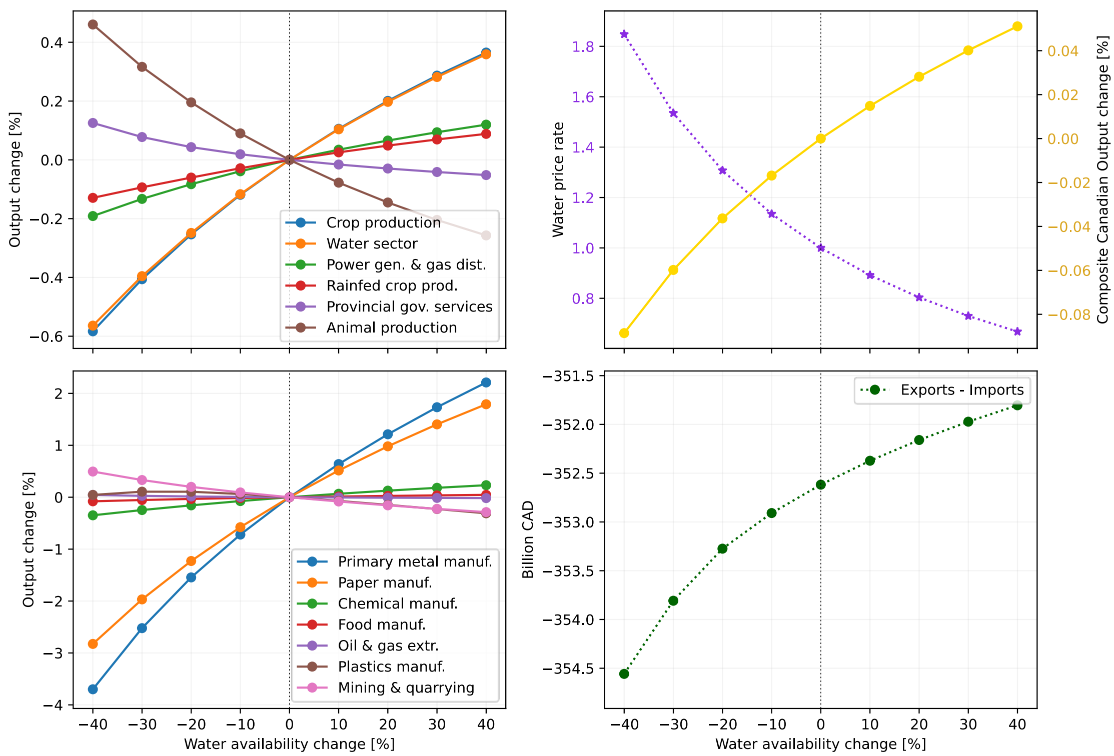

Figure 2. Results for scenario A: *upper left:* Output change of main water-intensive industries; *upper right:* water price and composite output of Canada; *bottom left:* output change of heavy industry water consumers; *bottom right:* trade balance

Experiments of scenario B (Figure 3) show that for all the targeted industries, water supply variations have a positive correlation with GDP and income of HH. In terms of output, mining & quarrying is the only industry with a negative correlation with water shocks, but this behavior was also observed for scenario A.

Overall, water shocks to paper manufacturing and crop production have the highest impact on GDP, output, and HH income; while those to the water sectors have the least effect on the Canadian economy, leaving the trade balance virtually unchanged.

In order to make the results from scenarios A and B comparable, the median marginal response on four variables are calculated for each simulation experiment: GDP, households income (YHH), government income (YGOV), and total absorption (TABS) which is the market value of the domestic consumption.

The largest marginal response (CAD/cubic meter), shown in Figure 4, is produced by shocks to paper manufacturing, followed by those to crop production. The lowest response corresponds to shocks to water sectors. Results from scenario A, where a water market is implemented, seem to balance out the economic response observed on the industry-specific shocks on GDP, YHH and YGOV. This damping effect acts on both directions: reducing the economic loss when water endowment is decreased, but also capping the economic gain when water endowment is increased. Domestic consumption, as measured by TABS, is mostly unaffected under scenario A unlike the results from scenario B.

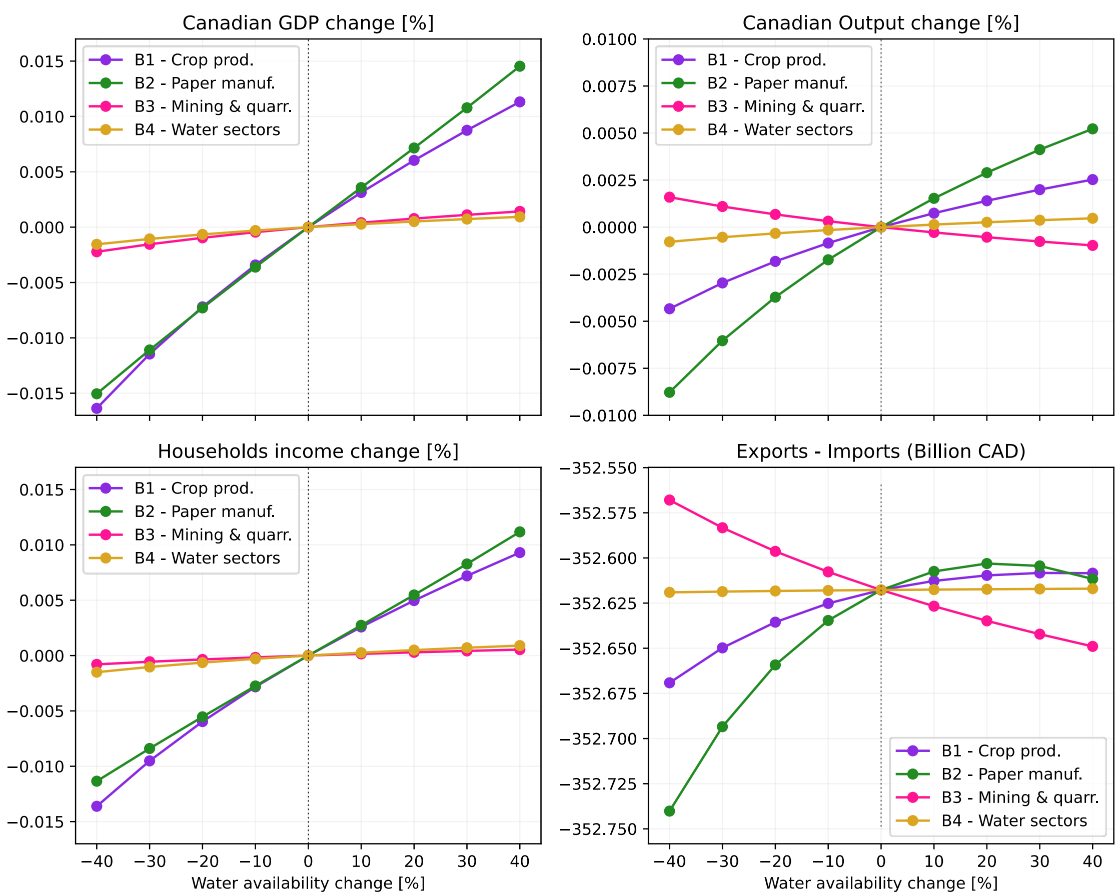

Figure 3. Results for scenario B: *upper left:* GDP change; *upper right:* output change; *bottom left:* HH income change; *bottom right:* trade balance

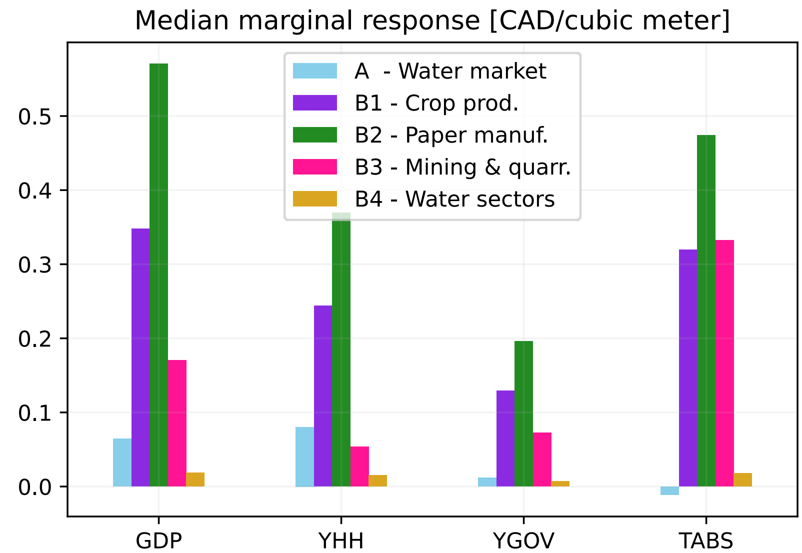

Figure 4. Comparison of median marginal response across the domain ($\Delta w \in [-40\%, 40\%]$) of water shocks for the scenarios tested; YHH: Canadian households income; YGOV: Canadian government income; TABS: total absorption, total domestic consumption at market prices

6. SENSITIVITY ANALYSIS

A major source of uncertainty in the data is found on the percentage of crop production output that comes from rainfed (non-irrigated) areas. The baseline scenario assumes 80% of the output comes from irrigated land, which comes from the number of farms that irrigate compared to the total number of farms (7,015/8,430 ≈ 0.83) for 2018 as presented by Statistics Canada (Statistics Canada, 2021e). However this estimate may be not be accurate because it does not consider the size of the farm or the market value of the crops. For this reason a sensitivity analysis is performed on the percentage of rainfed crop production (Figure 5).

The results show that although increasing the percentage of rainfed output decreases the costs of water shocks, its effect on the Canadian GDP is insignificant (less than 20 million CAD per year). There is also a clear trend showing that as the water shock increases, the difference in cost with respect to baseline increases as well. This pattern is only interrupted for a -40% shock, but even in this case more rainfed proportion yields lower costs. Therefore, the results of scenario A are mostly unaffected if the percentage of rainfed crops is in the range of [20%,80%].

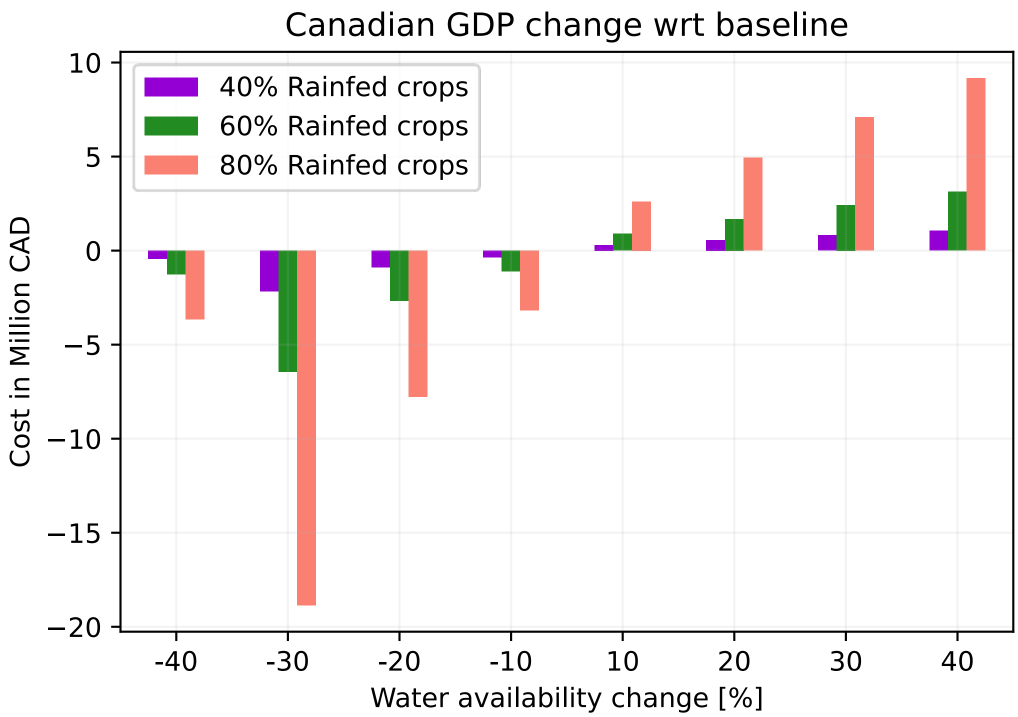

Figure 5. Cost in GDP with respect to the baseline scenario A

7. DISCUSSION & CONCLUSIONS

This paper presented a water computable general equilibrium (CGE) model for the Canadian economy which aims at exploring the effect of implementing a water market as a tool to cope with water level changes. The development of the CGE model entailed the creation of a social accounting matrix (SAM) from statistical data. Physical water flows and capital payments to obtain water by sectors are used to create the water price rates.

A novel insight produced by this study is that the Canadian economy responds more pronouncedly to shortages than exceedances on water endowment regardless of whether a water market is in place or not. It was also found that water variations have a relatively small effect overall on the economy, which goes in agreement with previous results in the literature (Rivers & Groves, 2013).

Implementing a water market across Canada has the effect of balancing out the economic costs that otherwise industry-specific water disruptions would produce. This effect acts in both directions, damping the economic loss due to water cutbacks but also the gains from increasing the water endowment.

If a water market is implemented, water variations affect mostly, in relative sense, to the primary metal manufacturing and paper manufacturing industries, followed by crop production and the water sectors.

Overall, the implementation of water markets deserves a closer look to incorporate the effect of spatially differentiated disruptions and the transaction costs. We believe these two aspects are better addressed on a spatially disaggregated model that would allow to introduce several local water markets. This remains a future direction to expand the CGE model of the Canadian economy.

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Appendix A. Balancing of detailed SAM

The optimization subroutine to balance the detailed SAM is the following:

1. Construct the detailed SAM from the data sources and calculate the difference between the column- and row-wise summation for each account.
2. Identify the accounts whose absolute difference > tolerance (1E-5).
3. Ensure the sum of differences is equal to zero, i.e., the errors cancel each other out.
4. Construct a submatrix that has as rows and columns the accounts with sum discrepancies. In all years calculated, these accounts belonged to the economic agents (A) and capital accounts (CAP).
5. Contruct a linear program to find the transfers among these accounts that balance all the accounts. These adjustments are made on the current and capital transfers matrices among agents and RoW, which are those at the intersections (A, A), (CAP, A), (CAP, CAP), (CAP, ROW), (ROW, CAP) seen in Figure A1.

	C	M	I	T	F	A	CAP	FF	RoW
C		Margins consumption	Intermediate consumption			Final consumption	Investment and stock changes		Exports
M	Transaction margins								
I	Domestic production								
T	Net commodity taxes		Net Industry taxes						
F			Payments to factors						
A				Tax revenue	Income agents	Transfers and income taxes			Current transfers from RoW
CAP						Depreciation and savings	Capital transfers	Borrowing	Capital transfers from RoW
FF							Lending		Borrowing from RoW
RoW	Imports					Current transfers to RoW	Capital transfers to RoW	Lending to RoW	

Figure A1. Depiction of the aggregated SAM

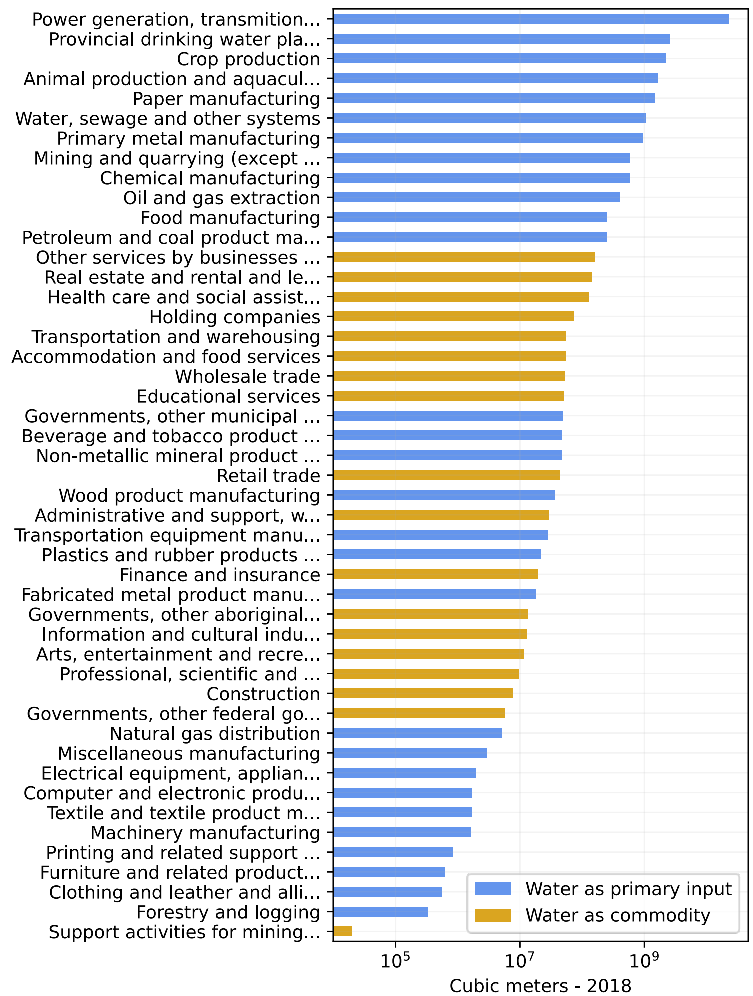

Figure A2. Water use by industry (only industries with reported water use are shown)

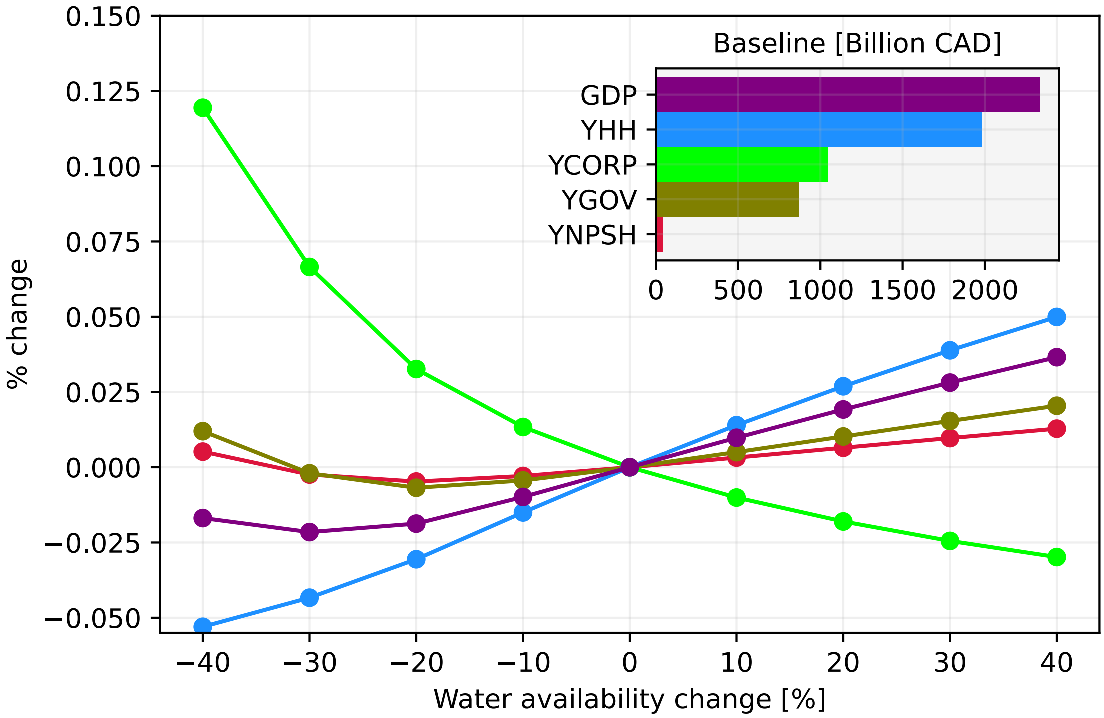

Figure A3. GDP and agents' income change for scenario A