An impact analysis of climate change and adaptation policies on the forestry sector in Quebec. A dyanamic macro-micro framework[1].

by

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Abstract

Quebec's forests represent 20% of the Canadian forest and 2% of world forests. They play a major role for habitat preservation, supplying goods and services to the population and hence contributing to the economy of this Canadian province. Climate change (CC) will have an impact on forests through increased droughts, warmer summers and winters or infestations such as the pine beetle (British Columbia and New Jersey). In our study we analyze the economic and distributional impact of CC on the forest industry in Quebec. To achieve this, we simulate two productivity changes in the forestry sector and two potential adaptation programs that could be implemented to help the sector cope with CC direct and indirect effects. Our analysis is performed over a 40 year using a recursive dynamic CGE-micro-simulation framework. We show that the economic impacts on the forest industry are relatively substantial but quite small for the rest of the economy. Moreover, the distributional impacts are present and significant but they are weak (below 0.1%).

keywords : Distributive analysis, computable general equilibrium model, micro-simulation model, climate change, adaptation policies

JEL codes: C68, D58, I32, O13, Q54, Q56,

[1] We would like to thank Ouranos and the ministère des ressrouces naturelles of Quebec for financial support and Anne Blondlot, Claude Desjarlais and Vincent Auclair for their precious comments. Standard caveats apply.

Introduction

Forests are ubiquitous in Quebec and play a major economic, environmental and social role. Moreover, the forest industry is a pillar of Quebec's economy. Climate changes (CC) are likely to have an important impact on forests and the forestry industry (Ciesla, 1997). Given the interdependence of the broad forest industry with the rest of the economy, the CC effects on forests could have an impact of the performance of other sectors and the economy as a whole. Our study aims to verify this assumption with two main objectives. The first one is to analyze the economic and distributive impact of CC on the forest industry in Quebec. We then investigate the economic and distributive impact of two adaptation programs aimed at attenuating the negative impact of CC on the forest industry in the province. The two adaptation programs are applied jointly with a reduction in forest productivity associated with CC. To achieve our two objectives we build a macro/microsimulation framework consisting of a recursive dynamic CGE model used in combination with a microsimulation model including dynamic components. These will be described in detail below We also apply poverty (Forster, Greer and Thorbecke-FGT 1984) and income distribution (Gini) indices for the distributional analysis.

Indeed, in 2012, 392 plants of first transformation were located in the province[2] (GOQ-MRNF 2012). The forestry sector generated 60900 direct jobs when including this first level transformation with the logging and timber sector (GOQ-MRN 2013) and each job in the forest industry creates 1.6 jobs in the rest of the economy. Moreover, forests play an important ecological role as carbon sink, habitat for over 200 species of birds and 60 species of mammals (GOQ-MRNF 2008). As shown in Table 1 below, the broad forest industry accounted for a fifth of total value of export for the province in 1994 and has been in decline since then to reach 12.7% in 2013. The weight of the industry is higher in Quebec compared to the rest of the country, where export account only for 12.7% in 2013 compared to 6.6% for the rest of the country. The exports of the forest industry ranked in

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[2] This first transformation is essentially sawmills mainly located in Chaudière-Appalaches, Bas-Saint-Laurent, Eastern Townships, Saguenay-Lac-Saint-Jean and Abitibi-Témiscamingue where over 30 sawmills are located. (Gouvernement du Québec-MRNF, 2012)

first place in 1994 and in 2013 they rank in third place for the province (Statistics Canada 2014).

Table 1: Exports of forest industry for Quebec and Canada

		1994	2000	2006	2013
Québec	Total value of exports (in million CAD)	38621	71303	69060	64421
	Wood and derivative products	6,1%	6,0%	5,2%	3,5%
	Pulp and paper and derivative productions	15,1%	11,9%	11,6%	9,2%
	Total forest industry	21,2%	17,9%	16,8%	12,7%
Canada	Total value of exports	212493	385679	411493	443116
	Wood and derivative products	6,8%	5,2%	4,2%	2,9%
	Pulp and paper and derivative productions	8,9%	7,7%	5,5%	3,7%
	Total forest industry	15,7%	12,8%	9,7%	6,6%

*Figures computed by authors from data drawn from Statcan Canadian International Merchandise Trade Database (http://www5.statcan.gc.ca/cimt-cicm/).

Economic actors in the sector will likely face a drop in income, employment is likely to decline and the welfare of communities relying on the industry for their livelihood could also be affected. The effects of CC will modify the severity and length of seasons. Therefore, winters in Quebec and Canada are likely to be warmer and shorter with a reduction in snow cover (Ouranos, 2010). The changes will also have an impact of the variability and climate extreme events with more droughts and abundant rain (GIEC, 2007).

There are already signs of impact of CC on forests in Canada through changes in frequency of forest fires, droughts, violent storms, diseases and insect infestations (Johnston *et al.*, 2010). The mountain pine beetle (Dendroctonus ponderosae) epidemic in Western Canada is considered to be linked to CC (Johnston *et al.*, 2010).

The rest of the paper is structured as follow. First we review the literature focusing on CC impact analysis with recursive dynamic CGE models, followed by a presentation of our methodological framework. We then move on to the presentation of our simulations before analyzing our results. We end the paper with our concluding remarks.

Literature review

A CGE model is an analytical tool that allows one to integrate various economic agents and production sector which interact on various markets. They include macroeconomic and sectoral variables and hence can produce relatively broad economic impact analysis. Detail and specific behavior can be included to capture specificities for consumers or producer. At the origin, they were mostly used for comparative static analysis but have been extended to become a dynamic analytical tool (Decaluwé et al (2001)). Three types of dynamic models are found in the literature. First, the recursive dynamic models which do not include rational expectation by consumers, producers and the government. Then others have drawn from the macro dynamic literature to propose forward looking dynamic CGE models with rational expectations and finally CGE models with overlapping generations (OLG) used mainly for pension sustainability but some authors applied them to environmental issues[3]. On their part, forward looking dynamic CGE models quickly become very large and detailed modeling of a broad industry can quickly become computationally cumbersome to solve (Boccanfuso et al 2014). The most widely used CGE approach to analyze the economic impact of climate change is the recursive dynamic approach among which; Bosello *et al.* (2007) Berrittella *et al.* (2006) and Roson and van der Mensbrugghe (2010).

Among CGE applications to perform CC impact analysis on the forest industry, Rive *et al.* (2005) use a recursive dynamic CGE model to capture the effects of CC on the forest industry. They find that an increase in productivity in the forestry sector favors the broad forest industry, with increase in production, reduction in prices and increases in exports. More recently, applications were performed for the Canadian economy among which Ochuodho et al., (2012) who analyze the economic impact of potential CC and adaptation measures for forestry in six Canadian regions between 2010 and 2080 with a recursive dynamic CGE model. They find that CC will have important physical and economic impact. More specifically, logging and timber sector, forest industry and other sectors will see their output increase by 2% generating an increase in GDP of equivalent value.

[3] See Gerlagh and van der Zwaan (2001) for an application and Tchouto (2007) for a survey of applications.

Ochuodho and Lantz, (2014) improve on their previous model to include agriculture and find stronger impact.

Marbek et Lantz (2010) study also focuses on the forestry industry in Canada. They evaluate the cost of CC and adaptation for the Canadian forestry industry which is decomposed in 6 regions with a recursive dynamic multi-region CGE model to capture the economic impact. One of the weaknesses of the Marbek et Lantz (2010) model is the absence of export taxes which are used in the province of Quebec and they also omit to use a world demand for forest products with a finite elasticity. Hence, in their model, producers are faced with an infinite world demand for their goods. In Quebec, regulation prevents exporting non transformed timber cut from public land. The only exports allowed are cut from private properties and the wood cut from private forest represented 16% of the total production in 2010 (FPFQ 2012). In their model, they do not provide for the possibility of tradeoff for forestry output between the local market and export market when relative price changes on both markets. This limits that capacity of adaptation and can overestimate positive or negative effects of an external shock on the sector.

Our study is in the same strand as Marbek and Lantz (2010) but we focus on the Quebec economy. This allows us to provide a more detailed modeling of the forestry industry compared to Marbek and Lantz (2010). Among the differences in our model we have the modeling of timber production, destination of wood chips, world demand for forest industry exports and externalities of public expenditure. Moreover, our study is the first to perform distributional impact analysis of CC on the forest industry with a CGE-microsimulation framework. These specificities are presented in the following sections.

Methodological framework

Let us recall that our methodology is a recursive dynamic CGE model used in combination with a dynamic microsimulation model. For our poverty analysis we rely on decomposable indices proposed by Foster, Greer and Thorbecke (1984) and the Gini index for inequality changes. First, we present our accounting framework used for our two models before moving to the presentation of our models and the methodology for the distributive analysis.

The social accounting matrix (SAM) draws from the one used in Boccanfuso et al (2014a). Their SAM built from 2006 data includes 25 production branches[4]. This level of aggregation does not include the various branches in the forest industry. For the purpose of our analysis, we needed to extract the following sectors; *wood products*, *sawmills and wood preservation*, *pulp and paper*, *furniture and related products* from the *other manufacturing* branch and *forestry support activity* was extracted from the *agriculture and forestry support* sector. Finally, we extracted cogeneration from utilities. The *forestry* sector was already isolated in the initial SAM.

The disaggregation of these production branches was performed with data from various sources such as : Statcan's input-output tables, final demand tables, manufacturing sector tables and the interprovincial and international trade flow tables. We also used the annual report of the Ministry of natural resources (MRN) on the forest industry[5].

Hence, the SAM we used has 30 productions sectors, 4 agents (aggregate household, an aggregate firm, government and the rest of the world), two factors (labor and capital) and one savings and investment account.

The microsimulation model database was constructed using the Survey of Household Spending of 2009 (SHS) produced by Statistics Canada. This database includes detailed information of household expenditure and hence facilitates the process of synchronizing the micro household data with the SAM[6]. We had 1275 households at the provincial level for Quebec in the SHS.

The CGE model

In this section, we present the main features of our CGE model that builds on the one proposed by Boccanfuso *et al*. (2014a), to which numerous changes were introduced to capture the specificities of the forest industry in Quebec. The complete model is presented in Boccanfuso et al (2014b). We focus here on the hypotheses that play an

[4] This is the most disaggregated level publicly available data for Canadian provinces.
[5] Our SAM was validated by forestry economist from the private sector, Ouranos economist as well as the group of forestry economist of the MRN of Quebec.
[6] This syncronysation consists in doing a mapping between the nomenclature of the household survey and the SAM. With the process we need to aggregate over 200 goods and services consumed into the 30 found in our SAM. The same process is applied to the income component found in the household survey.

important role in our analysis, namely the specificities of the forest industry. We complete the section with a presentation of the microsimulation model.

The recursive dynamic CGE model includes 30 production sectors. It also incorporates four agents, namely an aggregate household[7], one aggregate private firm, the government and the rest of the world. Production for most sectors is determined through a 3-tier system[8]: the total production of the branch (*XS*) is made up of a fixed share between value-added (*VA*) and intermediate consumptions (*CI*). *VA* is a combination of composite labour (*LD*) and capital (*KD*), which are related with a Cobb-Douglas function. Producers minimize their cost of producing *VA* subject to the Cobb-Douglas function. Optimal labour demand equations are derived from this process. We introduce an infrastructure externality parameter into this function, which we describe in more detail below. This element plays a key role in capturing the effects of the adaptation programs. We assume that capital is not mobile between sectors within a period[9]. Intermediate consumptions are determined by a fixed share (Leontief) assumption in a standard fashion[10]. The multi-level production structure is composed of fixed coefficient intermediate inputs and these total intermediated inputs are combined to value added in fixed share (Leontief assumption).

As in Savard (2010) and Boccanfuso et al (2014a), the key assumptions to capture the positive effects of new infrastructure spending via the adaptation program is associated with the positive production externalities of public infrastructure[11]. This first equation (1) is the government budget constraint where government savings (*Sg*) is the difference between its income (*Yg*) and its expenditure (*G*), the transfers to other agents (Tg_a) and interest payments on debt to agents ($Intr_a$). The savings is used entirely for public investment.

[7] It is important to highlight that the distributional analysis is performed with the results of the microsimulation model and not this aggregate household.
[8] A detailed presentation of the forestry sector is done below as we formulated different assumptions for this sector.
[9] In the dynamics of the model, the new capital will go in priority to sectors exhibiting the highest returns. This mechanism captures some implicit mobility of capital between sectors.
[10] With the exception of wood chips consumption detailed below.
11 We extend from Savard (2010) insofar as we have a recursive dynamic model that can include debt as a variable and funding tool for public infrastructure. The first to propose such externalities of public investments in CGE models are de Melo and Robinson (1990).

$$1.\ Sg = Yg - G - \sum_a Tg_a - \sum_a Intr_a$$

We assume that public spending is exogenous and that public savings (the budget surplus) is endogenous. The public investment in infrastructure (*ITG*) will be set exogenously and government will in part fund its investment objective with its current savings (*Sg*) but will have access to a change in the stock of debt as a funding tool. We will identify this change in debt as a *deficit*.

$$2.\ ITG = Sg + deficit$$

The deficit will be funded by the three other agents in the model, namely households, private firms and the rest of the world[12]. In our simulation process we will modify the closure of this equation where the deficit will be held fixed and a tax rate will be used to balance this constraint[13]. An increase in debt will generate more interest payment for the government in subsequent periods but we will describe this below in the dynamic version of the model.

The public capital externality equation (3) is the other important assumption, given its role in increasing the total productivity of factors in the value added equation (4). For this, we draw on the vast literature linking public infrastructure to private sector factor productivity, including Dumont and Mesplé-Somps (2000) in a CGE context, although our externality function does not include private investment. This function was also used in Savard (2010) and Estache et al. (2012). The function defining the externality is the following:

$$3.\quad \theta_{t,i} = \left(\frac{Kg_t}{Kg_0}\right)^{\xi_i}$$

where θ_i is the externality or sectoral productivity effect, which is a function of the ratio of new stock of public capital (Kg_t) over public capital of the reference period (Kg_o) with a sector-specific elasticity (ξ_i)[14]. It is important to understand that externalities from

[12] We calibrated the share of households at 30%, firms at 50% and rest of the world at 20% based on discussions with debt managers of the Ministry of Finance of Quebec. This is an approximation on their part since they don't have the exact information on who hold Quebec government bonds.

[13] We will explain this in more detail when we describe our simulations.

[14] The values for this parameter were estimated using data from Quebec for the 1961-2008 period. The estimation approach used is the same as Harchaoui and Tarkhani (2003). In general, the values of our parameters are conservative with respect to this literature, ranging from 0.01 to 0.038. The complete results

public capital stock at the reference period are calibrated in the A_i parameter of the Va_i function below (equation 5). The externality measured by θ_i represents the portion associated with the new investments of the adaptation program[15]. The stock of public capital is determined by the following equation:

$$4.\ Kg_t = Kg_{t-1}(1+g_k)^t(1-\delta_g)^t + ITG_{t-1}(1-\delta_g)^{t-1}$$

where the level of stock of public capital of the previous period (Kg_{t-1}) grows at an exogenous rate of g_k which corresponds to the level of investment required to maintain the capital stock. The δ_g is the depreciation rate of public capital and ITG_{t-1} is the public investment in new capital of the previous period. We assume that $g_{k=}\ \delta_g$ in a business as usual scenario where the government chooses to maintain its public capital constant. The ITG_t is an exogenous variable that allows us to capture the investment program to build new infrastructure in the economy via an adaptation program described below. This program will increase the public capital stock compared to the reference period and produce a production externality $\theta_i > 1$. This externality is introduced in the following value added (Va_i) equation:

$$5.\ Va_i = \theta_i A_i Ld_i^{\alpha_i} Kd_i^{1-\alpha_i}$$

where A_i is the scale parameter, Ld_i, the labour demand, Kd_i, the capital demand, and α, the Cobb-Douglas parameter. Hence, an increase in θ_i above 1 represents a Hicks neutral productivity improvement, like the one modelled in Yeaple and Golub (2007)[16]. With this formulation, the infrastructure investment can act as a source of comparative advantage because the function is sector specific.

As in Ballard *et al*. (1985) and Blonigen *et al*. (1997) we assume an endogenous labour supply. The workers decide to work more (less) when the real wage increases (decreases) relative to the reference period or the previous period which enables us to take into

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are forthcoming in Boccanfuso et al (2014c). Given that parameters are below 1, the returns to public infrastructure are positive but the growth occurs at the decreasing rate $\frac{\partial \theta}{\partial KG} > 0, et\ \frac{\partial^2 \theta}{\partial KG^2} < 0$.

[15] In fact, as we modeled we would capture the negative externalities of non-maintenance of public infrastructure but we do not simulate such policies in the model.

[16] This formulation is also commonly used in studies estimating externalities of public infrastructure on total factor productivity such as Ashauer (1989), Gramlich (1994) and Dessus and Herrera (1996), among others.

account the presence of equilibrium unemployment (Decaluwé et al., 2010)[17]. Representative households acquire their income from wages ($s\sum_i Ld_i$), interests on investments ($\sum_i rKd_i$), dividends (*Div*) and net transfers from the government (*Trg*) and from abroad (*Trw*).

$$6.\ Yh_i = s\sum_i Ld_i + \sum_i rKd_i + Div + Trw + Trg$$

As for expenditures, households pay a proportional income tax, save a fixed proportion of their disposable income, and spend the rest of this income on the consumption of goods and services. The *firms* receive the largest share of returns to capital paid by production branches, after deduction of depreciation of capital. Firms then pay income taxes, dividends and interests to other agents. Governments obtain their revenues from various direct and indirect taxes and transfers for other agents[18].

Commodity markets are balanced through adjustments in market prices. The current account balance is fixed; accordingly, the nominal exchange rate varies to allow the real exchange rate to clear the current account balance. The GDP deflator is used as the numeraire in the model. We also assume in a standard manner that the Quebec economy is a small open economy. Armington's (1969) assumption is adopted for the demand of imported goods (imperfect substitution with constant elasticity of substitution function (CES)) and constant elasticity of transformation (CET) functions are used to model export supply.[19]

Finally, private investment is endogenous and determined by the level of savings generated by households and firms[20]. The savings of households is a fixed portion of its disposable income. For firms, it is a balance between its income and expenditure. Once the total level of private investment is determined, it is distributed between branches according to an investment decision rule that puts into relation the capital return and its cost. The new capital is added to the initial capital stock or the capital stock from the previous period as described in the dynamic of the following model.

[17] We essentially model the substitution effect of the labor supply.
[18] These include income from public firms, various transfers from the federal government such as the Federal Equalization program.
[19] The complete set of equations and variables can be provided upon request.
[20] The exogenous current account balance also contributes to the private savings.

Forestry sector

We do not detail the modeling of the forestry sector but simply highlight the main hypothesis[21]. The objective to introducing specific behaviour for the forestry sector and forest industry is to capture some constraints faced by the sector. Among these constraints is the fact that a limited amount of threes are available for harvesting each year. This is set by the government and the model is calibrated to this value and adjusted over time based on government estimates. A second constraint concerns increasing returns in the production of timber when harvesting in the south (diminishing cost) and as loggers move north, the producers face diminishing returns (higher cost) because of a more limited access and size of the wood being harvested. We capture these specificities with a Wiebull production function.

Another specificity of the forest industry is the destination for wood chips produced by sawmills. Those can be sold to the pulp and paper industry or to the cogeneration sector to produce electricity. The choice of the destination is determined through an income maximization process constrained by a constant elasticity of transformation function (CET). Finally, we also introduce a world demand with finite elasticity for the outputs of the broad forest industry (including all forestry associated sectors) since the producers of the province cannot export unlimited quantities of their output. To increase their market share they must reduce their market price.

Dynamics of the model

The dynamics of our model is relatively standard and full details are presented in Boccanfuso et al. (2014b). The main features are that private capital accumulation is a function of the level of private savings generated in the economy and the capital depreciation rate. The destination of new capital is a function of returns to capital in the sectors, distribution of capital at the reference period and a sectoral elasticity. The labor force grows at the same pace as the population growth rate (0.7%) of the province with a 15 year lag[22]. We calibrate the model in order to have a 2% growth rate of real GDP for

[21] For more a more detailed presentation of this part of the model, the reader can consult Boccanfuso et al (2014b).

[22] This figure is the average for 10 years around 1991 which is 15 years prior to our reference year for our SAM. The figure was computed from statistics drawn from the Bilan démographique du Québec (2013) of the Institut de la Statistique du Québec-ISQ.

our business as usual scenario. We use the technological change or scale parameter of the production function in a standard fashion to calibrate this 2% growth rate of GDP.

The microsimulation model

Microsimulation (MS) models are analytical tool that are used to simulate the effects of a policy or reform on a set of agents (individuals or households) at the unit level. They capture the economic and institutional constraints of agents. Orcutt (1957) was the first to propose this analytical tool. The heterogeneity found at the individual level makes it a powerful tool for distributional analysis that has been increasingly combined with CGE models for this purpose[23].

MS models are composed of three main elements: i) a set of database representative of a larger population ii) economic constraints such as factor endowment, set of fiscal constraints, etc. and iii) the theoretical behavioral model (Bourguignon et Spadaro 2003). MS models can be of the accounting type without behavioral reaction by households/ individuals or behavioral models in which rich behavioral assumptions can be introduced or estimated[24]. Most MS models are used in a static context but over the last decade, dynamic MS models have emerged as widely used analytical tools.

For our model, we constructed a MS model with limited behavior. We do not estimate a labor supply model or consumption function but assume an expenditure function derived from a Cobb-Douglas utility function. We assume that the marginal savings rate is exogenous but this savings rate plays an important role in the dynamics of the model as we explain hereafter. The MS model is solved sequentially, where we first compute gross income, followed by net income (net of tax and transfers), and disposable income. We can then compute the households' consumption by calculating changes in welfare measure by the equivalent variation (EV). This EV allows us to capture the income and price effect for each household of our different simulations.

The dynamics of the MS model

In the literature, we find very few dynamic CGE model used in combination with micro-simulation models. One of the rare examples is Annabi et al (2005) who do not introduce

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[23] For an extensive discussion on this macro-micro framework (CGE-MS) one can consult Bourguignon and Spadaro (2006) and Davis (2009).
[24] See Savard (2003) and Cury *et al.* (2010) for examples of such models).

dynamics in their micro-simulation model. In our model, we extend from their application by using the savings rate to determine the destination of new capital in the MS model. Moreover, we also account for demographic changes in 2030 and 2050 by applying a reweighting approach based on Deville and Sarndal (1992). This approach consists in reweighting households in order to reproduce the population age structure estimated for 2030 and 2050[25]. More specifically, we recalibrate data from external aggregates, namely age groups and gender composition. After the procedure, our sample represents 3 930 621 households in the province in 2029 (+18.3% compared to 2009) and 4 198 411 in 2050 (+26.4% compared to 2009)[26].

Distributional analysis methodology

For poverty and inequality analysis we use the empirical approach as opposed to the functional form approach. The empirical approach does not impose choosing a functional form to model the income distribution but a data smoothing approach is used in the process of computing indices. This approach was adopted *inter alia* by Cockburn (2006) and Boccanfuso and Savard (2007). The diagnosis of poverty and inequality changes is based on two indices commonly used in macro–micro modelling. The poverty index is the P_α index of Foster, Greer, and Thorbecke (1984).[27] We use the Gini index to analyse

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[25] Cf. The Institut de la Statistique du Quebec-ISQ provides estimates for population based on gender and age for 2006-2056.

[26] Our definition of household is the same as the one used by Statistics Canada, namely a household regroups people living under the same roof.

[27] The poverty indexes of de Foster, Greer, and Thorbecke (1984) are additively decomposable; as such they are useful for this analysis because they allow us to measure not only the proportion of the poor among the population but also the depth and severity of poverty. P_α indexes are calculated with the following equation:

$$P_\alpha = \frac{1}{\sum_{i=1}^{N} w_i} \sum_{i=1}^{q} w_i \left(\frac{z - y_i}{z} \right)^\alpha$$

where α is a parameter characterizing the degree of poverty aversion; z, the poverty line; y_i, household income; N, the total number of households; w_i, the sampling weight for household i; and q, the number of poor households below the poverty line. When $\alpha = 0$, P_α represents the proportion of households in a group or in the general population below the poverty line. If $\alpha = 1$, the relative weight of households below the poverty line is proportional to their incomes, which thus represents the poverty gap. For detailed information on this index family, see Ravallion (1994).

changes in inequality. In our distributive analysis we are limited by the small size of our sample and we decompose household on the basis of the size of urban areas in which households reside. Our three categories are i) urban areas larger than 100000 households, ii) smaller than 100000 and iii) rural households. We apply our distributional analysis at the reference period, 20 and 40 years later.

Presentation of simulations

For our analysis we performed two sets of simulations. In the first set, we apply simulations that represent direct impact of climate change and in the second set, we simulate two potential adaptation programs.

Productivity change is one of the most likely direct effects of climate change on forest in Quebec (Yamasaki et al., 2012). Moreover, the occurrence of natural disturbances is likely to increase such as insect epidemics or invasions by foreign species given the warmer winters. In this context, the first set of simulations is changes in productivity. The first simulation is an increase in productivity of the forest of Quebec by 3%. The next two are decreases in productivity. The second simulation is the mirror of the first one namely a decrease in productivity of 3% and the third is a decrease of 6% of the forest productivity. The figures for these optimistic and pessimistic scenarios are drawn from Yamasaki et al. (2012) and Marbek and Lantz (2010). We apply these decreases (increase) in productivity in a progressive and proportional manner. For the third simulation, the 6% decrease in productivity requires a 0.155% reduction every year to reach the target of 6% after 40 years.

Adaptation programs aim to attenuate the negative effect of climate change. In the second set of simulations, we attempt to capture the effects of adding such an adaptation program to a decline in productivity (of simulation 2). We perform two scenarios which encompass a wide variety of programs. The first of these scenarios is an infrastructure program (roads, bridges, forest fire fighting infrastructure, etc.). Indeed, improving forest infrastructure provides better access to the forest and improves firefighting efforts as well as efficiency in wood transportation. In this scenario (Simulation 4) we simulate a 75 million $ infrastructure investment program to repair road and bridges damaged by CC effects (Gauthier et al 2014) or to build new and better roads. All these provide a better access to the forest and should improve productivity of the *forestry* and *forestry support* sectors. This program spans over three years with 25 million $ spent every year. This program will stimulate the construction sector during its implementation and produce positive externalities for the *forestry* and *forestry support* sectors via an increase in productivity as described above. The productivity gains will remain after the program but the productivity effects will diminish slightly as time goes by[28]. We fund this program with a temporary increase in the sales tax as Boccanfuso et al (2014a) show that this is the most efficient tax to fund this type of program in the province[29].

The second scenario could include various programs that would aim to support the forestry sector to improve productivity. These programs could be *inter alia* better forest management, better forest harvesting technics, valuing genetic diversity, pest management, limit habitat fragmentation, restoration of degraded areas, forestry regulation as described in Gauthier et al, (2014). This scenario can represent any of these initiative aimed at improving forest productivity.

Specifically the simulation (Sim 5) consists in an annual subsidy of 10 million $ to the *forestry support* sector for 5 years. This subsidy will generate a reduction in market price of the *forestry support* services and we assume that this subsidy will generate positive productivity effects in the forestry sector but the gains will be incremental (0.17% per year) peaking at 5% in 30 years. The productivity effects will remain to the end of the resolution (40 years). Like with the previous program, this one is also funded by an increase in the sales tax. The simulations are summarized in the following table.

Table 2: Summary of simulations

Code	Descirption of simulations
Sim 1	Increase in forest productivity of 3%
Sim 2	Decrease in forest productivity of 3%
Sim 3	Decrease in forest productivity of 6%
Sim 4	Infrastructure adaptation program funded by VAT increase + Sim 2
Sim 5	Forestry support adaptation program funded by VAT increase + Sim 2

[28] We assume that the government will not invest sufficient funds to maintain the road system and hence they will suffer from depreciation in time.

[29] The tax increase is quite small and is below 0.5% of a percentage point of the sales tax. Hence, using the 2013 TVQ rate of 9.975%, the tax increase would bring the rate at 10.025%.

Analysis of results

Given the wide range of result and number of simulations we focus our analysis on a few macro variables and sectoral production of the forest industry and three other important sectors in terms of their weight in the economy (36%) namely the *other manufacturing* sector, *retails* sector and the *finance* sector[30]. We present our results as variation in percentage between the levels of the simulation with the levels of our business as usual-BAU. Hence our graphs are percentage gaps or changes (x axis) over the 40 period/years (y axis) of resolution. We first analyze the macro variables followed by the sectoral output. We complete our analysis with the distributional analysis.

The first important element to highlight is that most of the effects are relatively weak especially for the macroeconomic variables. Even if the forest industry is relatively important (around 5% of GDP) as we presented in the introduction, the forestry sector represents less than 1% of GDP and therefore the impact of CC does not have a large impact on the economy. The largest impact on GDP is less than 0.1% for simulation 3. However, the sectoral effects in the forest industry can be relatively large (near 5% changes compared to its BAU levels). Our results must also be seen as indicating the directions or signs of effects of climate changes on variables presented.

Simulation 1: positive productivity impact

Sim 1 produces positive effects for most variables in the model (see Graph 1 for results of this simulation). GDP growth is faster compared to the BAU and this growth rate accelerates as time goes by and ends around 0.04% above the BAU. The same trend is observed for agents' revenues with firms income (*Ye*) exhibiting the largest gap with the BAU and government revenues (*Yg*) the weakest positive gap. Government income's growth generates a 1.5% reduction in public debt by the end of the resolution. The cumulative effect of debt reduction (less debt makes for less interest payment, which

[30] From hereon we will refer to the broad forest industry to include all seven sectors of the industry (*forestry, forestry support, wood products, sawmill and wood preservation, pulp and paper, furniture and related products* and *cogeneration*). Forestry sectors include *forestry, wood products and sawmills* and wood preservation) and forest industries (*forestry support, pulp and paper, furniture and related products* and *cogeneration*).

increases government income and frees funds to reimburse more debt, etc.) provides for an accelerating decrease in the debt in the latter part of the resolution[31].

At the sectoral level, we note a strong increase in output in the *forestry* sector as it is directly affected by the productivity gains. This increase in output produces a reduction in market price and provides gains for wood-intensive sectors. The sectors having the largest percentage of wood input in their cost structure benefit the most, namely the *wood product* sector and the *sawmills and wood preservation* sector. It is interesting to observe the decrease in output of the forestry support sector for over 15 years. This decrease is explained by the fact that increase in productivity of the *forestry* sector reduces the demand for inputs among which *forestry support* sector. In other words, the sector can producer more with the same amount of input and as supply increases less compared to the growth in productivity, it decreases its demand for inputs in the first part of the resolution. However, as the *forestry* sector continues to increase its production, it comes to a point where it needs more inputs and hence the output of the *forestry support* sector starts progressing (around year 16) until it passes back above the BAU around year 34 to finish over 0.13% above the BAU.

We also observe that gains of the *furniture and related product* sector, *pulp and paper* and *cogeneration* benefit less from this productivity gain ending around 0.1% above the BAU[32]. For the impact on other sectors, we observe an increase in output for the *retail* and *finance* sectors while the *other manufacturing* sector drops its production with respect to the BAU. This gap increases until year 25 and is reduced afterwards but stays below the BAU until the end of resolution. The gap is relatively small but illustrates that the gains in some sectors are compensated by reduction in others as factors and investments change destination vis-à-vis de BAU scenario.

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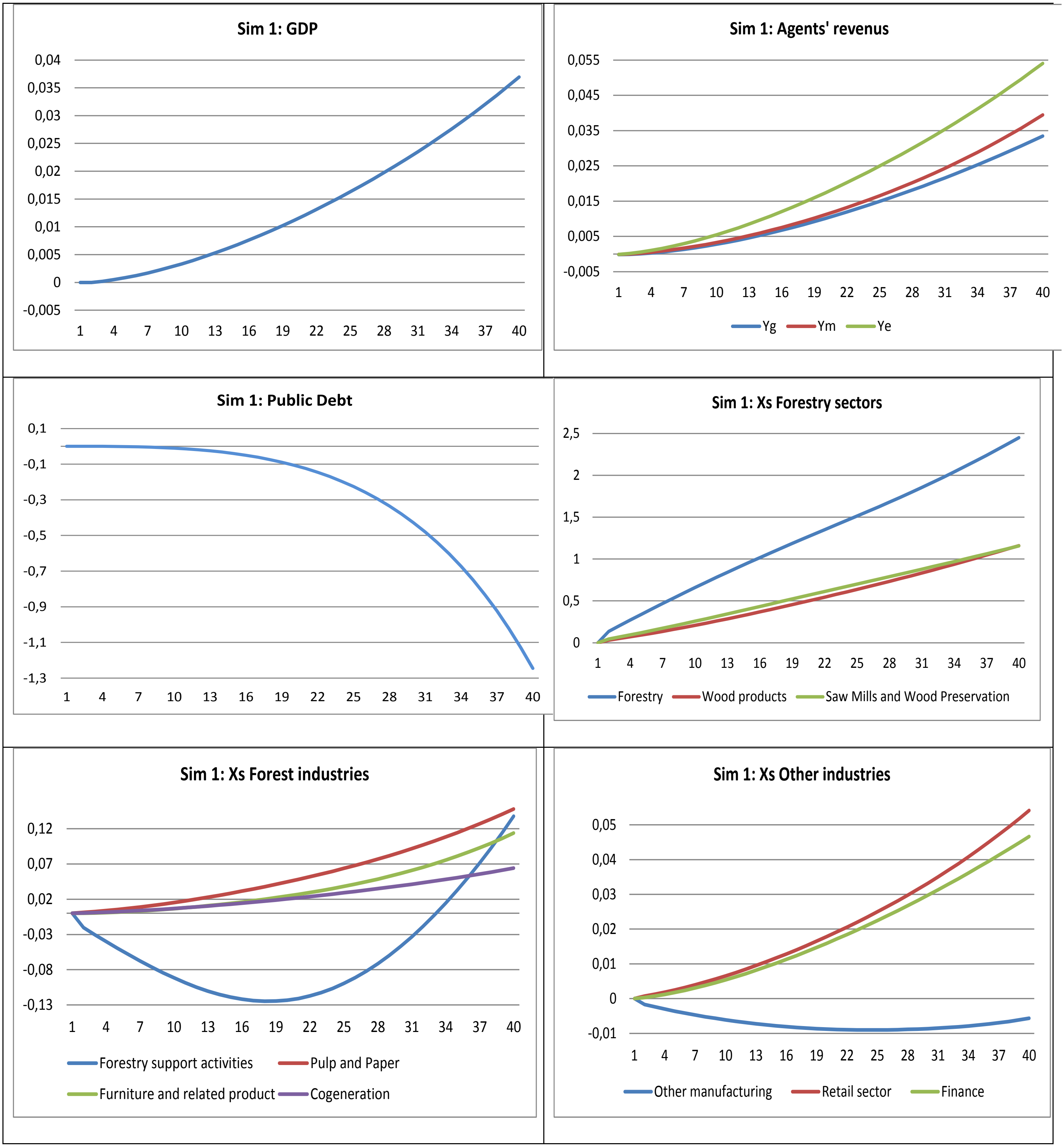
[31] It is important to note that this cumulative effect is reinforced by our assumption that all excess funds obtained by the government is used to pay the debt and not increase its expenditure. Hence, over the long run a small increase in government revenues can lead to a relatively large reduction in debt. The opposite is also true for decreasing government revenues. The cumulative effect will play a similar role in the opposite direction.

[32] It is important to highlight that the relatively small impact on the pulp and paper sectors is associated with a number of factors; first, recycled paper has grown tremendously as an input to produce paper. For example, an important paper producer in the province (Cascade) uses exclusively recycled paper in its production process. Second, the share of the cost of wood chips in total production cost is below 20% and finally, the sector has access to imported products in the production process.

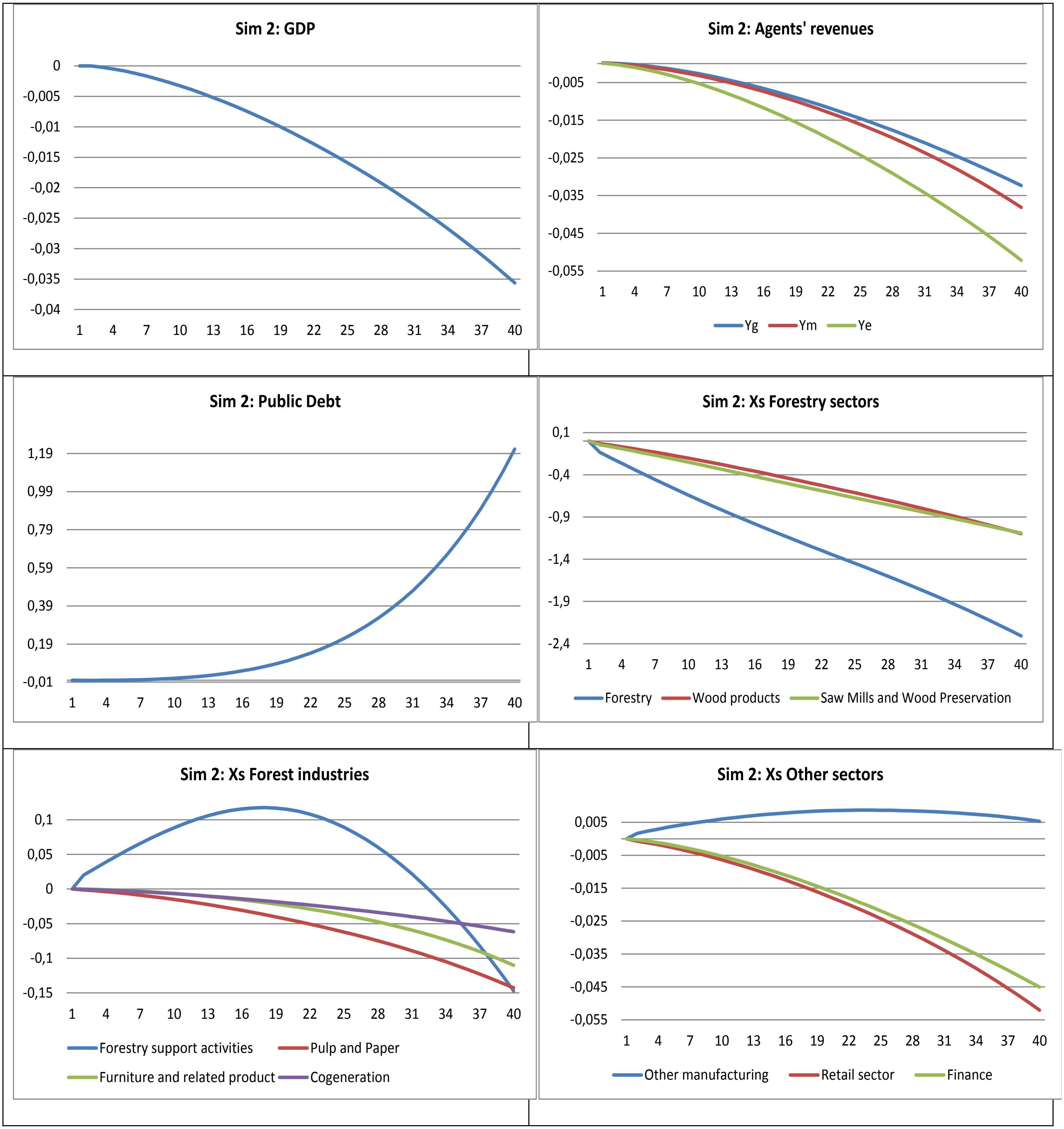
Graph 1 : Simulation 1, macro and sectoral results



Simulation 2: reduction in productivity of 3%

For simulation 2, we do not interpret the results since they are very similar to simulation 3 analyzed below. We still present the graphs for the simulation as it is later combined with the adaptation programs in simulation 4 and 5 and hence it is useful to isolate the productivity effects for these two simulations.

Graph 2 : Simulation 2, macro and sectoral results



Simulation 3: Negative productivity on forestry sector of 6%

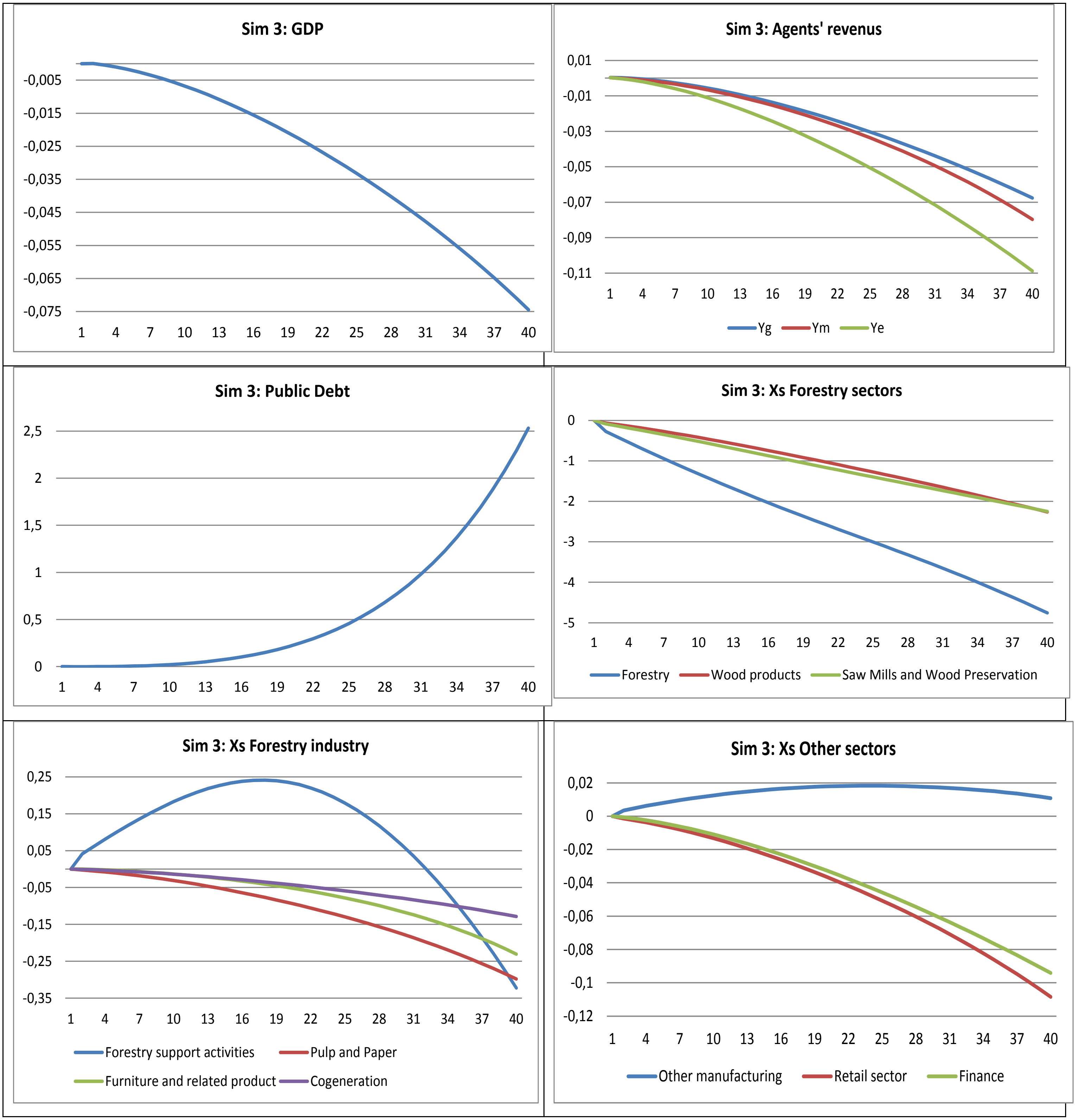
For this simulation, we considered the pessimistic scenario predicted by some experts. A 6% reduction in productivity applied to the forestry sector. As in simulation 1, the effects on macroeconomic variables are negligible but relatively large on the forest industry sectors. We observe a negative gap for the GDP compared to the BAU and this gap grows at an increasing rate to end around 0.08% below the BAU. We have a similar trend for the agents' revenues with the strongest gap (around -0.11% at the end) with the firms income (*Ye*) with and the weakest (around -0.07%) is observed for the government revenues (*Yg*).

As we observe, since the government income is below the BAU, we have a growth in public debt and this growth increases as we move along in time given the cumulative effects described above. The gap at the end of resolution is 2.5% higher compared to the original debt level (the debt level is constant throughout the resolution of the BAU).

At the sectoral level, we have a reduction of output in the forestry sector at around 4.8% at the end of the resolution which is below the reduction in productivity. This reduction in supply generates an upward pressure on prices for wood and in turn wood-intensive sectors suffer from this increase in input cost. The output for the *sawmills and wood preservation* and *wood product* sectors drops by 2.3% compared to the BAU which is a relatively large contraction in production. As opposed to the effect on GDP, we observe a much more linear effect for the forestry sectors.

The other branches of the forest industry all exhibit a reduction in output with the exception of the *forestry support* sector. The reduction in output for the three other sectors; *pulp and paper*, *cogeneration* and *furniture and related products* range from -0.13% to -0.3%. The increase in the *forestry support* sector is a response to counter the negative productivity effect and this helps attenuating the negative effects of climate change on the forest.

Graph 3 : Simulation 4, macro and sectoral results



For the other sectors in the economy, the *other manufacturing* sector seems to benefit from this negative productivity effect since its production is above the BAU for all the resolution with an increasing gap until year 20 and a decreasing gap for the last 15 years of the resolution. At its maximum, the gap for this sector is around 0.02%. For the two other sectors retained (*retail* and *finance*) in the analysis, we have a level of output below the BAU with the gap increasing in time at an increasing rate (stronger than proportional decrease). Both of these sectors have an output around 0.1% below the BAU at the end of the resolution. The trend of price increase has a negative impact on all sectors since cost of inputs are affected. However, the main element explaining this difference is the trend of the exchange rate which depreciates as time goes by and ends at 0.24% below the BAU. Since *other manufacturing* exports over 70% of its production and the two other sectors exports below 10% and 4% respectively for *finance* and *retail trade*, the depreciation is beneficial for other manufacturing and reverses the negative impact of price increases while it is not sufficient to change the trend for the two other sectors. The other factor amplifying these different effects is related to the return to capital. The three sectors benefit from an increase in return to capital but the growth is stronger for the *other manufacturing* and hence, it will benefit from a growth in investment relative to the other two sectors. This last factor explains in part the non-linearity or non-proportional trends[33].

Simulation 4: Infrastructure adaptation program and Sim 2

This scenario is a combination of simulation 2 with an adaptation program targeting investments in infrastructure. This program consists in building forestry road, bridges or other infrastructure that will facilitate access to the forest. We assume that these new infrastructure will generate positive production externalities on the *forestry* and the *forestry support* sectors both of which benefit from better access to the forest. These positive production externalities should compensate the negative productivity effects of CC. Moreover, during the construction phase, the construction sector and suppliers will benefit from additional projects.

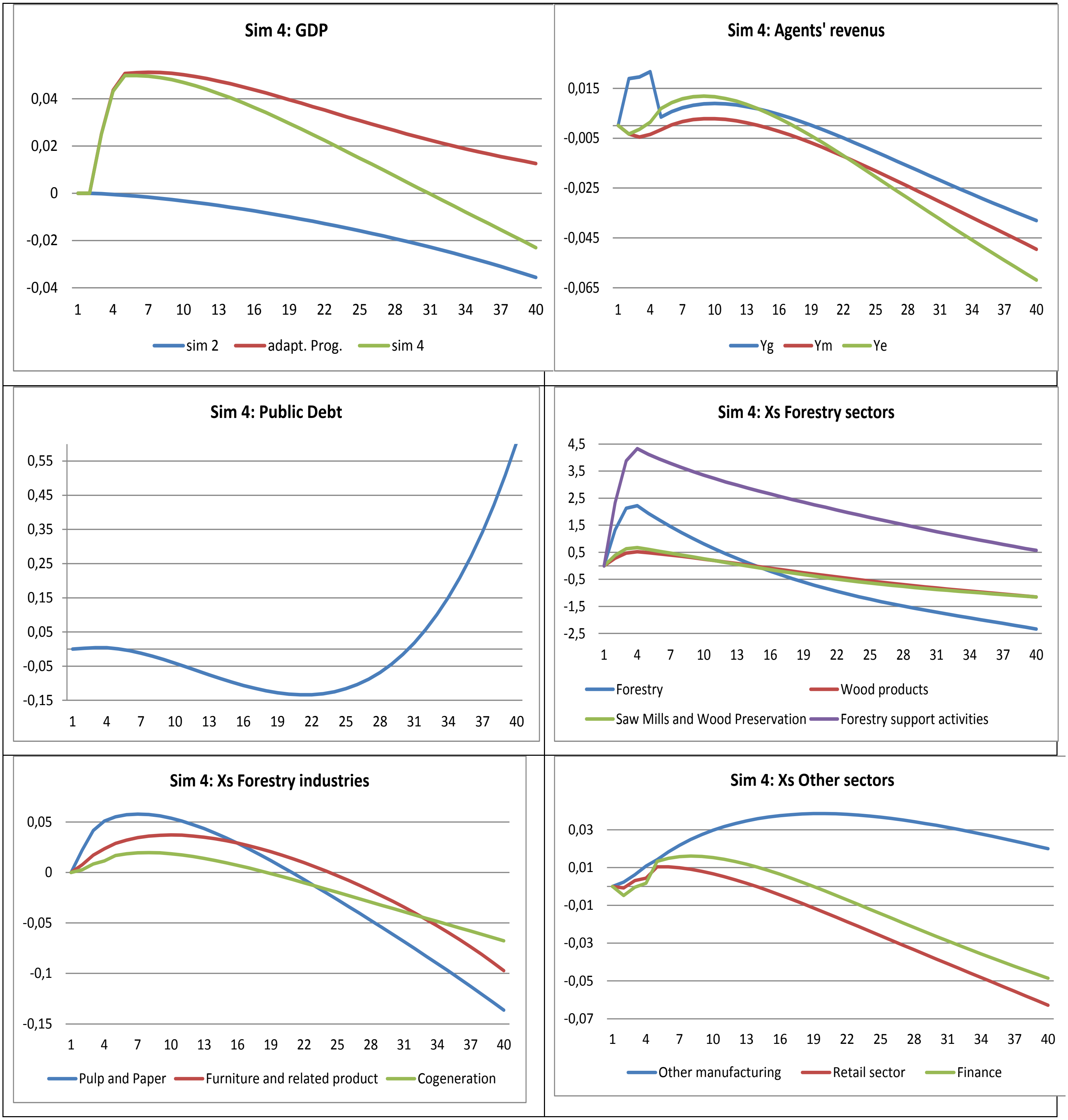
[33] Unfortunately, we cannot go in detail into the causes of these changes since too many inputs and too many prices are involved as well as numerous trade elasticities involved in foreign trade.

In Graph 4 in the panel presenting the GDP, we isolate the effects from simulation 2, the adaptation program and simulation 4 which combines both. We note that the investment program has beneficial effects on GDP but the benefits of the program start decreasing at the end of the program as the infrastructure built will depreciate in time albeit the gap remains positive to the end of the resolution. When combining CC effects with the program we have positive effects until the 30th year and the GDP falls under the BAU afterwards to the end. Given our hypothesis on the externalities of the program, we observe an attenuation of the negative impact of climate change for most of the resolution.

For the agents' income, we note an increase in government revenues (*Yg*) in the first part of the graph that is the consequence of the increase in sales tax to fund the infrastructure program but it drops after the tax is reduced to its original level. For the period where production externalities are highest (year 5 to 12), the income of all agents are higher compared to the BAU scenario but they are decreasing after the end of the program. The revenues drop below the BAU after the 14th year for the aggregate household income (*Ym*), 18th for the firms' income (*Ye*) and 20th for the government revenues.

For public debt, the additional government revenues are used to fund the adaptation program and hence the debt remains stable until the end of the program. Afterwards, we observe a decrease in the debt given the stronger GDP growth described earlier up to the 20th year. From then on, we have an increase in the debt returning towards the BAU and this gap becomes positive with respect to the BAU after the 30th year. This is linked to the reduction of the GDP growth rate and reduction in the growth rate of government revenues. After the 30th year, the debt increases rapidly given the cumulative effect described earlier but it is less than half of the observed gap of debt at the end of simulation 2 (without the adaptation program).

Graph 4 : Simulation 4, macro and sectoral results



At the sectoral level, for the forestry sectors, the opposite productivity effects produce an increase in output of 2.3% for the *forestry* sector at year 4 (its peak) and the gap starts decreasing afterward to pass below the BAU from the 15th year and beyond. Since the *forestry support* sector benefits from two sources namely the productivity externality for the new infrastructure but also an increase in demand from the *forestry* sector given its increase in production. These combined effects generate an increase of almost 4.5% in the 4th year and decreases afterwards. For this sector, the output remains above the BAU throughout the resolution given the fact that it continues to benefit for the productivity gains of the program even if this productivity decreases after the program, it remains above the BAU at the end of resolution. For the *sawmills and wood preservation* sector and the *wood product* sector, the trend is the same as for the *forestry* sector but with a much smaller amplitude.

For other sectors, for the first five years, the three sectors selected show a growth rate above the BAU and the gap is increasing. For the *retail* sector and *finance* sector, the gap starts to decline beyond this point and drops below the BAU around the 13th year for the *retail* sector and at the 19th year for the *finance* sector. The gap increases for the *other manufacturing* sector up to the 20th year and start to decline after this but it remains above the BAU for the entire resolution and ends at around 0.02% above the BAU. This sector benefits from improve investment compared to the BAU given its better return to its capital.

Simulation 5: Forestry support adaptation program and Sim 3

As for the previous simulation, this one combines an adaptation program with simulation 2 (3% reduction in forest productivity). With this program targeting the *forestry support* sector, we have a more progressive positive effect on GDP compared to the previous simulation. In fact, the improve forestry practices that result from this program take more time to generate the productivity effect as shown with the red curve in the GDP graph. The gains in productivity grow progressively to generate an increase of just over 0.04% of GDP at the end of the resolution. Hence this program is sufficient to reverse the negative effects on GDP observed for simulation 2.

Graph 5 : Simulation 5, macro and sectoral results

The GDP growth is now above the BAU throughout the resolution. We note that around the 30th year, the gap stops increasing and decreases slightly afterwards.

For the income of agents, they are also above the BAU for the duration of the program. In the first part of the resolution, the revenues jump to come back towards the BAU at the 7th year during the program. The initial jump is higher for government income since the sales tax is increased to fund the program. Afterwards, they exhibit a positive progression up to the 35th year. The growth rate of revenues decrease after this point but remain above the BAU at the end of the resolution.

Since the GDP and government revenues are above the BAU throughout the resolution, the public debt decreases compared to the BAU scenario. There is a kink in the curve at the end of the program (5th year) as part of the benefits of the program disappear and we observe the same cumulative effect as in other simulation[34]. At the end of the resolution, the debt is around 0.7% lower compared to the BAU.

The gains in productivity in the *forestry* sector directly generate an increase in output up until the end of the productivity gains at the 30th year. The gap sharply decreases afterward but remain above the BAU at the end of the resolution. The *forestry support* sector also benefits directly via a reduction in its market price with a jump in output during the program. However for this sector, output drops below the BAU after the program ends and remains below the BAU until the program stops having a productivity effect on the *forestry* sector. The demand for the services of the *forestry support* sector is stronger at that point since the losses in productivity are compensated by use of more inputs to harvest the wood in the forest by the *forestry* sector.

For the *sawmills and wood preservation* sector and the *wood product* sector we have similar effects compared to the *forestry* sector but the size of the gaps with the BAU are much smaller. For the other branches of the forest industry (*furniture and related products, pulp and paper* and *cogeneration*) we have a similar trend where the difference with the BAU only becomes visible around the 7th year and this gap increases slightly until the end of the productivity effects (30th year) and declines slightly to the end of the resolution but remain above the BAU at the end of resolution.

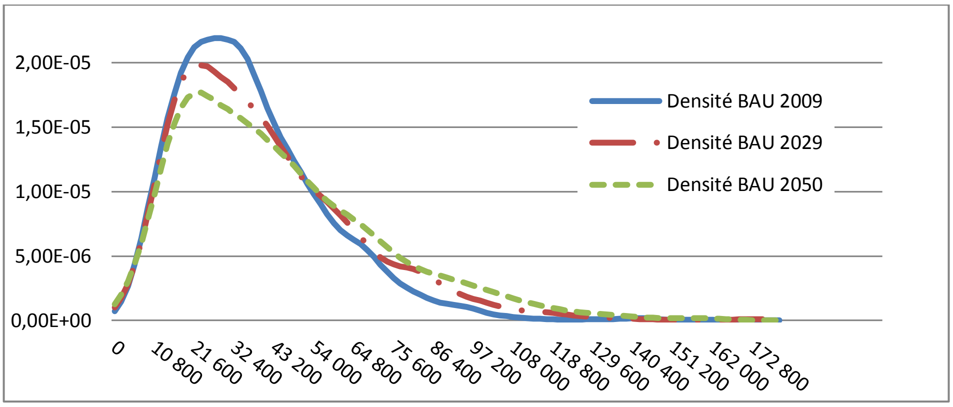
[34] The productivity gains continue to take effect but the cost of forestry support increases but to its BAU levels.

For the three other sectors selected for our analysis, we have a drop in the growth rate below the BAU up to the 7th year. Afterwards, the output increases for the *retail* and *finance* sectors and it goes above the BAU before the 10th year for both of these sectors. For the *other manufacturing* sector, the gap remains relatively constant between the 7th and 30th year and starts increasing afterwards and passes above the BAU around the 33rd year of resolution. This sector as in previous simulations seems to benefit from reduction in production of all sectors of the broad forest industry.

Distributive analysis

First, we present the evolution of income distribution with the dynamics of the microsimulation model over 40 years. Figure 1 illustrates income distributions for the reference year, and BAU in 2029 and 2050. We note a flattening of the distribution and a movement to the right as time goes by which would indicate a drop in poverty and an increase in inequality. The size of the middle class (between 50 000$ and 150 000 $) grows during this period.

Figure 1 : Distribution of income by adult equivalent (BAU - Quebec)



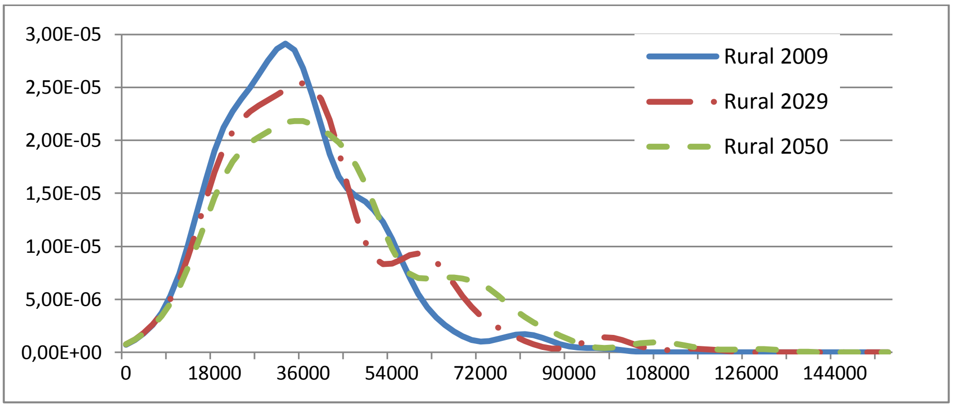
Source : EDM et calculs effectués par les auteurs.

When we decompose the population based on zone of residence[35], we observe similar evolution in the two urban areas and for households with income below 40 000$ in rural areas (Figure 2)[36].

[35] Given the data available in the Survey of Household Spending (SHS), we decompose households based on size of communities in which they reside since the impact of CC on forestry could have a different impact for these different groups. Our results will inform or confirm this assumption. Moreover, we did not have many variables on which we could decompose households such that our groups were large enough to apply our distributional analysis with significant results.

[36] Household income is normalized to have adult equivalent level throughout our analysis.

Figure 2 : Distribution of income by adult equivalent (BAU – Rural households)



Source : EDM et calculs effectués par les auteurs.

For rural households with an income higher than 40 000$, the distribution becomes bimodal with a contraction of the middle class between 2029 and 2050.

Table 3 shows that all FGT indices (head count-FGT_0, depth-FGT_1 and severity FGT_2) at the provincial level, would drop between 2009 and 2050. This result is valid for a poverty threshold of 15 000$. However, poverty increases for thresholds above 15000$[37]. As for inequality, it increases in the province (Table 3) growing from 0.307 in 2009 to 0.369 in 2050 for a 20.08% increase.

Table 3 : Poverty and Inequality – Variation of BAU (%) - Quebec and decomposition

	Variation in %	FGT_0	FGT_1	FGT_2	Gini
Quebec	2009-2029	-8,62*	-17,89*	-19,97*	+10,92*
	2029-2050	-6,51*	-12,71*	-13,78*	+8,25*
	2009-2050	-14,57*	-28,33*	-31,00*	+20,08*
100 000 and more	2009-2029	-9,09*	-17,30*	-20,16*	+11,50*
	2029-2050	-8,38*	-13,47*	-14,63*	+9,18*
	2009-2050	-16,71*	-28,44*	-31,84*	+21,73*
Less than 100 000	2009-2029	-11,14	-26,15*	-27,96*	+8,87*
	2029-2050	-1,99	-12,12*	-12,75*	+5,00*
	2009-2050	-12,91	-35,10*	-37,15*	+14,32*
Rural	2009-2029	+14,59	+7,50	+4,89	+9,53*
	2029-2050	-3,43	-7,62	-9,41	+3,89*
	2009-2050	+10,65	-0,69	-4,98	+13,80*

Source : SHS and calculation by authors. * Significant at 5%.

The same trends are observed for decomposition in both urban zones but with a non-significant decrease in poverty for small urban areas for the headcount index (Table 3). For the rural zone we have increases and decreases for poverty but none of the

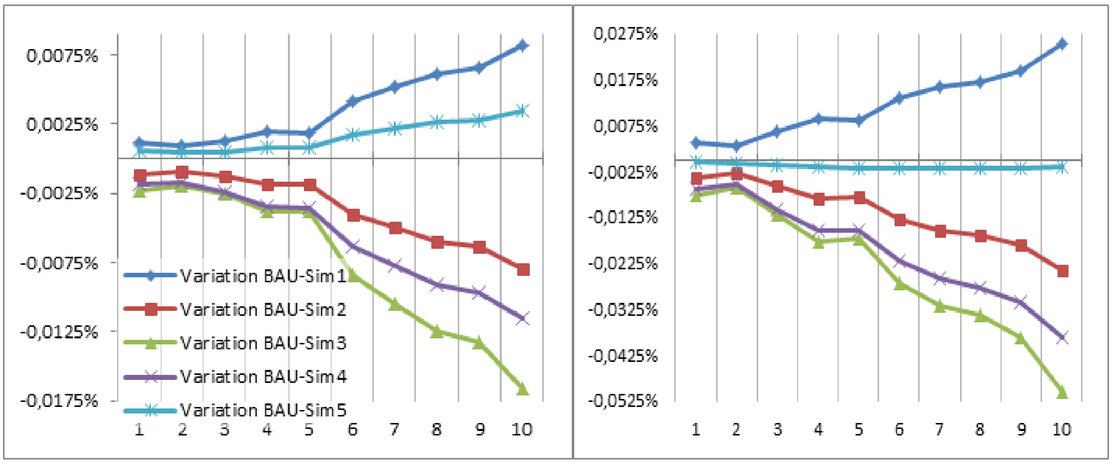
[37] This result is also valid for FGT_1 and FGT_2 curves.

changes are significant. All zones exhibit significant increases in inequality. Hence, for the BAU, we have decreases in poverty and increases in inequality. We now analyse the distributional impact in relation to these BAU results.

We first look at the impact of our simulations on the average income of each income deciles for 2029 and 2050 (Figure 3a and b)[38]. The first finding is that the impacts are relatively small for all deciles and more so for the bottom five. The effects observed in Figure 3 would tend to indicate that inequalities will decrease (increase) when the mean income decreases (increases). The productivity simulations (Sim 1, 2 and 3) produce changes in average income as anticipated where the positive (negative) productivity scenario produce increases (decreases) in average income. The stronger productivity scenario produces a stronger change in average income. The effects become larger in time as the productivity effects are gradual and cumulative.

Figure 3 : Impact on average income by deciles in 2029 (a) and 2050 (b)

(a) (b)



Source : SHS and calculation by authors.

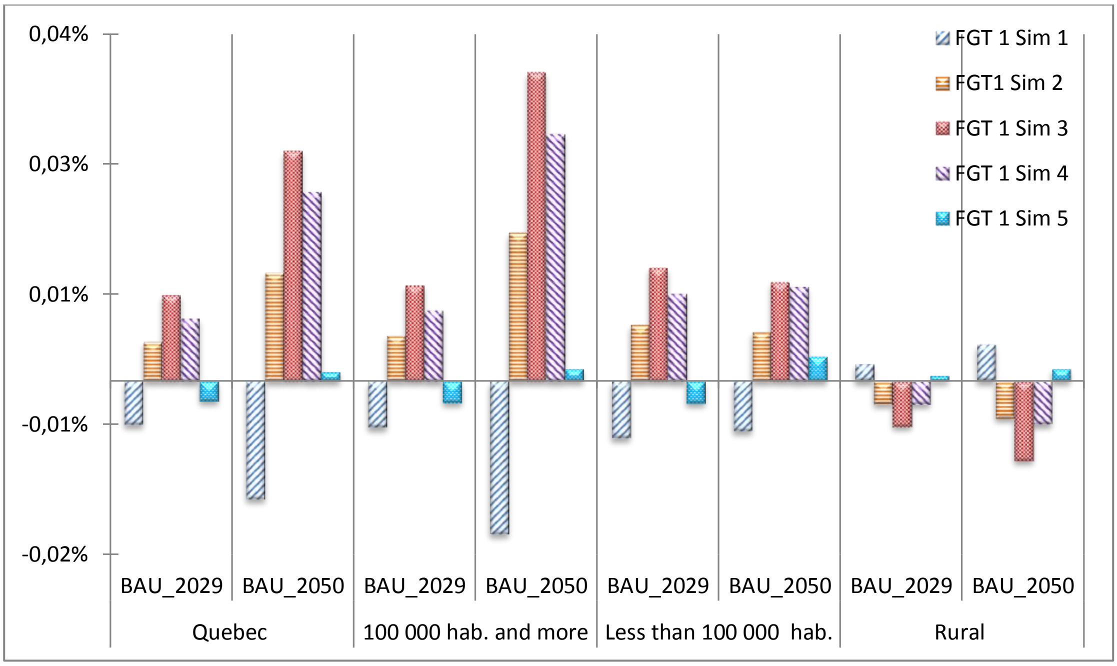
The two adaptation programs do not produce similar distributional effects. The infrastructure investment program (sim 4) induces a decrease in average income for all deciles. In 2029 (panel a of Figure 3), the income decreases for the first five deciles are close to the ones obtained for Sim 3 and seem to distance themselves in 2050 (panel b of Figure 3). For the higher deciles, we have to opposite effect where there seems to be a convergence of the average income with simulation 3 when the productivity reduction converges to 3%. This program does not seem to play its

[38] It is important to reiterate that we refer to change in income but we use the disposable income as a proxy of welfare and the changes are computed with the change in equivalent variation and hence the income after simulation capture income and price effects.

compensatory role at least in terms of income distribution. The results also reveal a relatively strong increase in market price which plays a negative role for households with an increase in cost of their consumption basket. This negative impact on households is much stronger for the households in the top five deciles.

The second program seems to play a better role in attenuating the negative effects of CC. In 2029, the program generates an increase in average income of each deciles with stronger positive effects for higher deciles. At the end of resolution, the average income by deciles is quite similar to the ones observed for the BAU. Even if this program is also funded via a sales tax increase, the distribution effects tend towards a reduction in inequality and hence compensate for the negative CC effects.

Figure 4 : Poverty depth impact (Quebec and decomposition)



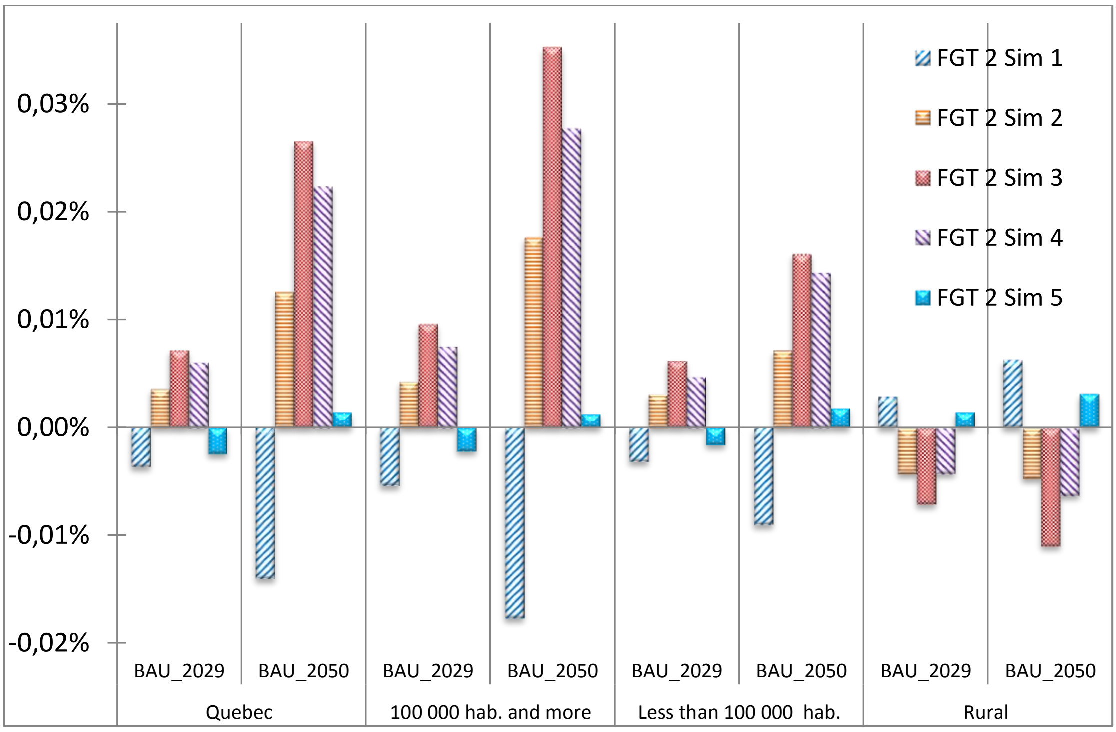
Source : SHS and calculation by authors.

Poverty and inequality impact analysis results are presented in Figures 4 to Figure 6 and in Table 6 in the appendix. The first element that we highlight is the fact that poverty headcount index is unchanged for the province and for the three zones (urban over 100 000 hab., urban under 100 000 hab. and rural zones)[39]. The effects on the other indices are small but in most cases the changes are significant with the exception of small urban areas (less than 100000hab) and the rural zone. As expected, the increase in productivity (Sim 1) reduces poverty depth in the province.

[39] It is important to highlight that for the time trend (BAU) analysis we had a reduction in the three poverty indices.

Hence, we observe a decrease in FGT_1 of 0.005% in 2029 and 0.014% in 2050 versus the BAU (Figure 4). The size of the effects is similar for severity (FGT_2 in Figure 5). Larger urban areas seem to benefit most while the situation is practically unchanged for rural households. The decrease in productivity (Sim 2 and Sim 3) produces an increase in severity and depth of poverty with stronger impact in larger urban centers. Sim 3 produces larger changes in poverty indices with an increase in poverty depth of 0.039% at the end of resolution compared to an increase of 0.017% for simulation 2. The negative effects on poverty depth and severity are weak but always statistically significant for the province for these two simulations (2 and 3) with variations ranging from 0.013% to 0.027% at the end of resolution. Once again, the results are non-significant for these two simulations in the rural area.

Figure 5 : Severity of poverty impact (Quebec and decomposition)

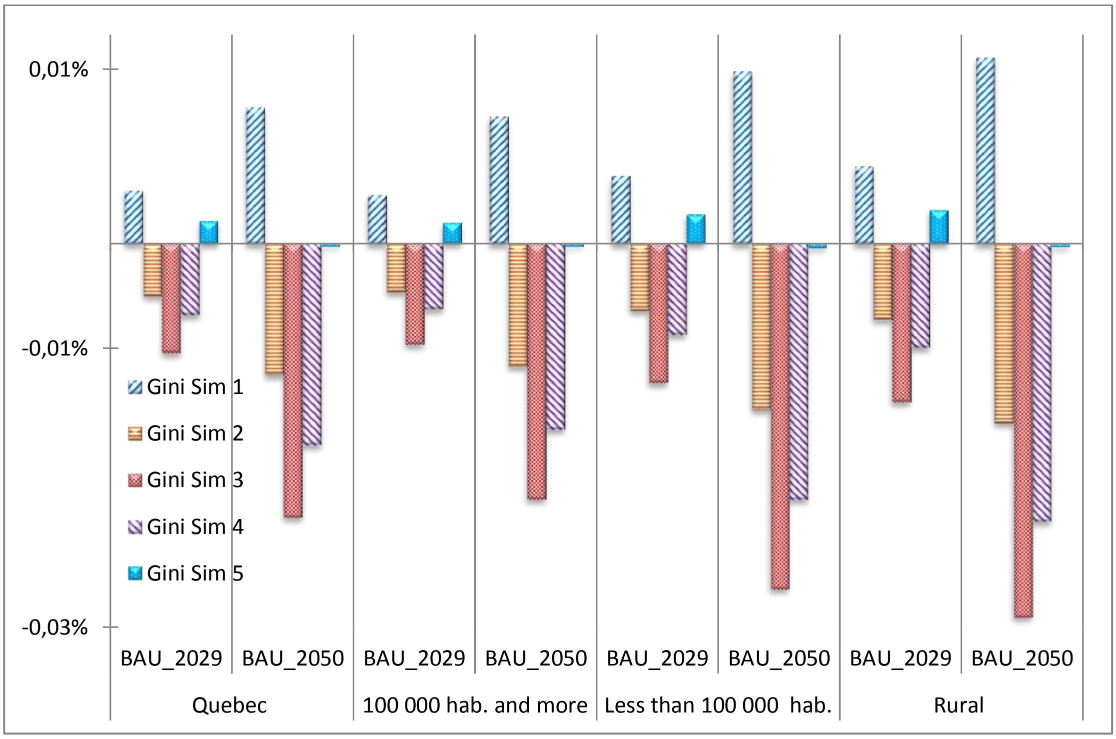


Source : SHS and calculation by authors.

It is interesting to note that when the government invests in an infrastructure program (Sim 4), the negative effects of the drop in productivity are amplified. The price effect referred to earlier is at the origin of this result. This increase in price seems to have a negative impact on households throughout the income distribution (see Figure 4). The only group of households isolated from this negative effect is the rural household group. The second adaptation program (Sim 5) as mentioned earlier plays its compensatory role by bringing the poverty depth and severity indices back to its BAU level. The subsidy to the *forestry support* sector generates a reduction in production cost and pushes market prices downwards to provide welfare gains at the origin of these reductions in poverty indices.

As for the inequality changes following these simulations, they are weak for the province and the three zones considered. As expected, an increase in average income for higher deciles (Figure 3) following the productivity gain (Sim 1) produces an increase in inequality compared to the BAU for all groups. Inequality continues to grow in time to the end of the resolution.

Figure 6 : Inequality changes (Quebec and decomposition)



Source : SHS and calculation by authors.

The opposite is observed for the negative productivity impact with a stronger contraction of average income for higher deciles (Sim 2 and Sim 3). Simulation 4 produces similar results compared to simulation 3. The adaptation program consisting of subsidizing the forestry support sector (Sim 5) is the one producing the weakest impact on inequality in comparison to the BAU. In this respect, this policy plays its compensatory role.

In conclusion of this distributional analysis we can state that even if the distributional impacts are relatively small, most are statistically significant with the exception of the ones concerning the rural household group. No simulation produces any effect on the poverty headcount ratio (FGT_0) but changes for the depth (FGT_1) and severity (FGT_2) are almost all significant as well as changes in the Gini index for inequality. The negative productivity impact of CC increase poverty and decrease inequalities compared to the BAU. The increase in productivity produces reversed effects on poverty and inequality. Of the two adaptation program, only the second one (Sim 5) seems to play its compensatory role at least for the distributional analysis.

Conclusions

Our analysis included two objectives with the first being the economic and distributive impact analysis of CC on the forest industry in Quebec. The second objective was to perform the economic and distributive analysis for two adaptation programs aimed to attenuate the negative impact of CC. To achieve these objectives we apply a recursive dynamic CGE model jointly with a micro-simulation model with dynamic components. We also make use of different indices (FGT and Gini) for the distributional analysis. We also needed to construct a new SAM detailing the forest industry. Our model includes numerous hypotheses to capture stylized facts observed in the forest industry in Quebec. We run our models over a 40 year/period time span to integrate CC impact as external choc to the model.

We ran five scenarios to capture CC impact and two adaptation programs and applied our distributive analysis indices. The main findings of our analysis are that the impacts on macroeconomic variables are relatively weak where the largest impact on GDP is less than 0.1% (which represents a loss of 300 million dollars) even if the forest industry is relatively important in the province. However, the effects of CC on the forest industry can be quite large in the short or long run (near 5% impact). The weak effect can be explained by the fact that the model allows for economic agents to adapt in time and factors reallocation across sectors. These kinds of results are not possible in more rigid analytical framework such as input-output analysis or partial equilibrium framework.

As for the distributional impacts, they are relatively small but most are statistically significant with the exception of the ones concerning the rural household group. All simulations produce significant results in terms of poverty severity and depth changes as well as inequality changes. As expected, negative (positive) CC impact increase (decrease) poverty and decrease (increase) inequalities. It is also interesting to highlight that the two adaptation programs produce different distributional impact.

It is important to highlight some caveats to our results. First, one must keep in mind that we include only the CC impact on the forestry sector and combining the CC impact on agriculture and health among others would produce larger effects on macroeconomic variables. We intend to extend our model to include a detailed agriculture sector to address this issue. As for our micro-simulation model, we did not use an estimated labor supply which would have enriched our distributional analysis as shown in Bourguignon and Savard (2008) but this would have been difficult to integrate into our model since the household surveys do not provide complete and simultaneous information on labor supply and consumption in Canada. We have a labor supply micro-simulation model but the task to link the two databases is quite substantive. This is one of our future research agenda to improve our modeling framework. Finally, another weakness in our analysis is that we made assumptions on the link between our second adaptation program and the productivity gains in the forestry sector since no information is available for this link. Obtaining rigorous estimation of the relative importance of this link would be very costly and difficult to implement given the lack of data on this issue. We will investigate further the feasibility of extending our research agenda in this direction. This said, our analysis provides very rich information on the links between CC and CC adaptation programs and macroeconomic, sectoral variables and income distribution. These types of applications should be useful for policy makers in the area of CC.

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Table 4 : Impact of simulations on welfare – Quebec and regional decomposition– Variation in % versus BAU

		Québec		100 000 et +		- de 100 000		Rural	
		Sim-BAU_2029	Sim-BAU_2050	Sim-BAU_2029	Sim-BAU_2050	Sim-BAU_2029	Sim-BAU_2050	Sim-BAU_2029	Sim-BAU_2050
FGT0	Sim 1	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
	Sim 2	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
	Sim 3	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
	Sim 4	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
	Sim 5	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
FGT1	Sim 1	*-0,005%*	*-0,014%*	*-0,005%*	*-0,018%*	*-0,007%*	*-0,006%*	0,002%	0,004%
	Sim 2	*0,005%*	*0,013%*	*0,005%*	*0,017%*	0,007%	0,006%	-0,003%	-0,004%
	Sim 3	*0,010%*	*0,027%*	*0,011%*	*0,036%*	*0,013%*	0,011%	-0,005%	-0,009%
	Sim 4	*0,007%*	*0,022%*	*0,008%*	*0,028%*	*0,010%*	*0,011%*	-0,003%	-0,005%
	Sim 5	*-0,002%*	*0,001%*	*-0,002%*	*0,001%*	*-0,003%*	*0,003%*	0,001%	*0,001%*
FGT2	Sim 1	*-0,004%*	*-0,014%*	*-0,005%*	*-0,018%*	-0,003%	*-0,009%*	0,003%	*0,006%*
	Sim 2	*0,004%*	*0,013%*	*0,004%*	*0,018%*	0,003%	0,007%	*-0,004%*	-0,005%
	Sim 3	*0,007%*	*0,027%*	*0,010%*	*0,035%*	*0,006%*	0,016%	-0,007%	-0,011%
	Sim 4	*0,006%*	*0,022%*	*0,008%*	*0,028%*	0,005%	0,014%	-0,004%	-0,006%
	Sim 5	*-0,002%*	*0,001%*	*-0,002%*	*0,001%*	-0,002%	*0,002%*	0,001%	0,003%
Gini	Sim 1	*0,004%*	*0,010%*	*0,004%*	*0,009%*	*0,005%*	*0,012%*	*0,006%*	*0,013%*
	Sim 2	*-0,004%*	*-0,009%*	*-0,003%*	*-0,009%*	*-0,005%*	*-0,012%*	*-0,005%*	*-0,013%*
	Sim 3	*-0,008%*	*-0,020%*	*-0,007%*	*-0,018%*	*-0,010%*	*-0,025%*	*-0,011%*	*-0,027%*
	Sim 4	*-0,005%*	*-0,014%*	*-0,005%*	*-0,013%*	*-0,007%*	*-0,018%*	*-0,007%*	*-0,020%*
	Sim 5	*0,002%*	0,000%	*0,002%*	0,000%	*0,002%*	0,000%	*0,002%*	0,000%