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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. Climate change will have an impact on the forest through *inter alia* increased droughts, forest fires, warmer weather and infestations. In this paper, we analyze the economic impact of CC on the forest industry in Quebec. We perform an economic impact analysis over a 40 year time span with a recursive dynamic CGE model. We find that the climate change effects will be relatively weak on macroeconomic variables as the agents adjust over time and factors move to other sectors but the sectoral effects on the forest industry are relatively important.

Keywords: Dynamic computable general equilibrium model, forestry, climate change, Quebec.

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

Introduction

Forests are ubiquitous in Quebec and play a major economic, environmental and social role. They represent an important economic engine for many regions of the province. According to the Government of Quebec MRNF 2012 report, one job out of six is linked

[1] We would like to thank Ouranos and the Department of Natural Resouces of Quebec (DNRQ) for financial support and Anne Blondlot and Claude Desjarlais from Ouranos and Vincent Auclair from DNRQ for their precious comments. Standard caveats apply.

to the broad forest industry and it creates 1.6 indirect jobs for every direct job in the rest of the economy. In 2012, 392 primary wood processing plants were located in the province[2] (GOQ-MRNF, 2012). The forestry sector generated 60 900 direct jobs when including this first level transformation with the logging and timber sector (GOQ-MRN, 2013). Moreover, the forest plays an important ecological role as a carbon sink (GOQ-MRNF, 2008). As shown in Table 1 below, the broad forest industry accounted for a fifth of total value of exports for the province in 1994 and has been declining 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 forest exports account for only 6.6% for the rest of the country (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/).

According to Marbek and Lantz (2010), climate changes (CC) are likely to have an important impact on the forest and the forestry industry in Canada and Quebec. The effects will modify the amplitude and length of seasons and therefore the winters are likely to be warmer and shorter with a reduction in snow cover (Ouranos, 2010). 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

[2] This primary wood processing 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)

considered to be linked to CC (Johnston *et al.*, 2010). The CC effects on the forest productivity will have an impact on the profitability of this industry as well as investment and employment. Given the interdependence of the broad forest industry with the rest of the economy, the CC effects on forests could have an impact on the performance of other sectors and the economy as a whole.

The main objective of this study is to analyze the economic impact of CC on the forest industry in Quebec and on its economy. To achieve this objective we build a recursive dynamic CGE model including specificities of Quebec's forestry industry to analyze the direct and indirect effects of CC. We solve the model over a forty year time span to capture the different effects of CC. To apply this model, we need to construct a social accounting matrix (SAM) detailing the forest industry of the province. The details of the SAM are found in Boccanfuso et al. (2014a).

We simulate five scenarios to examine the potential effects of CC on the forest industry. Two simulations consist in a change in forest productivity, the third represents a temporary increase in domestic supply of wood, the fourth is a reduction in world price of goods produced by the forest industry due to an increase in world supply and the last simulation is a reduction in demand for Quebec's exports from the forest industry.

Our main finding is that the general impact of CC on the forestry industry are relatively small but could represent up to a 300 million$ loss in GDP over a 40 years span. The forest industry suffers the most since it is directly affected by these changes in productivity. The rest of the economy compensates part of the losses due to a reallocation of factors across other sectors. Losses could sum up to 3 to 7.5% for the *forestry*, *wood products* and *sawmills and wood preservation* sectors and up to 0.2 to 0.5% for other sectors of the forest industry.

Our results are in sharp contrast with other findings even though we use the same time frame as in these other studies. Marbek and Lantz (2010) argue that the impact of CC will be a loss of between 300 million$ and 2 100 million$ in GDP for Quebec while Ochuodho *et al*. (2012) find that the CC will generate a gain of 7 billion$ in GDP in 2050 for Quebec. On the other hand, our results are in line with Rive *et al*. (2005). The discrepancy with the two first set of authors is due to our general equilibrium modeling that allows for more flexibility within the economy and factors reallocation in response to a contraction of the forest industry. In our model, the manufacturing sector seems to be the main beneficiary when the forest industry contracts.

The rest of the paper is organized as follows. We first present a literature review. Next, we present the methodology and the model. We then present the five scenarios for our simulations. The results are presented in the penultimate section and the last section concludes.

Literature review

A CGE model is an analytical tool that allows one to integrate various economic agents and production sectors which interact on various markets. They include macroeconomic and sectoral variables and hence, can produce relatively broad economic impact analysis. Detailed and specific behavior can be included to capture specificities for consumers or producers. 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 government. Then others have drawn from the macro dynamic literature to propose forward looking dynamic CGE models with rational expectations and finally overlapping generations (OLG) CGE models. These OLG models are mainly used for inter-generational issues such as 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., 2014a). The most widely used CGE modeling approach to analyze the economic impact of climate change is the recursive dynamic approach. For example, Bosello et al. (2007) focus on the impact of the increase in the level of oceans; Bosello et al. (2006), on the impact of CC on health; Berrittella et al. (2006), on the impact of CC on tourism; and Roson and van der Mensbrugghe, (2010), on the impact of CC on growth. These models can be applied and solved for the long run and they allow for integration of detailed behavior. Given our need to adapt the model to the specificities of the forest industry in the province, this approach is best suited to achieve our research objective. Moreover, as we

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

perform a distributional impact analysis, this approach allows for relatively straightforward links to a microsimulation model.

Among CGE applications to perform CC impact analysis on the forest industry, Rive et al. (2005) use a global recursive dynamic CGE model applied to the GTAP database 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 for the province of Quebec. Ochuodho and Lantz (2014) improve on their previous model to include agriculture and find stronger effects on the economy.

Marbek and 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. They draw their CC impact from Lemprière et al. (2008) and use it as an input in their recursive dynamic multi-region CGE model to capture the economic impact. They find relatively strong negative economic impact on the Quebec economy with a range of -0.08% to +0.23% of GDP over 40 years and -0.12% to +0.33% for the Canadian economy.

One of the weaknesses of their 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, timber exports are only allowed for wood cut from private properties. Crown land timber must go through a first transformation in the province before being exported. 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 the capacity of adaptation and can overestimate the 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. The other specificities of our model are specified in the following sections.

Methodology

Let us recall that our methodology is a recursive dynamic CGE model. We run this model over a 40 year timeframe. First, we present our accounting framework used for our model before moving to the presentation of our model. The social accounting matrix (SAM) used draws from the one used in Boccanfuso et al. (2014a). Their SAM is built based on 2006 data which 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 disaggregate 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].

The microsimulation model database was constructed using the Survey of Household Spending of 2009 (SHS) produced by Statistics Canada. This database includes detailed information on household expenditures and hence facilitates the process of synchronizing the micro household data with the SAM. We had 1,277 households at the provincial level for Quebec in the SHS.

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[4] This is the most disaggregated level publicly available for Canadian provinces The Quebec input-output table at the S level for 2006 was used as a starting point to construct the SAM.

[5] Our SAM was validated by forestry economist from the private sector, Ouranos economists as well as the group of forestry economist of the MRN of Quebec.

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[6]. We present the main hypothesis of the model with a focus on the specificities of the forest industry. The model includes 30 production sectors. It also incorporates four agents, namely an aggregate household, one aggregate private firm, the government and the rest of the world. Production for most sectors is determined through a 3-tier system[7]: 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 assume that capital is not mobile between sectors within a period[8]. Intermediate consumptions are determined by a fixed share (Leontief) assumption. 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 Ballard et al. (1985), we assume an endogenous labour supply in our model. The total labor supply is a function of real wage where an increase (decrease) pushes the labor supply higher (lower) relative to the reference period. This assumption allows us to take into account the presence of unemployment (Decaluwé et al., 2010). Representative households acquire their income from wages, interests[9], dividends and net transfers from the government and from abroad. As for expenditures, households pay taxes, save a fixed proportion of their disposable income, and spend the rest of this income on goods and services. *Firms* receive the largest share of returns to capital paid by production branches, after accounting for the depreciation of capital. Firms then pay taxes on their revenues, and

[6] This model was used to analyze the impact of public infrastructure investment in Boccanfuso et al (2014a). Their model is a dynamic CGE model with 24 sectors solve over 10 year period. In the presentation that follows, sections where assumptions are the same are taken in part from this paper.
[7] A detailed presentation of the forestry sector is done below as we formulated different assumptions for this sector.
[8] 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.
[9] Households hold private assets as well as government bonds and both generate income for households.

dividends and interests to other agents. Governments obtain their revenues from income tax and indirect taxes.

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 province of Quebec 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.[10]

Finally, private investment is endogenous and determined by the level of savings generated by households and firms[11]. The savings of households is a fixed portion of its disposable income. For firms, savings is the residual after payment of taxes and dividends to other agents. 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.

Forest industry

As stated above, we needed to adapt our model to capture specificities of the forest industry and more specifically the *forestry* sector. As we attempt to capture the impact of CC on forestry, we need to adapt our model to capture as best as possible the mechanisms at play in this broad sector. Two of the main features integrated in our model are the limited stock of wood available for harvest each year and the variable cost of production in the forestry sector. To capture these two characteristics simultaneously we use a Weibull function in the production process of the *forestry* sector. The Weibull function has two interesting features. First, the functions levels off asymptotically, capturing a cap on production. Second, its *S* shape allows capturing the variable returns in the production process in the two phases of production. In the first stage, returns increase (due to decreasing costs) when wood is easily accessible but in the second phase, after the inflexion point, as wood is

[10] The complete set of equations and variables can be provided upon request.
[11] The exogenous current account balance also contributes to the private savings.

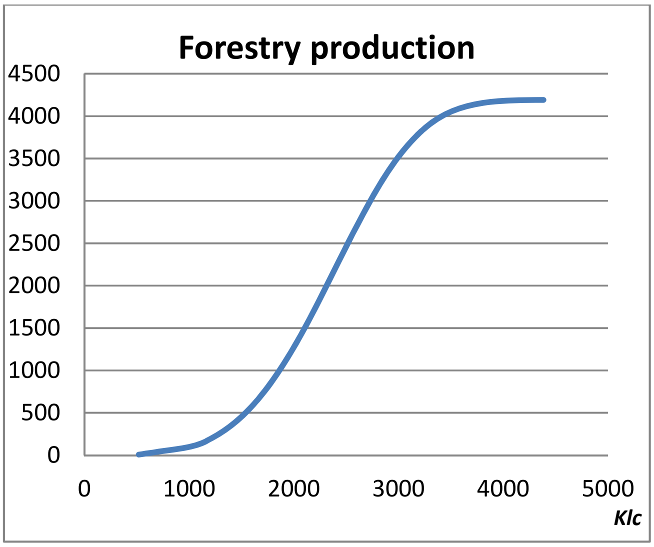
harvested in more difficult terrain or in the north, cost are increasing and the production function exhibits diminishing returns as production increases. This function is represented by the following relation:

$$XS_{fores} = \psi\left(1 - e^{-\left(\frac{Kls}{\phi}\right)^{\delta}}\right) \quad \textbf{(1)}$$

where ψ represents the asymptote or the maximum amount of wood available for harvesting at a given period, *Kls* is the composite production factor including labor (*Ld*) and capital (*Kd*). These two factors are linked through a Cobb-Douglas function coupled with intermediated consumption (*CI*) with a fixed share (Leontieff assumption). Finally, the parameter δ represents the technological capacity or height of the inflection point and ϕ the shape of the function. This function was calibrated to represent the main characteristics of the forestry sector[12]. As mentioned, this function also allows us to integrate the maximum amount of resource available for harvest at a point in time (one period of resolution in the model). This level is the annual volume of wood authorized for harvesting on forestry land that will allow maintaining its production capacity in the future (Government of Quebec-MRN 2012). The maximum level is represented by the ψ parameter and it is calibrated such that is represents the maximum amount of resource available namely 47.2 Mm^3 for the reference period (Government of Quebec MNRF, 2008).

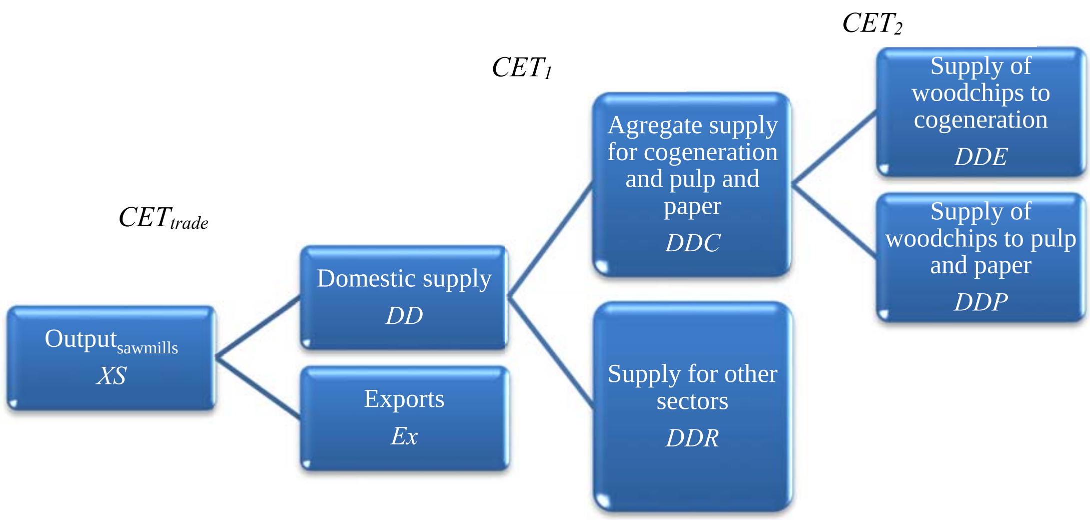
[12] This function was calibrated in consultation with the forest economist of the MRN of the government of Quebec. In the dynamics of the model, the ψ was calibrated based on estimates of the MRN.

Figure 1: Forestry production function



Another characteristic of the forest industry in the province is the possibility of selling wood chips produced by *sawmills and wood preservation* sector to different buyers and the destination will depend on the market price in the different destinations. First, wood chips are used intensively in the *pulp and paper* sector as an input in the production process but they are also used to produce electricity in the *cogeneration* sector. Finally, they are also used in smaller portions in other sectors of the broad forest industry. When the relative price changes between destinations, producers adjust their supply to increase sales in the sector offering the highest price. Hence, we introduced a multilayered CET functions to model the supply of wood chips. At the first layer, we have the output that is split between the domestic market (*DD*) and the export market (*Ex*) as is done in a standard fashion. At the second level, the wood chips destined for the domestic market are allocated to an aggregate pulp and paper and cogeneration sector (*DDC*) and to other domestic markets (*DDR*). Finally, at the last level, the *DDC* wood chips are allocated to the *pulp and paper* (*DDP*) sector and to the *cogeneration* (*DDE*) sector. With this CET function the *sawmills and wood preservation* sector can modify its share for the two destinations at all levels but cannot sell all its production in only one destination given the numerous constraints present in the industry captured by the CET functions. Figure 2 presents the complete structure of the supply of *sawmills and wood preservation* sector. We use a relatively high elasticity at the last level given the sensitivity of the industry to variations in prices[13].

Figure 2: Allocation of supply of wood chips



Dynamics of the model

Using a recursive dynamic model implies modeling growth. Three mechanisms contribute to growth: first, the accumulation of capital; second, the population/labor force growth rate and finally technological progress or innovation. We include these elements in the model. While the growth rate of capital is endogenous we assume that the two other elements are exogenous. We also need to include the evolution of the debt (asset) of agents.

The endogenous growth of capital is determined mainly by the level of savings generated in the economy. We follow Boccanfuso et al. (2014a) for this mechanism. As the total private savings is equal to total investment (*It*), this variable plays a key role in the dynamics of the model. Since part of the total investment is associated with variations in

[13] The information for these hypotheses was obtained in a consultation process with an advisory committee to a project where representative of the industry and forestry economist were present.

inventories (stocks), only a share (μ) of total investment will be converted in physical capital used in the next period. Moreover, since it is the physical capital that is important for production, we need to convert the investment value (*It*) into a volume to determine the total physical investment in volume (*Itvol*) and it is obtained from the following equation:

$$\textbf{(2)} \qquad Itvol = \left(\frac{\mu It}{Pk}\right)$$

where *Pk* is the price of investment. This price is a weighted sum of the market price (Pq_i) of investment demand (Inv_i) by origin (type of good used in the investment process). This is represented by equation 3 below:

$$\textbf{(3)} \qquad Pk = \sum_i \delta_i^{inv} Pq_i Inv_i$$

where δ_i^{inv} is the share of good *i* in the total investment.

This total investment will be allocated to different sectors of the economy and the destination is a function of the rate of capital return ($r_{i,t}$) over its user cost (U_t) with a sector specific elasticity (ξ_i) and the initial share of investment at the reference period (π_i) as shown in the following equation:

$$\textbf{(4)} \qquad Ind_{i,t} = \pi_i \left(\frac{r_{i,t}}{U_t}\right)^{\xi_t} Kd_{i,t-1}$$

The unit cost of capital (U_t) is dependent of the price of investment ($Pinv_t$), the depreciation of capital and the interest rate given the following function:

$$\textbf{(5)} \qquad U_t = Pinv_t(ir + \delta)$$

The level of investment demand at period *t* is used in the dynamics of the model by means of the accumulation of capital equation to establish the capital stock at period *t+1* as specified in a standard fashion in the following equation:

$$\textbf{(6)} \qquad Kd_{i,t+1} = (1-\delta)Kd_{i,t} + Ind_{i,t}$$

where $Kd_{i,t+1}$ is the capital stock of period $t+1$ obtained by the sum of the depreciated capital stock of the preceding period $(1-\delta)Kd_t$ and the new investment in the sector ($Ind_{i,t}$). Other adjustment mechanisms are also taken into account in the dynamic component of the model. Labor force growth (Ls_{t+1}) is introduced in a standard fashion using population growth rate (n)[14]:

$$\textbf{(7)}\ Ls_{t+1} = (1+n)Ls_t$$

For the public debt ($Pdebt_t$), we assume that it grows based on the level of government savings (Sg_{t+1}) as shown in the following equation:

$$\textbf{(8)}\ Pdebt_{t+1} = Pdebt_t - Sg_{t+1}$$

The government pays interest to holders of the debt[15]. The holders of the debt are households, firms and the rest of the world. The share of debt remains exogenous in the model but the debt asset of each agent evolves as the debt level changes. For illustrative purpose, let us take the example of firms. We have the following equation determining the evolution of its asset:

$$\textbf{(9)}\ Asset_{t+1}^{Firms} = \gamma^F Pdebt_{t+1}$$

where γ^F is the firms' share of public debt. Given this formulation, when debt increases, payments on debt reduces government savings further and this pushes the debt higher. We will refer to this mechanism as the cumulative effect of debt movement.

In a standard fashion, we use technological progress to calibrate our GDP growth rate for our business as usual at 2%. Other exogenous variables such as government transfers to households, current account balance and other are increased by the population growth rate from one period to the other. Government expenditure grows at 2.3% representing the observed growth rate in the five years prior to the reference period. The government debt

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[14] The population growth rate used is the average of yearly rates published by the *Institut de la Statistique du Québec* for the working age population (15 to 65 years old) for the 2001-2011 period. The value is 0.67%. We rounded at 0.7% for use in the calibration of the model.

[15] 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 estimate on their part since they don't have the exact information on who hold Quebec government bonds. We calibrate the interest rate at 4.6% representing the average cost of debt for the government of Quebec in 2006.

is maintained constant in the business as usual scenario[16]. During our simulations, it evolves according to the evolution of public savings.

Presentation of simulations

Two types of simulations are performed in the model. In the first group, we apply three simulations representing direct effects of climate change on forestry sector in the province. In the second group, we designed scenarios that represent indirect effects of climate change for the forestry industry in Quebec. In this group, we have changes in forest industry markets that could be the result of CC impact in economies outside of the province.

One of the possible direct effect of CC on the forest in Quebec is a change in productivy of the forest. Indeed, according to Williamson et al. (2009), the temperature and concentration of CO_2 are two key factors determining the growth of trees. Moreover, CC can affect the frequency of events such as droughts, forest fires and floods that are also factors affecting forest productivity (Yamasaki et al., 2012). There can also be natural disruption such as pest infestation, arrival of invading species and warm spells in the winter.

For the first two simulations, we apply changes in productivity of the forest. The simulations will allow capturing the potential positive and negative productivity effects of CC on the forests of the province. The first simulation is a slight increase in productivity applied in a progressive manner such that productivity grows constantly every period to reach 3% above the original level of the BAU at the end of resolution (40 years). The second simulation is a 10% progressive and proportional decrease in productivity over the 40 year time span of our resolution. The scenarios are based on optimistic and pessimistic scenarios presented in Yamasaki et al. (2012) and Marbek and Lantz (2010). This represents an annual cumulative decrease of 0.238% to end at 10% below the BAU productivity at the 40th period.

This simulation (Sim 3) aims to replicate a pest infestation for the province forest industry such as the one experienced in British Columbia and more recently in New Jersey where

[16] This is done by calibrating the public expenditure variables in time. We start with the level of growth of public expenditure as 2.4% with represents the average growth rate of public expenditure in Quebec for the 2 years prior to our reference period of 2006.

the industry needs to harvest the wood quickly before it roots on stump[17]. Concretely, it consists in applying an increase of 20% of supply of logged timber for a period of 3 years, such that we have a yearly increase of 6.27% per year. After this 3 year period, the stock of wood available is lower compared to the BAU up to the end of the resolution of the model.

The fourth simulation is similar to the previous but the pest infestation such as the mountain pine beetle would occur outside of the province and hence the simulation captures an indirect effect of CC on the forest industry in Quebec. In this case, the forest is logged intensively to prevent the loss of the stock outside the province and this produces a strong increase in supply on the world market and in turn pushes world price of wood downwards Hence we apply a 20% reduction in the world price of wood over a 15 year time span. We apply this reduction in price on the world price of imports and also exports. We also apply a reduction in price of other goods of the broader forestry industry. The size of the reduction in price is a function of the proportion of wood entering in the production process of the given good. For example, if wood represent 20% of the cost structure on a given good; its world price will be decreased by 4%.

For the fifth simulation, we use a different mechanism to capture an increase in supply of wood coming from competing economies and this goes through a reduction of the elasticity of world demand for the broad forestry industry products exported by the province. This reduction in elasticity is applied for a period of 5 years[18].

Table 1: Summary of simulations

Code	Summary of simulations
Sim 1	Increase in forest productivity of 3%
Sim 2	Decrease in forest productivity of 10%
Sim 3	Temporary increase in wood supply of 20% over 5 years
Sim 4	Reduction of 20% of world price of wood over 15 years
Sim 5	Reduction in world demand for the province's wood over 5 years

[17] See New York Times front page article for more information on this issue: http://www.nytimes.com/2013/12/02/science/earth/in-new-jersey-pines-trouble-arrives-on-six-legs.html?hp&_r=1&.

[18] The simulations were designed with the assistance of a steering committee including forest economist from the MRN of the province of Quebec, forest industry representative and the economist of Ouranos.

Results and analysis

We start our analysis with the presentation of macroeconomic results followed by a few selected sectoral results. These results are presented as gaps in percentage with the BAU scenario for which we simulated a GDP growth rate of 2%. Hence, we present the results in graphs over the 40 period time span for the variables selected. [19]. The first element to highlight before starting the analysis is that the simulations produce relatively weak impact on the macroeconomic variables. This is not surprising since the changes in productivity are below 0.25% per year and the forestry sector represents less than 0.5% of GDP while the broad forest industry accounts for around 5% of GDP. However, the results presented give an indication of the direction of the effects and the model provides a tool to measure the links with the rest of the economy by capturing the general equilibrium effects of the CC on forestry in the province. For these sectoral results, we focus on the 7 branches in the broad forest industry. We also present results for three other branches that contribute to a large share (36%) of value to the GDP. These branches are the *other manufacturing*, *finance* and *retail trade*. The sectoral variables analyzed are the output or production by sectors (Xs_i), the market price (Pq_i) and exports (Ex_i).

Simulation 1: Positive productivity shock on forestry of 3%

The first simulation (Sim 1) produces positive effects for most variables in the model. GDP grows 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. This government income growth above the BAU allows for a reduction of the public debt of close to 1.5% by the end of the resolution. As we have a cumulative effect of debt reduction (less debt makes for less interest payment, which increases government income and frees funds to reimburse more debt, etc.) which provides for a rapid decrease in the debt in the latter part of the resolution.

[19] Given the large volume of results produced by the model with 30 branches, 4 agents solved over 40 periods/years, we cannot present detailed results.

At the sectoral level, we note a strong increase in output of the forestry sector as it is directly affected by the productivity gains. This increase in output produces a reduction in market price and generates gains for sectors using intensively wood in their production process. 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 produce more with the same amount of inputs 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.

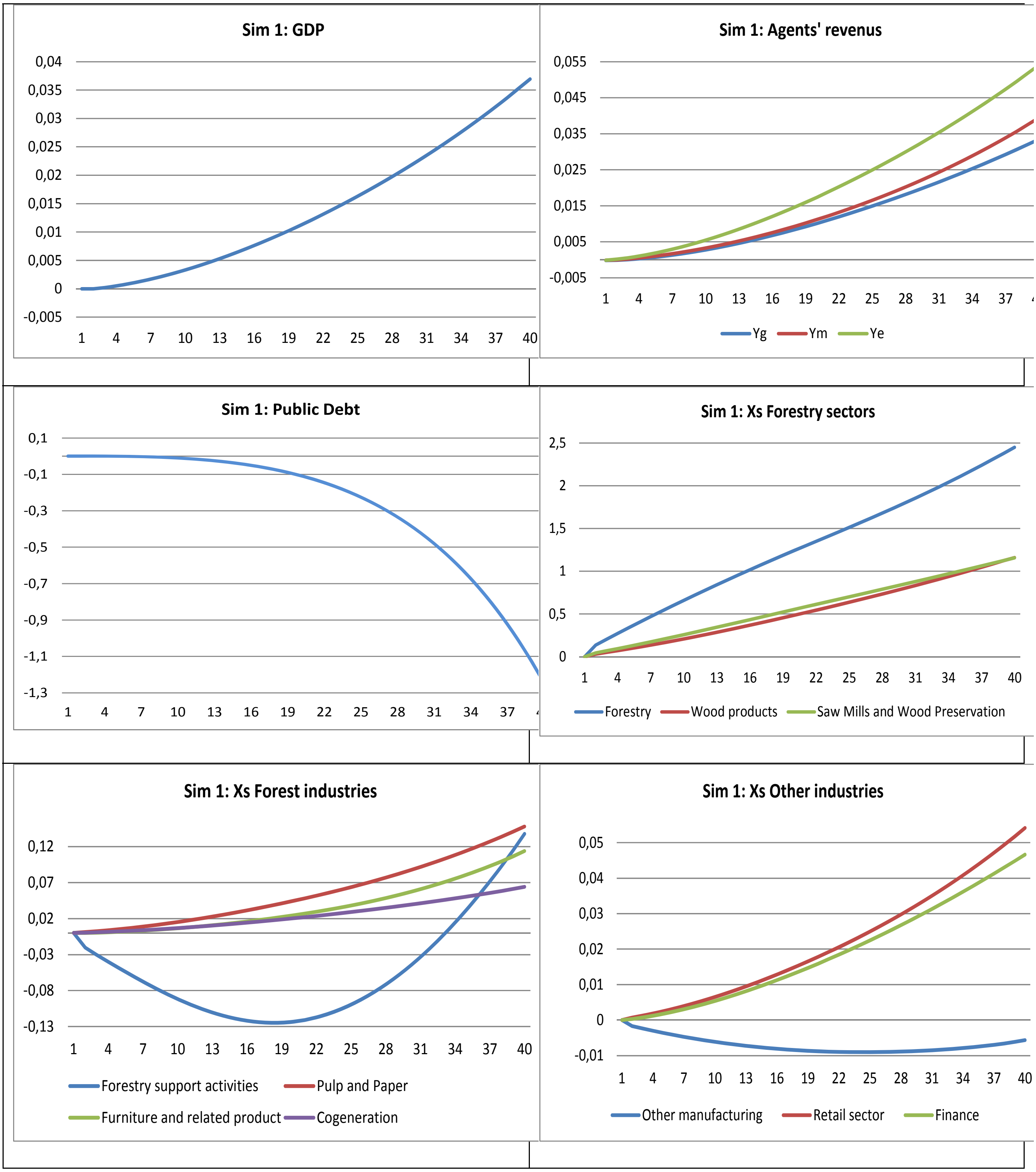
We also observe that gains of the *furniture and related product* sector, *pulp and paper* and *cogeneration* benefit less from this productivity gain ending around 0.1% above the BAU. For the impact on other sectors, we observe an increase in output for the *retail* and *finance* sectors while the *other 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* the BAU scenario.

As for price effects, we have a relatively strong reduction for the forestry sector market price linked to the productivity gains since we have an increase in supply. The reduction in unit cost of production also contributes to this reduction in market price. The reduction in price is progressive and reaches almost -1.9% compared to the BAU. The impact on other sectors of the forest industry are indirect through a reduction in price of inputs namely for the *wood products* and *sawmills and wood preservation* sector but the trend is similar and the drop reaches -0.8% at the end of resolution. We have a similar trend for the other sectors of the forest industry but with smaller amplitude given the smaller weight of wood as an input in their production process.

For our three other sectors, they also exhibit a reduction in market prices but the level of the decreases are much smaller and they don't exceed 0.07%. The price of *other manufacturing* diminishes the most of the three since it uses more inputs from the broad forest industries in its production.

For exports, we note that the price effect plays an important role in the increase in exports since the goods produced are more competitive especially in the forest industry. The increase in supply also contributes to the increase in exports. As for output, the progression of growth for exports is relatively uniform along the resolution. The exports of the *wood products* and *sawmills and wood preservation* increase by over 1.5% at the end of the resolution. For other sectors of the forest industry, the trend is similar but with weaker increases. The forestry support sector has a different path where exports decrease up to the 20th period and then increase to 0.05% above the BAU at the 40th period. The reduction in output and the smaller decrease in market price are the two factors explaining this evolution. The exports for the three other sectors decrease before changing its trend to an upward movement at the 15th year for the *finance* sector and at the 30th period for the two other sectors (*retail trade* and *other manufacturing*) albeit the reduction in exports is quite small. This adjustment is linked to the appreciation of the domestic currency to balance the current account.

Figure 3: Simulation 1, macro and sectoral results



Simulation 2: 10% reduction in productivity of forestry sector

For this simulation, we considered the pessimistic scenario predicted by some experts. A progressive reduction in productivity is applied to the forestry sector with the drop in productivity reaching 10% at the end of resolution. As in simulation 1, the effects on macroeconomic variables are relatively small for the whole economy but large for the forest industry sectors. We observe a negative gap of the GDP compared to the BAU and this gap grows at an increasing rate to end at around 0.12% below the BAU. We have a similar trend for the agents' revenues with the strongest gap for firms' income (*Ye*) at -0.17% after 40 years and the weakest gap is -0.11% for the government (*Yg*) revenue at the end of resolution.

Since the government income is below the BAU, the public debt grows at an increasing rate as we move along in time given the cumulative effects described above. The gap at the end of resolution is 4% 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 7.3% reduction in output for the forestry sector at the end of the resolution which is below the reduction in productivity. This reduction in supply generates an *upwards* pressure on prices for wood. In consequence, the sectors using wood intensively in their production process will suffer from this increase in input cost. As a result, the output for the *sawmills and wood preservation* and *wood product* sectors drop by 3.5% 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 broad 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 -0.2% to -0.45%. The increase in the *forestry support* sector is a response to counter the negative productivity effect and this helps in attenuating the negative effects of productivity decrease on the forestry sector.

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 up to year 20 and a decreasing gap for the last 15 years of the resolution. At its maximum, the gap for this sector is around 0.03% above the BAU. For the two other sectors analyzed (*retail trade* and *finance*), we have a level of output below the BAU with the gap increasing in time at an increasing rate (stronger than proportional decrease in output). Both of these sectors have an output around 0.14% for the *finance* and 0.17% for the *retail* below the BAU at the end of the resolution. The main factor explaining this difference is the trend of the exchange rate which depreciates as time goes by and ends at 0.32% below the BAU. Since *other manufacturing* exports over 70% of its production and the two other sectors export below 10% (*finance*) and 4% (*retail trade*) of their production, the depreciation of the real exchange rate is beneficial for other manufacturing and reverses the negative impact of price increases on inputs 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 rental rate of 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[20].

The exports of the broad forest industry follow the same trend as production which is a progressive reduction in exports for all sectors except the *forestry support sectors* that benefits from an increase in exports for around 20 periods before seeing its export drop compared to the BAU and then passing below the BAU around the 35th year. The pace of reduction is slower for the *furniture and related products* and *pulp and paper* sectors.

For other sectors, we have a similar growth in exports for the three sectors for the first 10 periods and for the *finance* sector, exports start to decrease around the 15th year to pass below the BAU around the 35th year. For the *other manufacturing* and *retail trade* sectors, the growth continues to the 27th period and then declines slightly afterward and remains above the BAU at the end of the resolution.

The reduction in supply of goods of the broad forestry industry pushes all market prices of these branches upwards and the growth is relatively constant for all sectors. The only exception is with the *forestry sector* where the growth is larger and faster in the first 20 years and subsequently the growth tapers to the same pace as other sectors.

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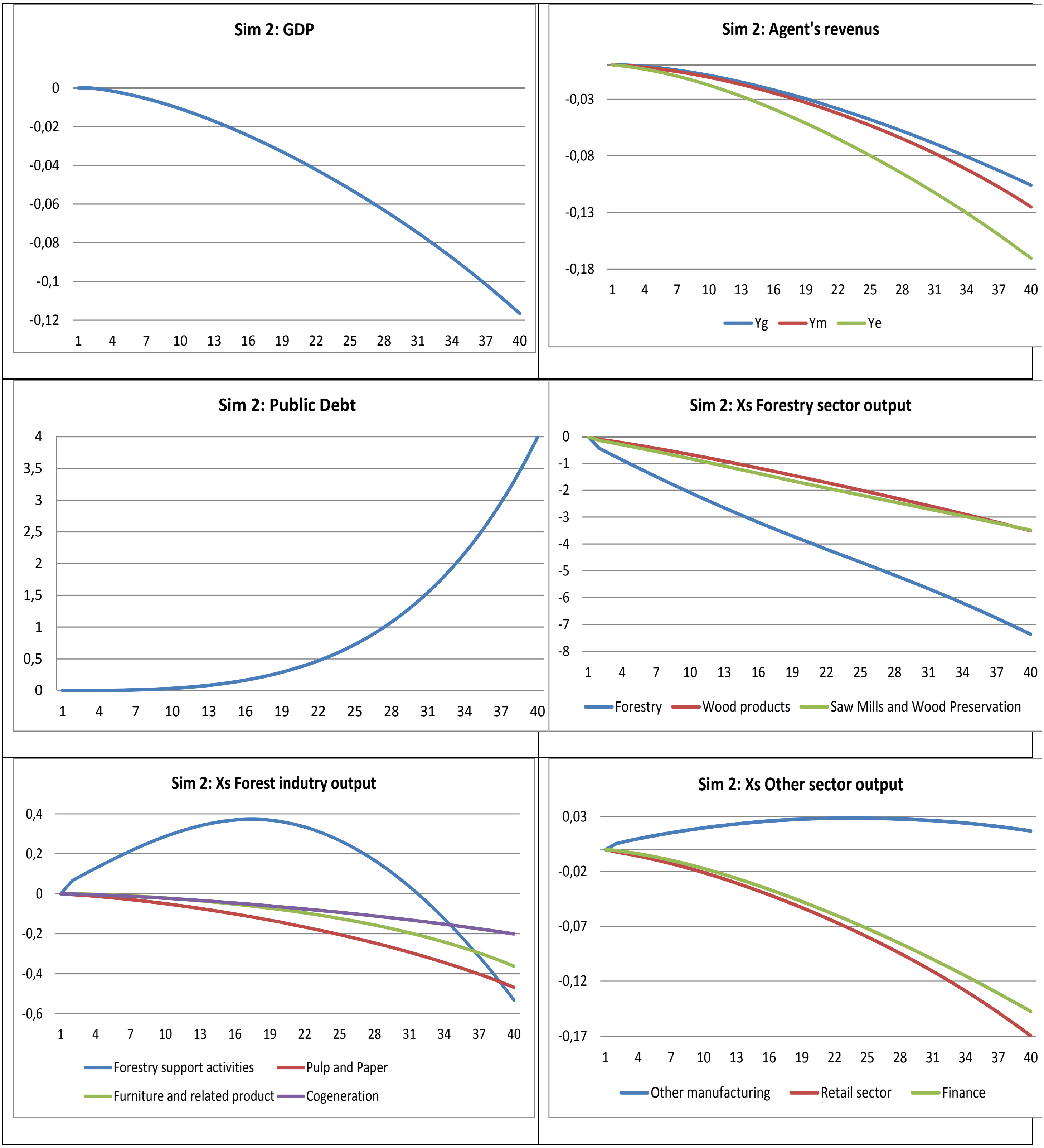
[20] We do not go in detail into the causes of these changes since the analysis would be too long given that a large number of variables play a role and numerous transformation elasticities are involved.

Figure 4: Simulation 2, macroeconomic and sectoral variables



The three other sectors also have increasing prices compared to the BAU for the duration of the resolution.

Simulation 3: Temporary increase in wood supply over 5 years

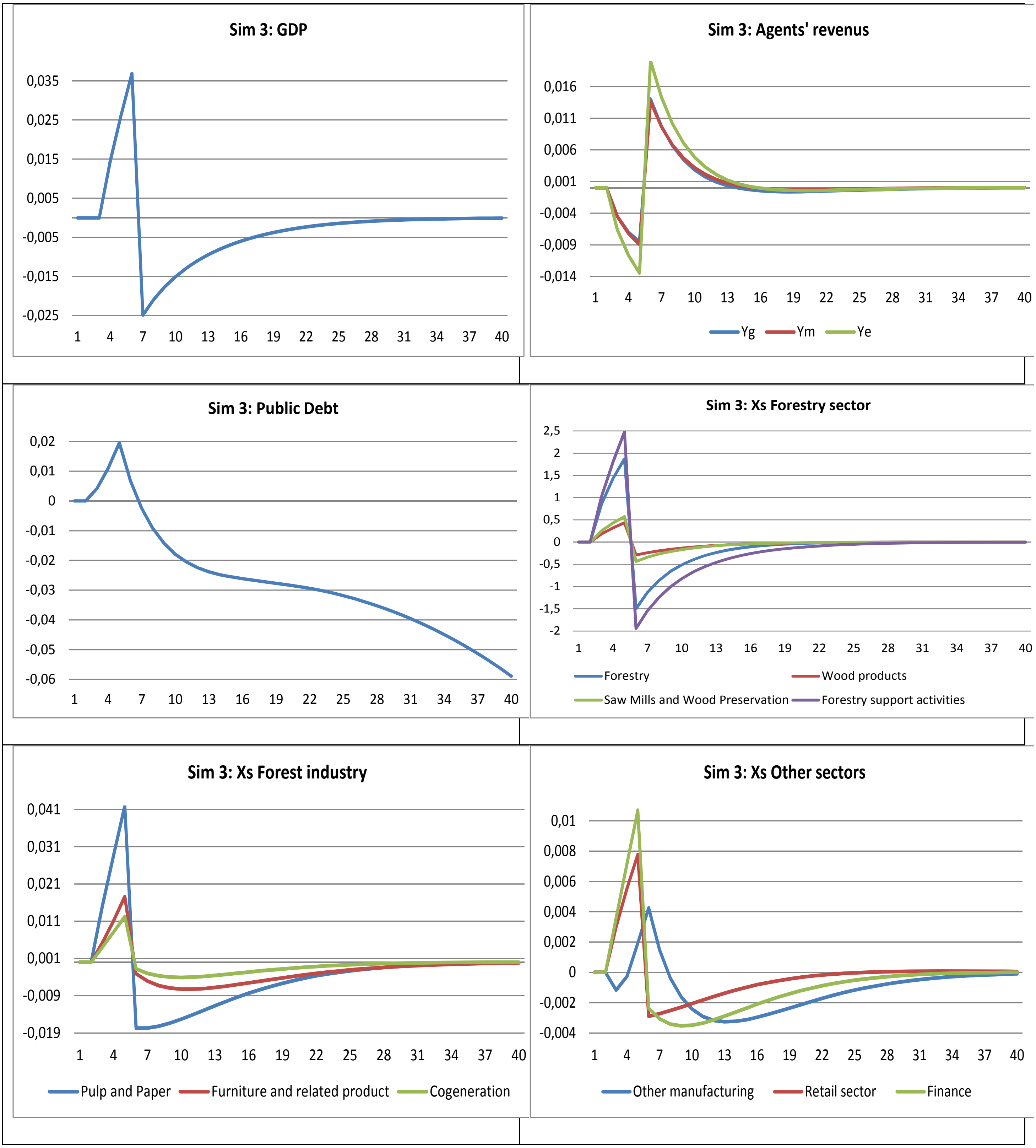
For the third simulation, the increase in wood supply has a positive effect on GDP in the short run namely during the period of increase supply, but after this temporary shock, the growth rate of GDP falls below the BAU scenario. The growth rate remains weaker up to the 30th year before coming back to the BAU level to the end of the resolution.

Agents' revenues decrease during the first five years and they grow after the end of increase in wood supply. The firms' income is the most sensitive to this shock even if the trend observed is relatively close to the two other agents. The income of the representative household and the government are affected in the same way as we cannot distinguish the two curves on the graph. The difference with the firms' income is related to the difference in variation of factor payments.

The evolution of public debt is above the BAU in the first part but drops below the BAU at the end of the temporary shock. The positive revenues for the government during the 5th to 13th periods are sufficient to push the debt in a cumulative reduction phase. At the end of resolution, the debt is slightly below the BAU debt by 0.06%. It is important to keep in mind that the variation of the debt with respect to the BAU is quite small all along the resolution.

At the sectoral level, for the forest industry, we observe a direct positive effect of the increase in supply of wood during the first five years. During the increase in supply, the *forestry support* sector increases by just below 2% above the BAU. The *wood products* and *sawmills and wood preservation* branches also progress above the BAU but at a slower pace; around +0.5% compared to the BAU. For periods post-increase in wood supply, as with the GDP, the output drops below the BAU and converges back towards the BAU afterwards. The *sawmills and wood preservation* sector reaches the BAU around the 15th year while other forestry sectors converge around the 20th period. The longer convergence time is the result of a stronger negative impact at the end of the shock.

Figure 5: Simulation 3, macroeconomic and sectoral variables



We have similar trends for other sectors of the broad forest industry but with smaller amplitude. The *pulp and paper* sector increases its output by 0.4% above the BAU at the peak of the shock while the *furniture and related products* and *cogeneration* increase by 0.15% and 0.1% respectively at the 5th year. We also observe a drop in output after the wood supply increase below the BAU and a convergence back toward the BAU which occurs around the 25th period.

The impact on the three other sectors are not the same insofar as the *other manufacturing* starts below the BAU for two periods before increasing above the BAU to reach a maximum around the 6th period and decrease below the BAU around the 8th year. The decrease continues up to the 14th year and the output moves upwards to converge to the BAU near the end of the resolution. The *retail trade* and *finance* sectors increase above the BAU at the second period and reach a summit at the 5th year and afterwards drop below the BAU at the 6th year and start converging towards the BAU.

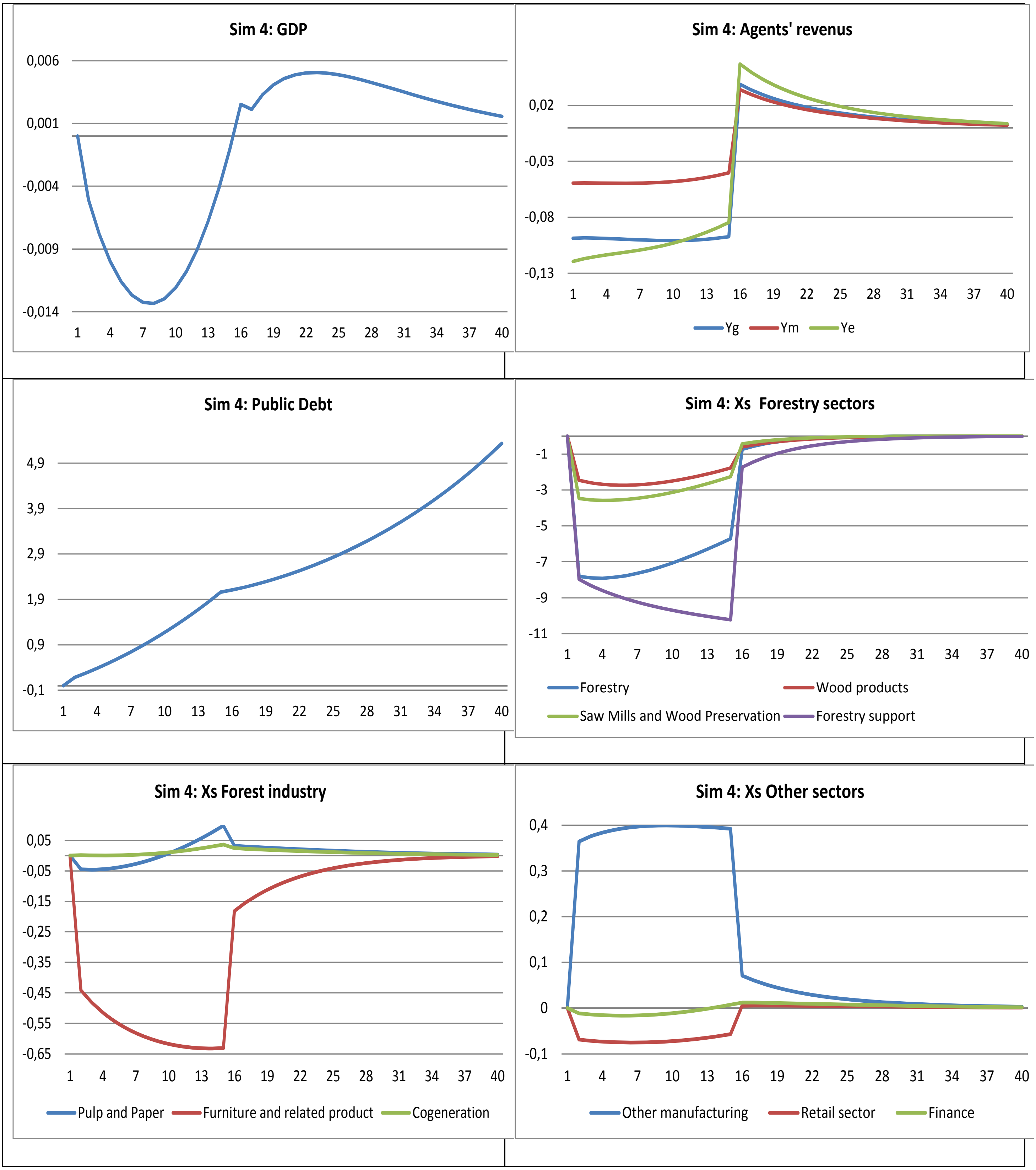
As for exports, we observe an increase above the BAU in all branches of the broad forest industry and this up to the 6th period. At this point, we observe a quick reduction to increase once again afterwards and converge towards the BAU. All these sectors converge to the BAU around the 15th year of resolution with the exception of the *forestry support* sector that takes more time to converge (around the 25th year). For other sectors, it is the opposite trend that is observed with a drop of exports in the first phase followed by a quick rise above the BAU before converging back down under the BAU around the 10th year. The exports move back up to converge towards the BAU but they don't converge completely and remain below the BAU at the end of resolution. The opposite trends are linked to the adjustment in the exchange rate required to balance the current account balance. The increase in exports from the forest industry leads to an appreciation of the exchange rate and the increase in value of the domestic currency reduces the competitiveness of other sectors which in turn reduces their exports.

As expected, the increase in wood supply pushes prices downwards with a decrease of 1.8% in the *forestry* sector during this five years phase and at the end, the price hikes to 1.4% and then converges towards the BAU. The convergence occurs around the 17th period. A similar trend is observed in other sectors of the broad forest industry but with weaker amplitude. The exception for this industry is the *forestry support* sector which sees its price increase during the five years phase and drops below the BAU afterwards and then converges to the BAU. The strong demand from the *forestry* sector with the fixed share coefficient for inputs pushes the price upwards in the first phase. Interestingly, we have the same trend for the prices of the three other sectors analyzed, i.e. increase in first phase, sharp drop before converging towards the BAU but the size of the effects are much smaller for these sectors compared to the price effects in the broad forest industry.

Simulation 4: Reduction of 20% of world price of wood over 15 years

This simulation has the direct consequence of reducing the attractiveness of the world market for the producers and reducing the cost of wood imports for producers of the forest industry. This simulation produces a reduction in GDP during the first part of the resolution. The trend is reversed around the 8^{th} period with the GDP becoming above the BAU after the end of the external shock and continues to increase up to the 23^{rd} period where it starts to decrease towards the BAU and reaching it at the end of the resolution. At the end of the resolution, the GDP is very slightly above the BAU at +0.001%.

Figure 6: Simulation 4, macroeconomic and sectoral variables



The agents' incomes are immediately negatively affected by this simulation even if the variations are relatively weak. The revenues remain low during the first 15 years and jump above the BAU at the end of the negative price shock. The incomes start decreasing towards the BAU and converge at the end of the resolution but remain slightly above the BAU. The firms' income is the most sensitive to this simulation and the aggregate household revenue the least sensitive. The decreases in GDP and government revenues contribute to increasing the public debt. The pace of increase grows during the negative price shock and this pace slows before growing again towards the end of the resolution given the cumulative effect.

At the sectorial level, the strong reduction in prices has a direct and immediate impact on the broad forest industry and specifically on the *forestry* sector and the *forestry support* sector. These two branches exhibit reduction in output of 8% in the second year and for the *forestry* sector, it starts to reduce the gap compared to the BAU while the *forestry support* sector continues to increase its negative gap with the BAU up to the 15th year. The drop in production in the broad forest industry is directly linked to the increase competition from imported wood available at a lower cost. Moreover, the loss in competitiveness generates a reduction in exports. Hence, we have an increase in imports and a decrease in exports for these two sectors.

As for the branches *wood products* and *sawmills and wood preservation* the drop in output is much smaller but is still relatively important at around 3%. The two sectors also have a slight increase in production up to the 15th year after the initial drop. These four sectors (*forestry, forestry support, wood products* and *sawmills and wood preservation)* all benefit from a strong increase in output at the end of the price shock (16th year) to return to the BAU levels of production. The *furniture and related products* suffer a similar trend but with smaller amplitude while the *pulp and paper* sector reduces its production slightly and it benefits from an increasing growth of output in the 3rd year to pass over the BAU around the 10th year. This is the sector of the broad forest industry the least negatively affected by the simulation for exports and imports since the portion of wood cost in its total production cost are weaker compared to other sectors of the broad forest industry. Moreover, this sectors benefit from the reduction in cost of wood imports for its production.

For other sectors, we have a weak reduction for the *retail trade* during the shock (15 years), while the *finance* sector seems isolated from this simulation and the *other manufacturing* benefits from the scenario. The output for this last sector jumps above the BAU at the second period around 0.38% and maintains itself around +0.4% up to the 15th year and the positive gap decreases to the 30th year but remains above the BAU to the end. This sector benefits *inter alia* of better returns to its capital which favors investments and a movement of workers towards this sector.

As we have stated, the drop in world prices makes forestry industry exports less competitive which is at the source of the reduction of exports in all of these sectors. The reduction is quite strong for the *forestry* sector at -15%. The exports for this sector start progressing from this low point of 15% but remain below 10% up to the 15th year. The reductions in exports for other sectors of the forestry industry are between 1 and 5% except for the *pulp and paper* sector.

For other sectors retained for our analysis, the trend is opposite with an increase in exports during the price shock and a convergence back to the BAU afterwards. This increase in exports is related to the depreciation of the local currency to balance the current account that is exogenous. The reduction of exports and increase in imports in the forest industry provides the impetus for the real exchange rate depreciation.

As for prices, the trend is the same as for world prices with a sudden drop in all sectors of the forest industry, followed by a stabilization through the price shock and an increase at the end (16th year) close to the BAU levels. For some branches (*furniture and related products* and *forestry support*), prices overshoot above the BAU and then converge back towards the BAU. For the three other branches, we observe the opposite effects with an increase in price during the price shock. For the *other manufacturing* sector, the amplitude of the increase is around 0.5% at its peak.

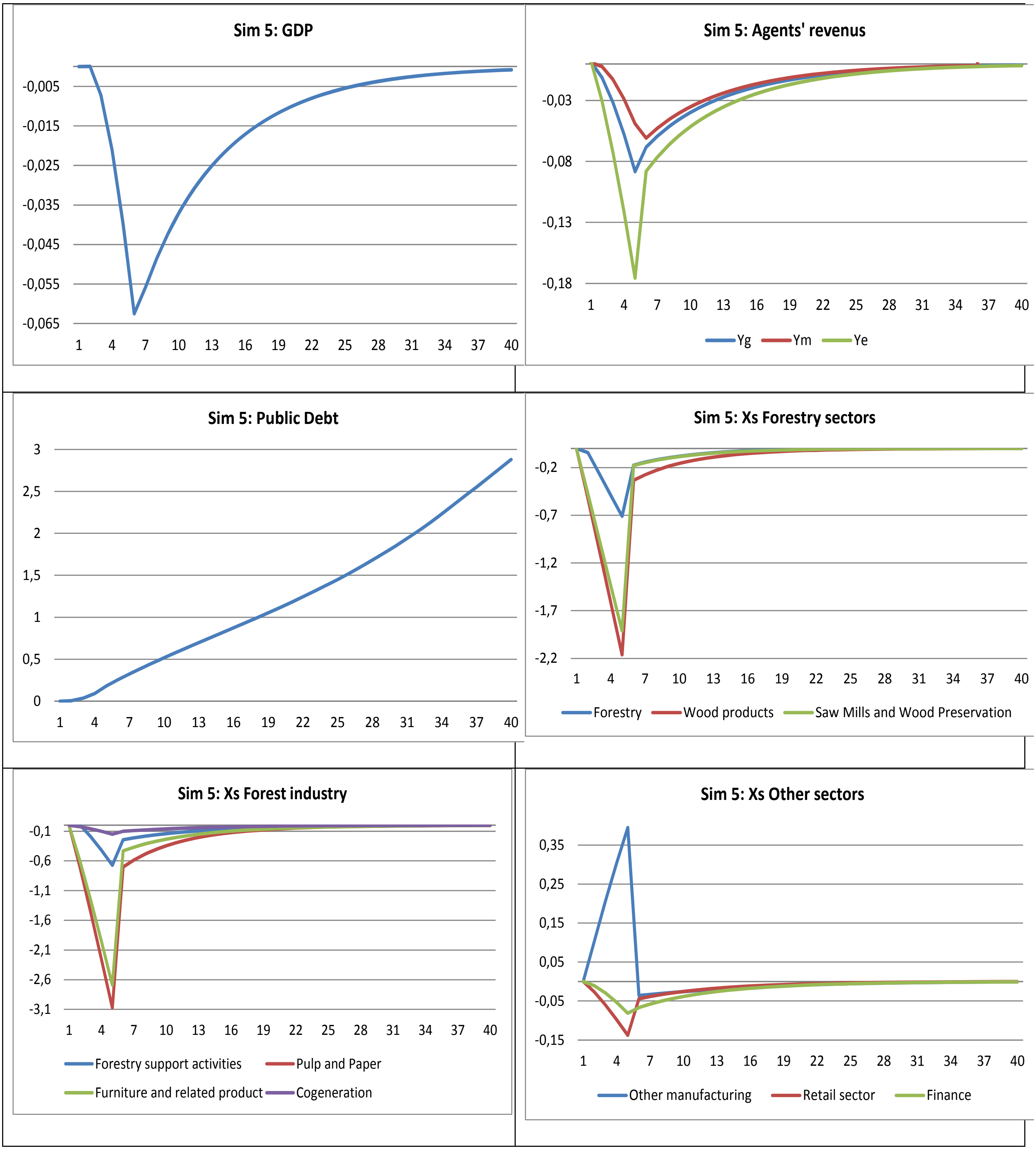
Simulation 5: Reduction in world demand for the province's wood over 5 years

For this simulation we have a negative impact on GDP that decreases progressively below the BAU to around -0.06% up to the end of the reduction in world demand for the province's wood exports. Afterwards, the GDP starts to converge back to the BAU and approaches the BAU at the end of the resolution. The agents' revenues follow the same trend but the income of firms decrease more at around -0.18% and the aggregate household income the least at -0.05%. The public debt increases constantly and in this case, the cumulative effect is not observed since we have an increase in GDP from its low point at the end of the shock (5th year).

For the forestry sectors, we also have a similar but stronger trend but the increase after the 5th year is faster compared to the GDP. The *furniture and related products* and *pulp and paper* sectors face a reduction of around 3% while the *wood products* and *sawmills and wood preservation* branches face a reduction in output just over 2.1%. The forestry, forestry support and cogeneration sectors all reduce their output around 0.6%. All the broad forest industry branches converge back towards the BAU around the 20th period.

For the other sectors analyzed, we have a similar trend but with weaker effects in the finance and retail trade sectors while the other manufacturing seems to benefit from this external shock with an increase in output during the 5 year period up to +0.37% above the BAU.

Figure 7: Simulation 5, Macroeconomic variables and output



Conclusion

Given the importance of the forest industry in Quebec, many are concerned that the impact of climate change (CC) on the economy could be important. The objective of this paper is to analyze the economic impacts of climate changes (CC) on the forestry industry in the province of Quebec. To achieve this objective, we constructed a SAM and a recursive dynamic CGE adapted to capture the specificities of the forestry industry and simulate five scenarios of potential direct and indirect effects of CC on the forest industry. Two simulations represent a change in forest productivity, the third is a temporary increase in domestic supply of wood, the fourth is a reduction in world price of goods produced by the forest industry (resulting from an increase in supply) and the last is a reduction in demand for the province's exports from the forest industry. The model is run over a 40 year time span.

Our main finding is that the general impact of our simulations representing potential impact of CC on the forestry industry are relatively small in percentage change (-0.12%) but the loss could represent up to 300 million$ of GDP at the last year of resolution (2050). The forest industry suffers since it is directly affected but the rest of the economy seems to compensate part of the loss given the reallocation of factors to other sectors in time. The losses could be up to 3 to 7.5% for the *forestry*, *wood products* and *sawmills and wood preservation* sectors. For other sectors of the forest industry, the losses could range from 0.2 to 0.5%. The results seem to contrast with findings of other studies where larger negative economic impacts were found. This is related to the general equilibrium modeling context that allows for more flexibility within the economy and the possibility of factors to move to other sectors in response to a contraction of the forest industry. In our model, the other manufacturing sector seems to benefit in many instances when the forest industry contracts.

When comparing our results with the ones of Marbek and Lantz (2010), Ochuodho *et al*., (2012), Rive *et al.* (2005), we note a very large discrepancy with Marbek and Lantz (2010) who find an impact of -2 100 million$ to -300 million$ loss of GDP for Quebec. As for Ochuodho *et al*. (2012), the gap is much larger as they find a gain of 7 billion$ in GDP in 2050 for Quebec. On the other hand, our results for Quebec are in the same range as Rive *et al*. (2005) for their NAFTA region. The time frame of our analysis is similar to the one used in these papers.

It is important to highlight some caveats in our analysis. First, one must keep in mind that we include only the CC impact on the forestry sector. Combining the CC impact on agriculture, health and building infrastructures would produce larger effects on macroeconomic variables. A possible extension will be to include a detailed agriculture sector to address this issue. Moreover, we intend to extend our model to link it to a micro-simulation model to allow for distributional impact analysis. This model has been extended for the analysis of CC adaptation policies targeting the forestry sectors in Boccanfuso et al (2014b).

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Appendices

Figure 8: Simulation 1, Prices and exports

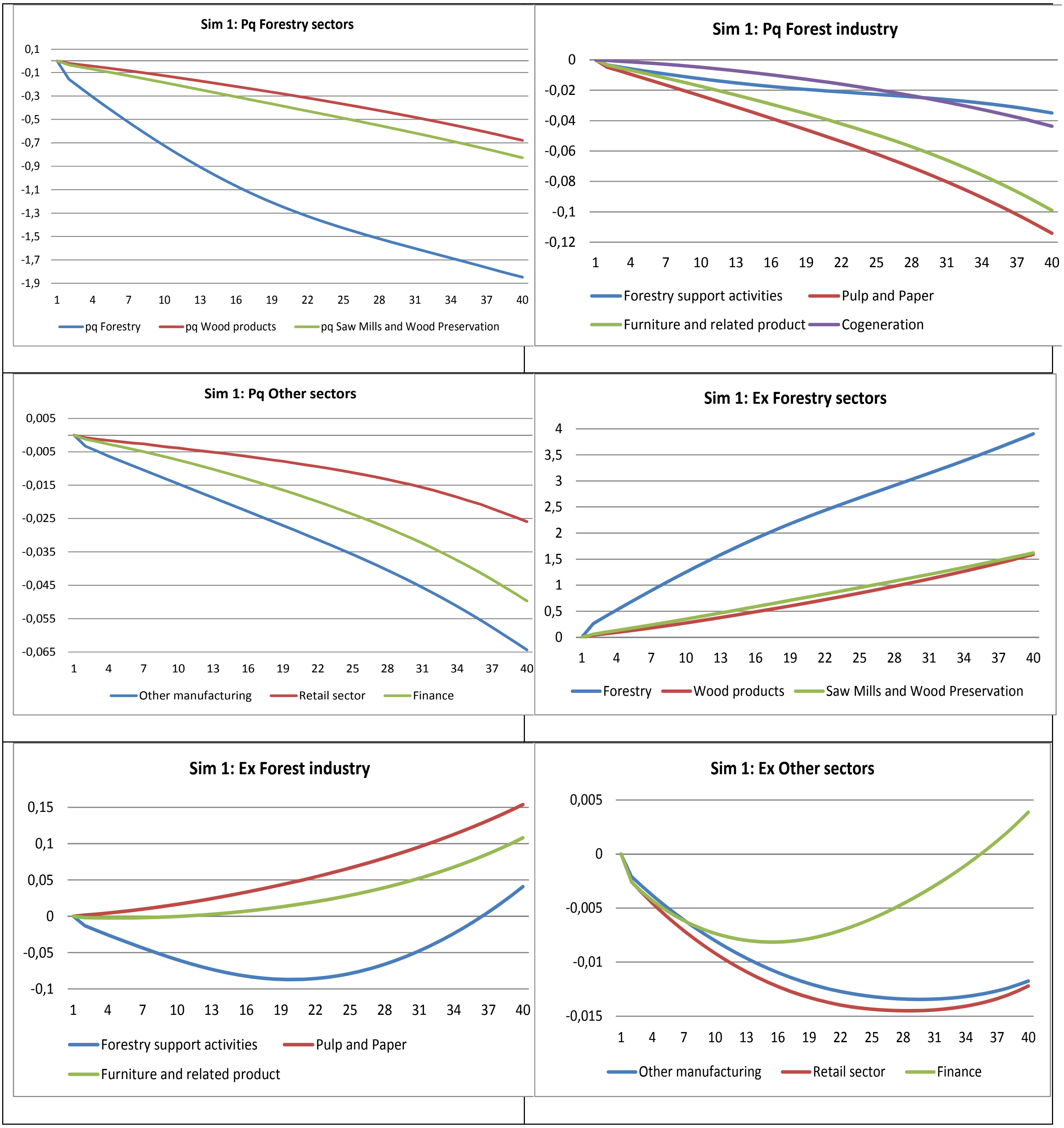

Figure 9: Simulation 2, Prices and exports

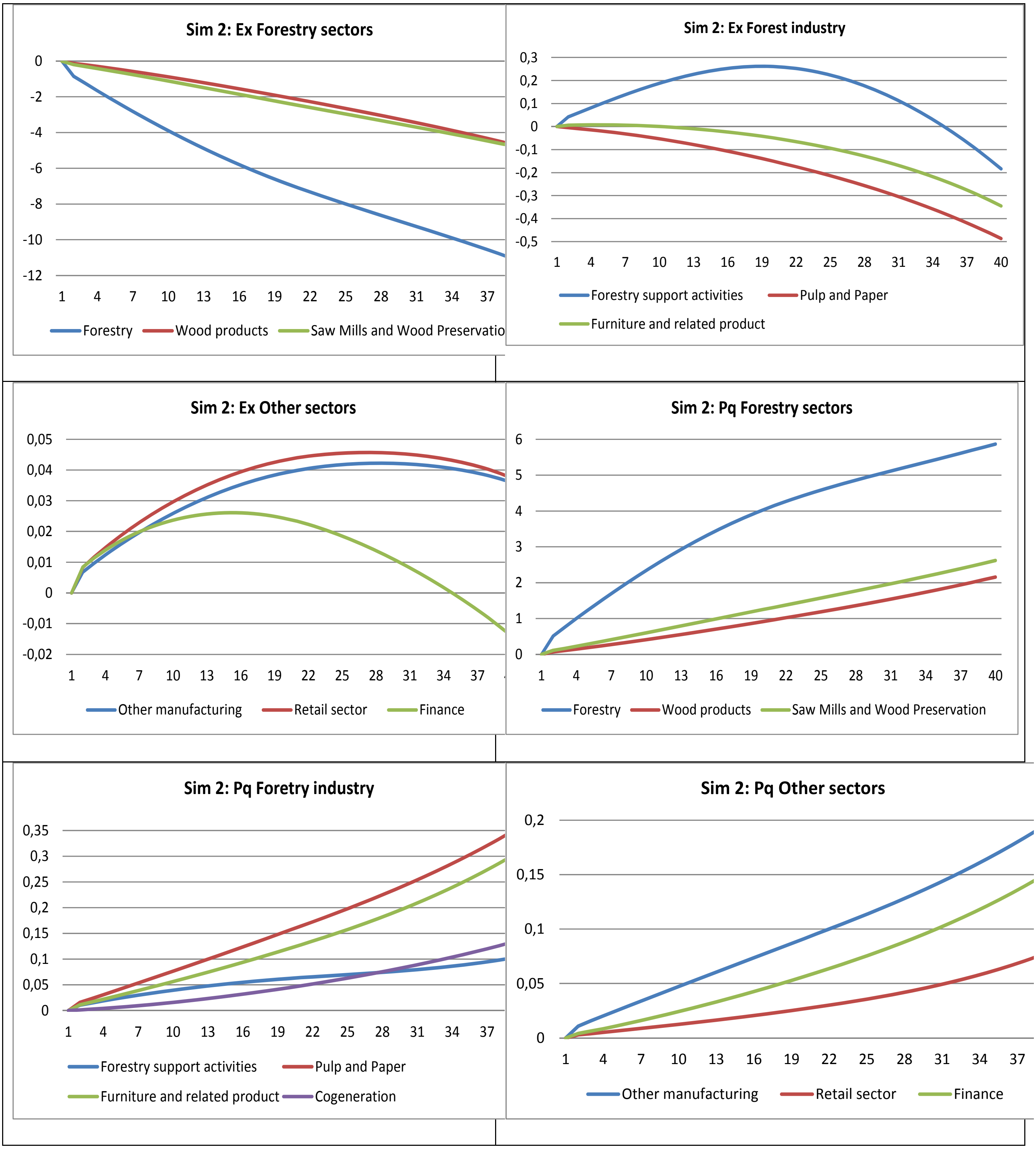

Figure 10: Simulation 3, Prices and exports

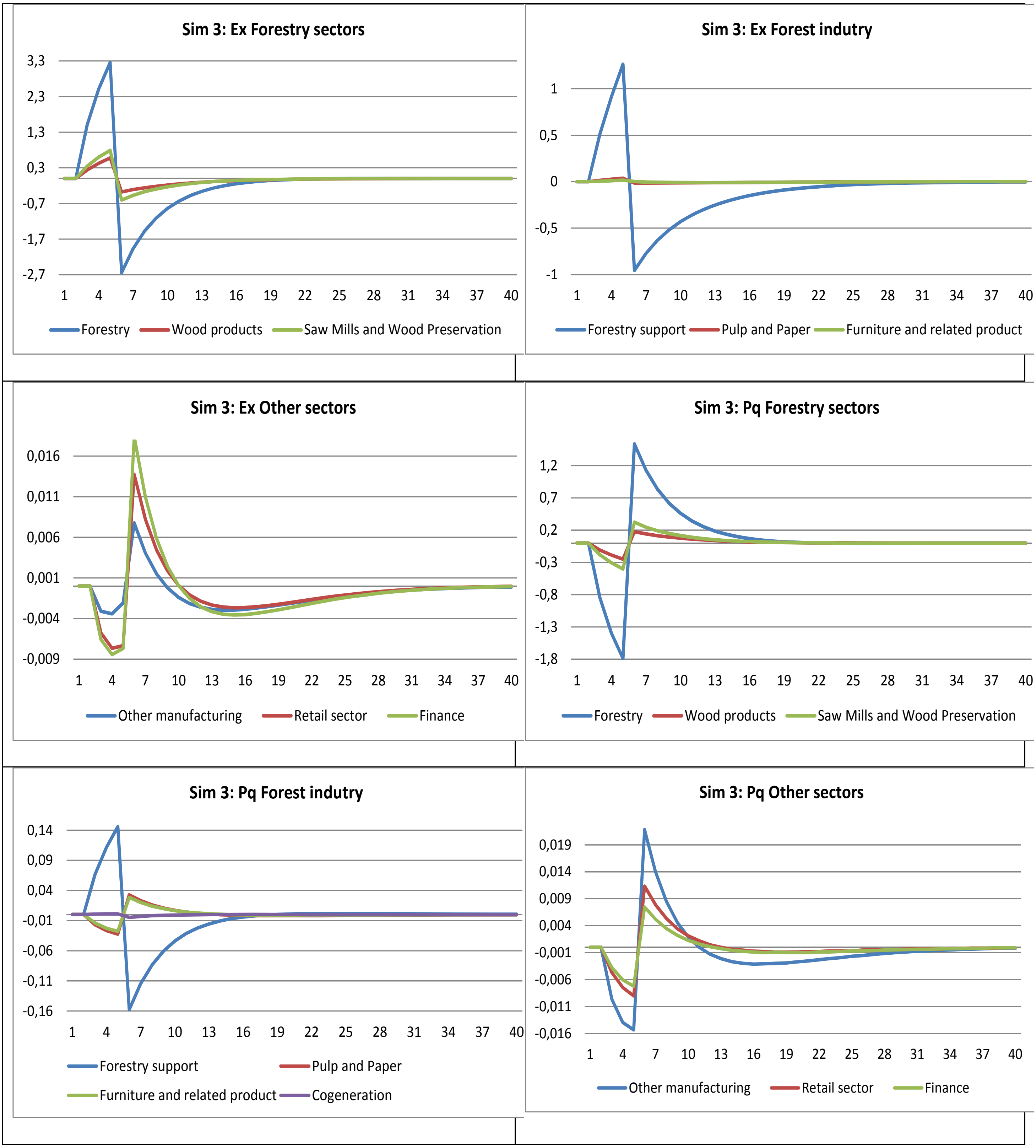

Figure 11: **Simulation 4, Prices and exports**