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Summary

This paper aims to present an extension of the ICES model to capture the public sector. Departing from a demand system mainly derived from the GTAP model, ICES-XPS model disentangles the private and the public actors. The paper reviews the changes in both the database and the model equations following the existing literature and considering the availability of data as well. The model is then tested with a series of simple experiments to highlight its contribution to economic analysis in which the public sector may play an important role. Finally, we show the flexibility in the closure rule of the public sector that allows addressing different policy research questions.

Keywords: Computable General Equilibrium, Public Sector, Government Budget

JEL Classification: C68, D58, H60

The research leading to these results has received funding from the Italian Ministry of Education, University and Research and the Italian Ministry of Environment, Land and Sea under the GEMINA project.

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Abstract

This paper aims to present an extension of the ICES model to capture the public sector. Departing from a demand system mainly derived from the GTAP model, ICES-XPS model disentangles the private and the public actors. The paper reviews the changes in both the database and the model equations following the existing literature and considering the availability of data as well. The model is then tested with a series of simple experiments to highlight its contribution to economic analysis in which the public sector may play an important role. Finally, we show the flexibility in the closure rule of the public sector that allows addressing different policy research questions.

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1. Introduction

Public policy challenges are diverse and pursue a variety of aims. Its objectives can range from fostering economic development and reduce poverty, to mitigating the negative environmental externalities, as well as providing a social welfare system. Given the diversity of objectives, there are also plenty of instruments that can be used to pursue a specific policy target, which should also be evaluated prior to its implementation since it will affect the public budget balance, and therefore its sustainability. In this context, there are two important public policy challenges which are apparently unrelated in the short-run but will definitely have intertwined implications for the long-run. The first one regards climate policy addressing long-run targets entailing a shift to a low carbon economy and the need to adapt to a future climate. The second one refers to public budget and debt evolution which has recently gained attention due to the financial crisis as well as the growing levels of indebtedness in many countries.

However, at the political level some concerns exist regarding possible trade-offs between environmental taxes and the need to foster the economic growth; or environmental public expenditure along with scarce public resources. Although these fears may be well intentioned they may not be well founded since it is necessary to consider several interrelated elements to perform a proper assessment. For this purpose this paper aims at extending a global Computable General Equilibrium (CGE) model, the Intertemporal Computable Equilibrium System (ICES) (Eboli *et al.*, 2009; Parrado and De Cian, 2014), by enhancing the representation of the public sector in order to address the indirect effects of climate change policies and impacts on public budget. This will provide an improved tool (ICES- XPS)[1] for policy assessment which will shade additional insights for policy design and implementation.

The choice of a CGE model is because this type of framework has been increasingly used to evaluate both climate change impacts as well as policies since it provides economy-wide assessments with a detailed sectoral and regional aggregation. Furthermore, this instrument allows considering indirect effects via changes in consumption or investment patterns.

However, including a public sector in a global CGE through the formalization of a government agent is a challenging theoretical and empirical issue. Difficulties arise from data collection for a wide number of countries, since information is not always available, and addressing lack of data sometimes requires simplifying assumptions. Consequently, the modelling choices are also forced to follow those assumptions, reducing the role of the public sector despite its importance to allow for a more detailed representation of the rest of the economy. This is mainly due to data gathering and harmonization processes. It is very difficult to collect data for several countries as in the GTAP database and then assemble a single and consistent global database. For instance, the GTAP model (Hertel, 1997), the most worldwide used global CGE model, considers the existence of a

[1] ICES- XPS stands for ICES model with eXtended Public Sector.

regional household which is composed of three final demand components, namely private consumption, government consumption and savings. They are linked each other via a Cobb-Douglas function which in turn means a fixed share among these three components. The main drawback of this formulation is that there is no direct link between government expenditures and tax revenues (Hertel, 1997).

There are not many studies addressing climate policies along with their possible effects on public budgets in a general equilibrium framework. As Osbergahaus and Reif (2010) argue, most of the analysis in terms of "fiscal" and "budgetary" effects of adaptation strategies has been pursued without using Computable General Equilibrium (CGE) models and without assessing the indirect effects resulting from forgone profits or responses on consumption after a change in investment and consumption behaviour.

CGE models have been mainly used to evaluate the effects of climate policy on the public budget. Olmos *et al.* (2011) use a CGE model (GEM-E3) coupled with an energy system model for the EU (PRIMES) to assess the public budget position and the fiscal direct effects related to a low-carbon economy transition in EU member states. Reducing carbon emissions via a carbon tax may have beneficial effects on the fiscal position due to the increase in public revenues (namely revenues form carbon pricing), although other policies increasing public expenses, such as increasing direct investments (to promote low-carbon technology development) or transfer payments, may worsen the fiscal position. These are fiscal direct effects which mostly affect the public budget, but there are other notable indirect effects, such as changes in state revenues and expenditures due to impacts of climate policy on economic activities. Another CGE application is the phasing-out of fossil fuel subsidies which could alleviate the pressure on public budget as well as reduce fossil fuel consumption and emissions (Burniaux and Chateau, 2011). Other examples include McKibbin (2012) which focuses on the potential positive effects of carbon pricing on the government budget and comparing different options of carbon tax recycling in the USA. In addition, most of the CGE models which contemporaneously address both aspects are single country models (e.g. World Bank, 2010).[2]

This paper describes how the government may be introduced in a general equilibrium framework. Section 2 presents a literature review about the representation of the public sector in global CGE models. Section 3 focuses on the extension of the database to improve the description of government budget accounts. Section 4 explains how the government allocates its income between expenditures and savings, since in a recursive dynamic framework, there is also the need for a within- and between- period specification. Section 5 presents the evolution over time of the debt stocks and interest payments. Section 6 discusses different closure rules for the public sector, presenting in a simplified framework alternatives on how to treat government budget. Section 7 considers some simple experiments to test the extended model. Finally, section 8 concludes.

[2] The World Bank report is about the economics of adaptation to climate change in which five single country studies are performed with CGE models: Vietnam, Mozambique, Ethiopia, Ghana, and Bangladesh.

2. Representation of the public sector in global CGE models

The main stream of global CGE models stem from the Global Trade Analysis Project (GTAP). As it is described in Hertel (1997), the GTAP model does not consider explicitly a government institution. In its database, we can find different types of taxes plus government consumption, but no government savings (McDonald and Thierfelder, 2004). The focus of the model is mainly on trade relationships across countries rather than different institutions within each country. In fact, there is no income split between the private household and the government. A representative agent in each region holds indiscriminately income from both primary factors and tax revenues. Regional income use is modelled according to a Cobb-Douglas function that allocates it among three final components (i.e. private consumption, public consumption, and savings) according to constant shares. The choice of this functional form is the main drawback of the model for the proper representation of the government agent. According to Hertel (1997): "*cutting taxes by no means implies a reduction in government expenditures in the GTAP model. Indeed, to the extent that these tax cuts lead to a reduction in excess burden, regional real income will increase and real government expenditure will likely also rise*". However, there is a clear motivation for this modelling choice as the GTAP data have incomplete coverage of tax instruments in each region. Furthermore, the greatest advantage of this formulation is the existence of a unique welfare indicator derived from the regional utility function (Hertel1997). It considers welfare out of private, public consumption and savings together.

Further developments to introduce an explicit government institution can be recapped in three main strands. Firstly, there are models that split the regional income, and savings according to a differentiated household and government (e.g., GLOBE, McDonald *et al.*, 2007). This means an income allocation according to its ownership (i.e. endowment repayment to household, and tax revenues to government). Household and government savings are derived as residuals. In this case the only source of government income is tax revenue while expenditures are limited to the consumption of goods and services.

Secondly, another group of models extends the government budget representation introducing public transfers to households. However, they focus more on representing the intra-regional structure of the government budget rather than considering its inter-regional structure. Models belonging to this category comprehend LINKAGE (van der Mensbrugghe, 2011), ENV-Linkages (Chateau et al., 2014), and ENVISAGE (van der Mensbrugghe, 2008). Most global CGE models addressing the issues of climate change and environment enters this second group of models (GEM-E3, Capros et al., 2013; and GTEM, Pant, 2007).

In the third strand the MyGTAP database and model (Minor and Walmsley, 2013a, 2013b) assume a wider description of the government budget, allowing for both regional and international transfers. This model focuses on the distributive effects of policies. The regional household is split in two distinct and independent agents, namely the private household and the government and both consume and save a fraction of their income according to a Cobb-Douglas function.

3. Creating a consistent augmented GTAP database

The structure of a GTAP Social Accounting Matrix (SAM) is illustrated by means of a representative SAM for one region in Table 1. The GTAP database is a series of regional SAMs linked each other via a detailed representation of the international trade in goods and services. In general terms, its structure follows the conventions of the System of National Accounts (UN, 1993) and the basic SAM principles (Pyatt and Round, 1977; Pyatt and Round, 1985; Pyatt, 1991).

This section builds on the description of a SAM by McDonald and Thierfelder (2004) and highlights the modifications made in order to include a more detailed the public sector. The representative SAM summarizes six groups of demanding agents: productive activities, private representative households, government, investment, global transport services (or margins) and other regions (international trade). These transactions take place at market prices following GTAP terminology (sellers' prices). Furthermore, associated with each purchase there is an additional payment to the government that represents sales taxes (defined as the difference between market and agent prices). The SAM shows that for imported commodities sellers' prices are the sum of the world price paid to the exporter, the per unit transport cost, and the per unit tariff rate (Mcomm - column 1 in Table 1). In terms of domestically produced commodities, sellers' prices are the (producer) prices received by domestic activities. This means that export taxes are considered as expenditures by the domestic commodity accounts (Dcomm - column 2). Domestic producer prices derive from the production costs, composed of the costs of intermediate inputs (at sellers' prices), payments to primary inputs, as well as taxes.[3] Income accrues first the regional household and then is distributed among the private household, the government and the capital account (column 5). Ultimately, the regional household provides a method by which the limitations imposed by lack of data on intra-institutional transactions can be partially bypassed (Hertel, 1997).[4] Regional income (cell L5) is composed of payments to factors (net of factor income taxes) and depreciation, plus total net indirect tax revenues (trade, sales, factor use and production taxes), and income taxes (row E). While both the private household and the government obtain income from the regional household, the capital account has two sources of income: depreciation and the balance on the capital account of the balance of payments. Therefore, there are no records of transactions between private households and the government or the capital account; nor between the government and the capital account. The formulation of a regional household implies that the private household does not pay income taxes nor does it save directly. Similarly, the government neither saves nor borrows meaning that there is an implicit balance on the government budget equal to zero.

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[3] All taxes producers must pay, namely: taxes on intermediate uses, taxes on primary factor uses, and output taxes is summarised in Table 1 cell I2.

[4] This method limits how the model is built; since it implies imposing a particular vision about the distribution of domestic consumption expenditure (see section 4 for further details).

International trade is considered with two elements: a) expenditures on commodities (column 11) and b) expenditures on transport margins (column 10). The value of exports is free on board (FOB) after paying export duties. Exports of transport services that are part of the global transport pool are separately recorded. Imports of commodities consider also FOB prices, with transport services taken into account separately as well. Their sum represents expenditure on imports including cost, insurance and freight (CIF). The implications of this formulation is that there are two sets of trade balances: i) one representing the trade balance with respect to each of the transport services (cell H10) and ii) one recording the trade balance with respect to each region (cell H11).

To extend the database and account for an explicit government with its own budget, the crucial aspect is the regional household assumption. Following Table 1, the regional household earns income from factor and taxes (row E), then the endowment of primary factors becomes:

$$HF_{f,r} = \sum_i VFM_{f,i,r} \quad (1)$$

Total tax revenue is:

$$TTAX_r = \sum_i \sum_s MTAX_{i,s,r} + \sum_i \sum_s XTAX_{i,r,s} + \sum_j PTAX_{j,r} + \sum_f DTAX_{f,r} + \sum_i PSTAX_{i,r} + \sum_i GSTAX_{i,r} + \sum_i ISTAX_{i,r} \quad (2)$$

Therefore, in the representative region total income by sources is:

$$YR_r = \sum_f HF_{f,r} + TTAX_r \quad (3)$$

It must be equal to the definition of regional income by destinations:

$$YR_r = YH_r + YG_r + SAVE_r \quad (4)$$

where: $YH_r = \sum_i VIPM_{i,r} + \sum_i VDPM_{i,r} + \sum_i PSTAX_{i,r}$ (5)

$$YG_r = \sum_i VIGM_{i,r} + \sum_i VDGM_{i,r} + \sum_i GSTAX_{i,r} \quad (6)$$

Finally, the regional household choice affects the Saving-Investment macroeconomic balance that becomes:

$$VDEP_r + SAVE_r + \sum_i \sum_s VTWR_{MRG,i,r,s} - VST_{MRG,r} + \sum_i \sum_s VIWS_{i,s,r} - \sum_i \sum_s VTWR_{MRG,i,r,s} - \sum_i \sum_s VXWD_{i,r,s} = \sum_i \sum_s VIIM_{i,s,r} + \sum_i VDIM_{i,r} + \sum_i ISTAX_{i,r} \quad (7)$$

Table 1: An archetypal GTAP SAM

		1	2	3	4	5	6	7	8	9	10	11	12
		Mcomm	***Dcomm***	***Act***	***Fact***	***REG***	***Phhd***	***Govt***	***Inv***	***Tax***	***Trade margins***	***ROW***	***Totals***
A	***Mcomm***			$VIFM_{i,j,r}$			$VIPM_{i,r}$	$VIGM_{i,r}$	$VIIM_{i,s,r}$				$VIMS_{i,r}$
B	***Dcomm***			$VDFM_{i,j,r}$			$VDPM_{i,r}$	$VDGM_{i,r}$	$VDIM_{i,r}$		$VST_{MRG,r}$	$VXWD_{i,r,s}$	$TVOM_{i,r}$
C	***Act***		$VOM_{i,j,r}$										$VOM_{i,j,r}$
D	***Fact***			$VFM_{f,i,r}$									$VFM_{f,i,r}$
E	***REG***				$HF_{f,r}$					$TTAX_r$			YR_r
F	***Phhd***					YH_r							YH_r
G	***Govt***					YG_r							YG_r
H	***Inv***				$VDEP_r$	$SAVE_r$					$VTWR_{MRG,i,s,r}$ - $VST_{MRG,r}$	$VIWS_{i,r,s}$ – $VTWR_{MRG,i,s,r}$ -$VXWD_{i,r,s}$	INV_r
I	***Tax***	$MTAX_{i,s,r}$	$XTAX_{i,r,s}$	$PTAX_{i,r}$	$DTAX_{f,r}$		$PSTAX_{i,r}$	$GSTAX_{i,r}$	$ISTAX_{i,r}$				$TTAX_r$
J	***Trade margins***	$VTWR_{MRG,j,s,r}$											$VTWR_{MRG,j,s,r}$
K	***ROW***	$VIWS_{i,s,r}$											$VIWS_{i,s,r}$
L	***Totals***	$VIMS_{i,s,r}$	$TVOM_{j,r}$	$VOM_{i,r}$	$VFM_{f,i,r}$	YR_r	YH_r	YG_r	INV_r	$TTAX_r$	$VTWR_{MRG,j,s,r}$	$VIWS_{i,s,r}$	

Legend: $VIFM_{i,j,r}$: Imported intermediate commodity *i* in sector *j* in region *r*; $VIPM_{i,r}$: Private consumption of imported commodity *i* in region *r*; $VIGM_{i,r}$: Government consumption of imported commodity *i* in region *r*; $VIIM_{CGDS,I,r}$: Imported capital good in region *r*; $VIMS_{i,r,s}$: Total imports of commodity *i* from region *r* to region *s*; $VDFM_{i,j,r}$: Domestic intermediate commodity *i* in sector *j* in region *r*; $VDPM_{i,r}$: Private consumption of domestic commodity *i* in region *r*; $VDGM_{i,r}$: Government consumption of domestic commodity *i* in region *r*; $VDIM_{CGDS,I,r}$: Domestic capital good in region *r*; $VXWD_{i,r,s}$: Exports of commodity *i* from region *r* to region *s*; $TVOM_{i,r}$: Domestic disposable supply of commodity *i* in region *r*; $VOM_{i,r}$: Domestic production of commodity *i* in sector *j* in region *r*; $VFM_{f,i,r}$: Factor *f* use in sector *j* in region *r*; $HF_{f,r}$: Income out of factor *f* in region *r*; $TTAX_r$: Total tax revenue in region *r*; YH_r: Private household income; YG_r: Government income; $VDEP_r$: Depreciation of factor *f* in region *r*; $SAVE_r$: total regional savings in region *r*; INV_r: Total investment in region *r*; $MTAX_{i,r,s}$: Import duties on imported commodity *i* from region *r* to region *s*; $XTAX_{i,r}$: Export tax for exported commodity *i* from region *r* to region *s*; $PTAX_{i,r}$: Production taxes (comprehensive of sales taxes paid on intermediate inputs, the expenditure on factor use, production taxes) in sector *j* in region *r*; $DTAX_{f,r}$: direct tax on factor *f* in region *r*; $PSTAX_{i,r}$: Sales tax on private consumption of commodity *i* in region *r*; $GSTAX_r$: Sales tax on Government consumption of commodity *i* in region *r*; $ISTAX_{i,r}$: Sales tax on investment of commodity *i* in region *r*; $VTWR_{MRG,j,r,s}$: Trade margins on imported commodity *i* from region *r* to region *s*; $VST_{MRG,r}$: Trade margins on exports of commodity *i* to region *s*; $VIWS_{i,s,r}$: Imports of commodity *i* at world prices from region *r* to region *s*;

Sets: *i*, *j*: productive sectors and commodities; *f*: factors of production; *r*, *s*: regions; *CGDS*: capital goods; *MRG:* trade margins;

The first stage to extend the database is disaggregating the regional household account for each region, which is straightforward when data on government borrowing/saving are available. Following this approach has two main advantages, as McDonald and Thierfelder (2004) suggest: i) the specification of only three institutional accounts for each region, namely private household, government and capital account when available information is limited; and ii) the identification of transactions between these institutions. As a consequence, a more realistic representation of the government budget is possible. In the second stage, we used IMF data on inter-regional and intra-regional transactions are added to the data base; focusing on transactions that include payments for debt interests, social transfers to households, and official transfers.

The extended SAM for a representative region is shown in Table 2. The major differences between Table 1 and Table 2 are the elimination of the regional household account and the inclusion of an additional account called Globe, following the GLOBE model specification (McDonald and Sonmez, 2004). The artificial notion of the Globe account is required because data on inter-regional transfers does not provide a bilateral matrix for the transactions among regions but defines for each region only inflows and outflows. Hence, the Globe account is an accounting artifice: its income is the sum of all the outflows from each region and its uses are the inflows to each region. This implies that their sum is equal at the world level by definition. However, at the regional level inflows and outflows are not necessarily equal, and the net inflow/outflow is recorded as an income in the region's capital account. This is a practical solution to the lack of complete information.

Table 2: An archetypal extended GTAP SAM

		1	2	3	4	5	6	7	8	9	10	11	12
		Mcomm	***Dcomm***	***Act***	***Fact***	***Phhd***	***Govt***	***Inv***	***Tax***	***Trade margins***	***ROW***	***Globe***	***Totals***
A	***Mcomm***			$VIFM_{i,j,r}$		$VIPM_{i,r}$	$VIGM_{i,r}$	$VIIM_{i,s,r}$					$VIMS_{i,r}$
B	***Dcomm***			$VDFM_{i,j,r}$		$VDPM_{i,r}$	$VDGM_{i,r}$	$VDIM_{i,r}$		$VST_{MRG,r}$	$VXWD_{i,r,s}$		$TVOM_{i,r}$
C	***Act***		$VOM_{i,j,r}$										$VOM_{i,j,r}$
D	***Fact***			$VFM_{f,i,r}$									$VFM_{f,i,r}$
E	***Phhd***				$HF_{f,r}$		$TRANS\_GOV_r$+ $INTD_r$+$OEXP_r$					$INTFI_{s,r}$	YH_r
F	***Govt***					$OINC_r$			$TTAX_r$			$AIDI_{s,r}$	YG_r
G	***Inv***				$VDEP_r$	SAV_HHLD_r	SAV_GOV_r			$VTWR_{MRG,i,s,r}$ - $VST_{MRG,r}$	$VIWS_{i,r,s}$ – $VTWR_{MRG,i,s,r}$ $VXWD_{i,r,s}$	($INTFI_{s,r}$- $INTFO_{r,s}$)+ ($AIDI_{s,r}$- $AIDO_{r,s}$)	INV_r
H	***Tax***	$MTAX_{i,s,r}$	$XTAX_{i,r,s}$	$PTAX_{i,r}$	$DTAX_{f,r}$	$PSTAX_{i,r}$	$GSTAX_{i,r}$	$ISTAX_{i,r}$					$TTAX_r$
I	***Trade margins***	$VTWR_{MRG,j,s,r}$											$VTWR_{MRG,j,s,r}$
L	***ROW***	$VIWS_{i,s,r}$											$VIWS_{i,s,r}$
M	***Globe***						$AIDO_{r,s}$+ $INTFO_{r,s}$						$AIDO_{r,s}$+ $INTFO_{r,s}$
N	***Totals***	$VIMS_{i,s,r}$	$TVOM_{j,r}$	$VOM_{i,j,r}$	$VFM_{f,i,r}$	YH_r	YG_r	INV_r	$TTAX_r$	$VTWR_{MRG,j,s,r}$	$VIWS_{i,s,r}$	$AIDO_{r,s}$+ $INTFO_{r,s}$	

Legend: $VIFM_{i,j,r}$: Imported intermediate commodity *i* in sector *j* in region *r*; $VIPM_{i,r}$: Private consumption of imported commodity *i* in region *r*; $VIGM_{i,r}$: Government consumption of imported commodity *i* in region *r*; $VIIM_{CGDS,r}$: Imported capital good in region *r*; $VIMS_{i,r,s}$: Total imports of commodity *i* from region *r* to region *s*; $VDFM_{i,j,r}$: Domestic intermediate commodity *i* in sector *j* in region *r*; $VDPM_{i,r}$: Private consumption of domestic commodity *i* in region *r*; $VDGM_{i,r}$: Government consumption of domestic commodity *i* in region *r*; $VDIM_{CGDS,r}$: Domestic capital good in region *r*; $VXWD_{i,r,s}$: Exports of commodity *i* from region *r* to region *s*; $TVOM_{i,r}$: Domestic disposable supply of commodity *i* in region *r*; $VOM_{i,r}$: Domestic production of commodity *i* in sector *j* in region *r*; $VFM_{f,i,r}$: Factor *f* use in sector *j* in region *r*; $HF_{f,r}$: Income out of factor *f* in region *r*; $TRANS\_GOV_r$: Government transfers to households in region *r*; $INTD_r$: Government payment of interest on debt to residents in region *r*; $OEXP_r$: Government other expenditures in region *r*; $INTFI_{s,r}$: Payment of interest on debt from region *s* to region *r*; $OINC_r$: Government other income in region *r*; $TTAX_r$: Total tax revenue in region *r*; AIDI*s,r*: international aid inflows from region *s* to region *r*; YH_r: Private household income; YG_r: Government income; $VDEP_r$: Depreciation of factor *f* in region *r*; SAV_HHLD_r : Household saving in region *r*; SAV_GOV_r: Government savings in region *r*; INV_r: Total investment in region *r*; $MTAX_{i,r,s}$: Import duties on imported commodity *i* from region *r* to region *s*; $XTAX_{i,r}$: Export tax for exported commodity *i* from region *r* to region *s*; $PTAX_{i,r}$: Production taxes (comprehensive of sales taxes paid on intermediate inputs, the expenditure on factor use, production taxes) in sector *j* in region *r*; $DTAX_{f,r}$: direct tax on factor *f* in region *r*; $PSTAX_{i,r}$: Sales tax on private consumption of commodity *i* in region *r*; $GSTAX_r$: Sales tax on Government consumption of commodity *i* in region *r*; $ISTAX_{i,r}$: Sales tax on investment of commodity *i* in region *r*; $VTWR_{MRG,j,r,s}$: Trade margins on imported commodity *i* from region *r* to region *s*; $VST_{MRG,r}$: Trade margins on exports of commodity *i* to region *s*; $VIWS_{i,s,r}$: Imports of commodity *i* at world prices from region *r* to region *s*; $AIDO_{r,s}$: International aid outflows from region *r* to region *s*; $INTFO_{r,s}$: Payment of interest on debt from region *r* to region *s.*

Sets: *i*, *j*: productive sectors and commodities; *f*: factors of production; *r*, *s*: regions; *CGDS*: capital good; *MRG:* trade margins;

According to table 2, we rewrite the accounting relations previously described in equations (1) to (7). As previously stated, (3) is replaced by two distinct equations for the household and the government, respectively equations (10) and (11). The endowment of primary factors and total tax revenue are:

$$HF_{f,r} = \sum_i VFM_{f,i,r} \tag{8}$$

$$TTAX_r = \sum_i \sum_s MTAX_{i,s,r} + \sum_i \sum_s XTAX_{i,r,s} + \sum_j PTAX_{j,r} + \sum_f DTAX_{f,r} + \sum_i PSTAX_{i,r} + \sum_i GSTAX_{i,r} + \sum_i ISTAX_{i,r} \tag{9}$$

Household and government incomes by sources become:

$$YH_r = \sum_f HF_{f,r} + TRANS\_GOV_r + OEXP_r - OINC_r + INTD_r + \sum_s INTFI_{s,r} \tag{10}$$

$$YG_r = TTAX_r + \sum_s AIDI_{s,r} - \sum_s AIDO_{r,s} - \sum_s INTFO_{r,s} - INTD_r - OEXP_r + OINC_r - TRANS\_GOV \tag{11}$$

Last two relations must be equal to their respective definition by destinations. Respect to the GTAP formulation, for each agent, final uses of income comprehend expenditures (gross of sales tax) and saving:

$$YH_r = \sum_i VIPM_{i,r} + \sum_i VDPM_{i,r} + \sum_i PSTAX_{i,r} + SAV\_HHLD_r \tag{12}$$

$$YG_r = \sum_i VIGM_{i,r} + \sum_i VDGM_{i,r} + \sum_i GSTAX_{i,r} + SAV\_GOV_r \tag{13}$$

Therefore, the distinction of agents' savings and the introduction of inter-regional transfers modify the Saving-Investment macroeconomic balance that becomes:

$$VDEP_{f,r} + SAV\_HHLD_r + SAV\_GOV_r + \sum_i \sum_s VTWR_{MRG,i,r,s} - VST_{MRG,r} + \sum_i \sum_s VIWS_{i,s,r} - \sum_i \sum_s VTWR_{MRG,i,r,s} - \sum_i \sum_s VXWD_{i,r,s} + \left(\sum_s INTFI_{s,r} - \sum_s INTFO_{r,s}\right) + \left(\sum_s AIDI_{s,r} - \sum_s AIDO_{r,s}\right) = \sum_i \sum_s VIIM_{i,s,r} + \sum_i VDIM_{i,r} + \sum_i ISTAX_{i,r} \tag{14}$$

The last modification consists of the determination of a public and private investment (*GOV_INV*$_r$ and *PRIV_INV*$_r$). Since in GTAP there is a single regional investment (which is a homogenous composite of both types of investment), we split it into its components in order to define a different rule of accumulation in the recursive dynamic version of the model. In other words, we decompose total investments into public and private. Moreover, defining a public investment component allows to have all the fundamental components of the public budget, and to replicate the government net lending/borrowing for the base year. In terms of accounting rules, the model must satisfy the Saving-Investment balance in each region, so we introduce a new accounting identity that guarantees the sum of private and public investments that equals the total regional.

$$GINV_r + PINV_r = \sum_i \sum_s VIIM_{i,s,r} + \sum_i VDIM_{i,r} - \sum_f VDEP_{f,r} \tag{15}$$

In addition to the GTAP database, we used data from IMF Country Reports for the years between 2005 and 2008, especially tables on Balance of Payment and General Government Operation Statements (IMF, 2008/2011). Finally, we consider Gross Domestic Product (GDP) from the IMF World Economic Outlook (IMF, 2014)

Extending this framework requires external sources to evaluate the new entries of the SAM as in Table 2. As already said, the GTAP database is composed of interlinked SAMs, one for each country. For instance, each change in taxes for a country has a subsequent effect on the other SAMs. Thus, to avoid unbalancing the whole structure of the database we mainly focus on the introduction of different types of transfers, considering both intra-regional and inter-regional transfers. Intra-regional transfers consist of social transfers and benefits from the government to the private household, while inter-regional transfers count for inflows and outflows of foreign aid and interest payments on debt.

While intra-regional transfers reflect the official percentage respect to GDP of the IMF Country reports, foreign aids and interest payments require simplifying assumptions. From an accounting point of view, the global flow of foreign aid among countries must be equal to zero, since the total amount of outflows must match the total amount of inflows. Because data has been collected from different sources, the world sum for inflows and outflows was not always zero, as required by the accounting rule. In those cases, we assume the global value of outflows as the most realistic, and we apply regional shares to distribute inflows according to IMF country reports.

Similar simplifying assumptions have been applied to interest payments. From IMF Country reports we derive the total interest payments as a percentage of GDP. In many cases, especially developing countries, there is the distinction between payments to residents and non-residents. When the information is not available, we suppose that the distinction between domestic and foreign debt is a good approximation of interest payments. It is reasonable to assume that if a region has a higher fraction of domestic debt respect to total debt, then it will pay a higher amount of interests to residents instead of non-residents.

As in the case of foreign aid, the global amount of payments to non-residents must be equal to the global amount of payments to residents from abroad. However, this information is often missing. To allocate the global amount among countries we consider the percentage composition of Investment Income by region according to the balance of payments. Then, we portion the world total outflows of interest payments according to the regional share of investment income. We are aware that this procedure may not be the best alternative, but considering the lack of data on bilateral flows of interest payments, we assume that they are paid proportionally to the total credits from investment income.

As previously mentioned we do not want to unbalance the whole structure of the GTAP database, and at the same time we consider the fact that there is an incomplete coverage of countries taxation. Therefore, we introduce two balancing items: other income and other expenditures, which have not any real counterpart in the official statistics but they are useful to replicate exactly the recurrent account deficit/surplus of IMF official data.

4. The within- period specification

Once the benchmark year database has been extended, it is possible to improve the theoretical formulation of the ICES model. In this section we present the mathematical statements for the demand side system only, since the rest of the model remains unchanged. In the extended model, and according to the new SAM, the different agents borrow from each other and receive transfers as well. It is important to highlight that only government receives both domestic and foreign transfers. This means we must introduce transfers within and between regions, as well as interest payments (see section 5 for the definition of the rule). In the following description Greek letters represent fixed shares, while variables with a bar denote the benchmark year value of the variable itself.

Let us start from the private household in region *r*. Private income is modified to consider the new income sources (equation 16). All new income sources are defined in equations (17)-(20). Transfers are fixed shares of the income of the agent paying out the transfer. For instance, social transfers from government to the private household are a fixed share ($\alpha_{TR,r}$) of the government income. Similarly, other expenditures and other income (the balancing items of the new SAM) are respectively fixed shares of government and household income (according to shares $\alpha_{OGE,r}$ and $\alpha_{OGI,r}$). Interest income to households is the sum of interest paid from the domestic government and interest from abroad.

$$YH_r = YHL_r + YHK_r + YHTR_r - YHOGI_r + YHOGE_r + YHI_r \tag{16}$$
$$YHTR_r = \alpha_{TR,r} \cdot YG_r \tag{17}$$
$$YHOGI_r = \alpha_{OGI,r} \cdot YH_r \tag{18}$$
$$YHOGE_r = \alpha_{OGE,r} \cdot YG_r \tag{19}$$
$$YHI_r = INTD_r + INTI_r \tag{20}$$

As in the GTAP model, the aggregate regional private consumption and savings are fixed shares ($\beta_{PEXP,r}$) of the private income level, while private consumption is the sum of the single commodity consumption, where PP_r and $PPRIV_r$ are prices and QP_r and $QPRIV_r$ quantities, respectively.

$$PRIV\_EXP_r = \beta_{PEXP,r} \cdot YH_r \tag{21}$$
$$PRIV\_EXP_r = PPRIV_r \cdot QPRIV_r \tag{22}$$
$$PPRIV_r \cdot QPRIV_r = \sum_i PP_{i,r} \cdot QP_{i,r} \tag{23}$$
$$PRIV\_SAV_r = (1 - \beta_{PEXP,r}) \cdot YH_r \tag{24}$$

Private investment is a balancing item since it is computed as the difference between total regional investment (net of depreciation) and public investments:

$$PRIV\_INV_r = NETINV_r - GOV\_INV_r \tag{25}$$

The same reasoning is applied to government.

$$YG_r = TTAX_r - YHTR_r + YHOGI_r - YHOGE_r - YGI_r + AIDI_r - AIDO_r \tag{26}$$

Equations (27)-(29) show the definition of the new variables. YGI_r representing the total amount of interest paid from a government (so it is the sum of payment to residents and non-residents). Outflows of grants (AIDO) are a fixed share of government income, multiplied by a scaling parameter ($aidout_r$) which reflects the change in the global amount of grants to be allocated. Inflows of grants (AIDI), are simply rescaled considering the initial level.

$$YGI_r = INTD_r + INTO_r \tag{27}$$
$$AIDO_r = \alpha_{AIDO,r} YG_r \cdot aidout_r \tag{28}$$
$$AIDI_r = \overline{AIDI_r} \cdot aidin_r \tag{29}$$

As already discussed in the construction of the extended SAM, there is no bilateral matrix to track international transfers (i.e. grants), so we created an artificial accounting agent which collects all outflows and distribute them to the countries. This leads to a clearing condition in the global market of aid of this kind:[5]

$$\sum_r \overline{AIDI_r} \cdot aidin_r = \sum_r \overline{AIDO_r} \cdot aidout_r \tag{30}$$

Regional real government expenditures are a fixed share of real regional GDP,[6] while nominal expenditures are the sum of the single commodity consumption.

$$GOV\_EXP_r = PGOV_r \cdot QGOV_r \tag{31}$$
$$QGOV_r = \beta_{GEXP,r} \cdot QGDP_r \tag{32}$$
$$PGOV_r \cdot QGOV_{r_r} = \sum_i PG_{i,r} \cdot QG_{i,r} \tag{33}$$

Current government savings are simply the difference between net revenues and consumption of goods and services.

$$SAV\_GOV_r = YG_r - GOV\_EXP_r \tag{34}$$

[5] A similar clearing condition is present in MyGTAP (Minor and Walmsley, 2013b), following the treatment of international transfers according to McDonald and Sonmez (2004).

[6] The choice of government consumption as a share of GDP follows the approach in Env-LINKAGES (Chateau *et al.* 2014). However, how to model expenditures is strictly connected to the public sector closure and the kind of policy to analyse. For a detailed description of the options see section 6.

Government investment is financed through current government savings and borrowing from residents and non-residents.

$$I\_GOV_r = SAV\_GOV_r + GBOR_r \tag{35}$$

Note that a positive value of the variable $GBOR_r$ means a deficit, thus the government is borrowing, while a negative sign means a surplus so that the government is a lending resources.

5. The between- periods specification: debt and interests

ICES-XPS is a recursive dynamic model, thus each year is linked to the previous one via capital accumulation. The structure of the debt accumulation for the government is close to the capital accumulation. There is a stock from the previous simulation year ($GDEBT_{t-1,r}$) which is increased by government's borrowing in the current simulation year ($GBOR_{t,r}$). Denoting the current simulation year as *t* and the previous year as *t-1*, we have the following accumulation rule:

$$GDEBT_{t,r} = GDEBT_{t-1,r} + GBOR_{t,r} \tag{36}$$

Then, we split the accumulation rule to consider the repayment of debt for domestic and foreign households according to a fixed share $fdshr_r$, defined as the share of foreign debt on total debt in region r in the base year. So equation (36) becomes:

$$GDDEBT_{t,r} = GDDEBT_{t-1,r} + (1 - fdshr_r) \cdot GBOR_{t,r} \tag{37}$$

$$GFDEBT_{t,r} = GFDEBT_{t-1,r} + fdshr_r \cdot GBOR_{t,r} \tag{38}$$

Interest payments on government's domestic and foreign debt stocks are defined as an exogenous interest rate (ir_r) multiplied by each previous year debt stock.[7]

$$INTD_{t,r} = ir_r \cdot GDDEBT_{t-1,r} \tag{39}$$

$$INTF_{t,r} = ir_r \cdot GFDEBT_{t-1,r} \tag{40}$$

Similarly to the case of international grants, there is a clearing condition also in the world market for interest payments:

$$\sum_r INTI_{r,t} = \sum_r INTF_{r,t} \tag{41}$$

[7] Interests' payments of public debt suggest that the government finances its debt through public bonds. According to Lemelin and Decaluwé (2007) "*interest payments are nothing but a consequence of indebtedness: the higher the level of indebtedness, the heavier the burden of interest payments on the government budget*".

Moreover, each country receives an amount of interests from abroad that depends on the mean value of the interest collected in the world market (from equation 41), and on a scaling parameter (*psavhr*$_r$) which represents the country contribution to world private investment. Since interests are paid on previous year debt, the scaling parameter is calculated on those values:

$$psavshr_{r,t-1} = \frac{SAV\_PRIV_{r,t-1}}{\sum_r SAV\_PRIV_{r,t-1}} \tag{42}$$

This share reflects the contribution of each country household to finance total world debt. Since public and private savings are homogenous goods, private households lend a fraction of their savings to governments. As a consequence, the public agent pays interests to the household. If households save more, they could devote a higher fraction of their savings to finance public debt. This means that at time t+1 they obtain higher interest payments.

Therefore, foreign interest inflows become:

$$INTI_{r,t} = INTAVI_r \cdot psavshr_{r,t-1} \tag{43}$$

6. The closure rule in the public sector

In each CGE model, the public sector closure defines the causality the government follows to fulfil its budget constraint. According to Lofgren *et al*. (2013), this closure rule "is an important part of the simulations in the country studies of a project". Indeed, the choice of the closure rule is fundamental for the subsequent analysis. To better understand the causality of each closure rule choice, and eventually its implications in terms of a research question, we consider a simplified setup. There is only one type of government revenue, a tax on household income (with tax rate ty, and tax base Y_H), and the government consumes only goods and services for a total amount of C_G. Government savings (SAV_G) is the difference between revenues and expenditures.

$$Y_G = ty * Y_H \tag{44}$$

$$C_G = \sum_i Q_G \cdot P_G \tag{45}$$

$$SAV_G = Y_G - C_G \tag{46}$$

A first possible closure rule is to impose a fix tax rate, and an exogenous level of consumption. In this case the government savings moves and adjusts according to the level of revenues. This type of closure addresses the effect of a change in revenues on the final budget. Although the tax rate is fixed, the total amount of revenues changes as a consequence of changes in the tax base (here the level of household income). The assumption of fixed government consumption assumes that there is a minimum level of expenditures in the public sector which could not be altered.

Conversely, the closure rule could impose a fixed government saving level, because, for instance, the government may consider a certain level of borrowing as acceptable. In this case, however, another variable should become endogenous to change accordingly. There are two alternatives: either the tax rate or the level of consumption could be endogenous. The two choices represent two alternative policy options. Whenever we consider an endogenous tax rate, we get a tax rate level such that to maintain both the desired level of consumption and a predetermined level of savings. Consumption adjusts to achieve the desired level of savings given a fixed tax system.

Most of the CGE models considering an explicit government agent assume the second closure rule for public savings. They set an exogenous level of public saving and some instruments are considered as endogenous: (i) a specific tax rate, or (ii) transfers from the government to households. This is the case of the OECD Env-Linkages model, which assumes no changes in real public savings because “predicting corrective government policy is not an easy task” (Chateau et al., 2014). Conversely, the Globe model (McDonald et al., 2007) assumes in its base specification that government savings are a residual. This ensures that all parameters controlled by government are fixed (i.e. tax rates, quantities of goods and services consumed), consequently the only determinants of government income and expenditures that may change are those under no direct control of the government. Therefore, the balancing condition is that government savings is not fixed.

7. Model tests

To test ICES- XPS, we consider two different types of exercises. Firstly, we highlight the main advantages of using this enhanced version respect to the standard model. Secondly, we simulate a climate policy to demonstrate how the model works along with the flexibility of the closure rule choice in addressing different policy issues. For this purpose, we divide the world in 9 regions with 12 sectors within each region as shown in Table 3.

Table 3: Regional and sectoral aggregation

No.	*Regions*	*No.*	*Sectors*
1	EU	1	Agriculture
2	RoEurope	2	Coal
3	FSU	3	Oil
4	NorthAmerica	4	Gas
5	LACA	5	Oil_Pcts
6	MENA	6	Ely_Nuclear
7	SSA	7	Ely_Renew
8	ASIA	8	Ely_Other
9	Oceania	9	En_Int_ind
		10	Oth_ind_ser
		11	Construction
		12	Pub_Serv

a) A static comparison of ICES and ICES- XPS

For this first test, we consider two simple static experiments imposing changes only in the EU region and compare the results of ICES without the detailed public sector and ICES-XPS, to highlight the advantages of introducing explicitly the public sector in the analysis. First, we impose a 5 percent cut in labour taxes, and then a 5 percent reduction in labour use tax rates across sectors. For the ICES-XPS closure rule, we assume that government consumption is fixed at benchmark year levels in order to isolate the effects of tax changes on public budgets. The table below summarizes the outcomes in EU for the two models (ICES and ICES-XPS).

Table 4: Results of a 5% reduction on labour tax and labour use tax rates in EU (percentage changes)

Detail	Labour tax		Labour use tax	
	ICES	ICES-XPS	ICES	ICES-XPS
GDP	0	+0.1	+0.001	+0.1
Private consumption	0	+1.4	+0.01	+1.6
Public consumption[1]	0	0	-0.03	0
Investments	0	-0.1	+0.01	-0.2
Exports	0	-1.5	+0.01	-1.6
Imports	0	+0.5	+0.01	+0.6

[1]In ICES-XPS percentage variation of public consumption is null because of the closure rule choice.
All variables are considered in real terms

The first two columns compare the outcomes when a reduction in labour tax is implemented. In the standard ICES model this shock has no effect on GDP, private and public consumption, investments nor international trade, both in nominal and in real terms. This is a direct consequence of the "regional household" assumption. Indeed, a reduction in labour tax rate of 5 percent means a higher disposable income for the household and a contemporaneous reduction in income tax revenue of the same amount (295 $ billion). Since consumption (both private and public) and saving decisions are a fixed fraction of the regional income, they do not change. Finally, this leads to no changes in investment demand and foreign trade. However, ICES-XPS produces different results. The reduction in labour tax increases the available income for the private household which increases its private consumption level (consistently with the Cobb-Douglas function). Government consumption is exogenously set to zero in real terms. Higher imports are mainly driven by the increase in private consumption while exports decline because of a reduction in sectoral production of energy intensive industries. The output reduction in these sectors is caused by an increase in labour price, since they have a high share of labour in their cost structures (66% in the base year). Investments decline slightly.

Government income reduces by -2.1% (84 $ billion), while tax revenue reduction is nearly 254 $ billion (-295 $ billion is the direct reduction in income tax while the second round effect for indirect taxes counts for 40 $ billion). The reduction in government income is lower than the change in total tax revenue because of the reduction in net transfers paid to other agents (-170 $

billion). Because of the closure rule, public expenditures in goods and services and in investments move according to their prices.[8] Therefore they rise in nominal terms by 0.56% (+19 $ billion) and 0.52% (+3 $ billion) respectively. The final net effect is an increase in public deficit by +55.9% (107 $ billion). As explained in section 5, saving is a homogenous good at the regional level; this means that the higher public deficit is compensated by regional public savings which partially close the gap. Investment demand is determined by two elements: the differential in country and world rate of returns to capital and GDP growth rates. Furthermore, the former is affected by the regional saving price level which in turns depends on the available regional savings. Finally, government debt stock increases of the same amount of the post- simulation deficit, which means a 1.1% growth.

Columns 3 and 4 summarises the results of a 5 percent drop in labour use tax rates in all sectors showing the differences between models. For ICES, GDP growth is negligible. The tax cut not only stimulates exports given lower domestic production costs, but also slightly increases imports and investments. In absolute terms, the increase in exports is higher than the effect on import. The increase in investments is a combination of three elements: (i) the positive sign in GDP growth, (ii) the lower savings price level, (iii) the higher differential in rates of return of capital in the region and at the world level.

Because of the regional household assumption, private consumption and government consumption in nominal terms grow at the same rate, although in real terms private consumption slightly increases while public consumption declines. It depends on the composition of expenditures in the base year. Private household consumption has a higher level of domestic expenditures which lowers because of the tax cut (especially in the agricultural sector); public government, instead, has a differentiated consumption basket where goods with higher prices are a higher fraction (the most evident price reduction is in the domestic agricultural commodities which counts only for 0.002 percent of total government domestic consumption in the base year).

In the case of ICES-XPS, the decline in labour use tax slightly stimulates the production in labour intensive sectors with high tax rates. As a consequence, there is an increase in GDP. Then, lower production costs due to lower labour taxation, reduce market prices for commodities and stimulates final uses, mainly private consumption. Total tax revenue declines by 340 $ billion. The direct effect of the tax cut is a loss of 456 $ billion for factor use tax, while the induced changes in other revenues count for additional 108 $ billion in direct taxation revenue and 7 $ billion in the other indirect taxes. Government income declines by 3.4% (-136 $ billion) because there is a reduction in expenditures for net transfers (-205 $ billion). Public expenditures and investments are unchanged. This causes the growth in government deficit (+61.7% or 118.7 $ billion) and the

[8] As mentioned at the beginning of the section, the definition of the closure rule for the public sector is considered in real terms. Ultimately, this means that public expenditure moves according to price changes while its quantity is fixed at the base year level. This is coherent with the definition of the budget of the government, whose elements (including expenditures) are defined in nominal terms. Moreover, final indicators of the public sector, such as deficit and debt levels are in nominal terms as well.

consequent rise in debt stock (+1.2%). The increase in government deficit reduces the available regional savings and this has negative effects on investments. This effect is emphasized by the high saving price level which reduces the differential between regional and global rate of return for capital. The final effect on investment is quite reduced because of the positive effect of GDP growth in the investment allocation of the Global Bank.

The two models give similar results in terms of GDP and production, but they differ in terms of trade balance and investment demand. This is a consequence of the elimination of the regional household assumption. Although in ICES-XPS considers saving as a homogenous good, it deems private and public saving as perfect substitutes, so these two variables are outcomes of differentiated choices. This means that the final level of regional saving is no longer equal to the ICES standard model. Moreover, in the ICES standard model savings are completely exogenous and a fixed fraction of regional income, in the ICES-XPS model this is no longer the rule: we have in its basic closure an endogenous government saving level while households' savings are as usual fraction of their own income. To close the gap in the saving- investment balance the trade balance moves accordingly.

The introduction of an autonomous government and the elimination of the regional household assumption in ICES-XPS allow us to analyse changes in direct taxation, which in ICES are not captured because of netting out effects on household and government income that are aggregated as regional income. Moreover, extending the public sector allows us to show effects on the international allocation of investment related to the public indebtedness level.

b) A dynamic experiment: the effects of a carbon tax with different closures for the public sector

In this case we simulate a carbon tax in a dynamic recursive setup. The aim is to analyse the effects on fiscal variables (i.e. tax revenues, public consumption, government borrowing and debt accumulation) and on the economy as a whole (GDP and its macro components), following two different closure rules.

We use as a reference case the SSP2 scenario considering the corresponding population and GDP growth. The time horizon is 2007-2030. The World is aggregated in 9 macro regions as already shown in Table 3. The carbon tax is applied only in the EU and the following results will focus only in this region.

We compare our results with five studies about GDP effects of a carbon tax (Bohringer et al., 2009; Bosello et al., 2013; Durand-Lasserve et al., 2010; Orecchia and Parrado, 2013; Peterson et al., 2011). These studies consider a 20% reduction in emissions in EU27 and they estimate an effect on GDP ranging from +0.1% to -2% in 2020 with a carbon price ranging from 19 €/tCO_2 to 70 €/tCO_2. In this exercise we assume a value of 54 \$/tCO_2 (40 €/tCO_2) in 2020 and 95 \$/tCO_2 (70 €/tCO_2) in 2030. Regarding the public sector, we first assume that all the parameters the government could control are fixed and that its borrowing is a residual, thus, it adjusts according to the difference between revenues and outlays. The research question in this case aims at quantifying the positive effect of a implementing a new (carbon) tax on public borrowing and public deficits. Then, following different closure rules for the public sector it is possible explore how the carbon tax revenues could be recycled to lower other distortionary taxes assuming a revenue neutral policy to fulfil a target on public deficit.

To answer this question, we compare a baseline scenario, which is a reference scenario of how the economic system grows, with a scenario where the carbon tax is imposed (CTAX scenario) and then with a scenario where the carbon tax is used to lower distortionary burdens of labour tax (CTAX-recycle scenario). Table 5 summarises the main findings for EU comparing the baseline with the alternatives.

Table 5: Effects of two carbon tax scenarios on EU in 2030 (% changes with respect to baseline)

Macroeconomic data[1]	CTAX scenario	CTAX-recycle scenario
GDP	-1.25	-1.32
Investments	-1.65	-2.42
Private consumption	-2.31	-1.18
Public consumption	0	0
Exports	-2.50	-2.29
Imports	-1.32	-2.62

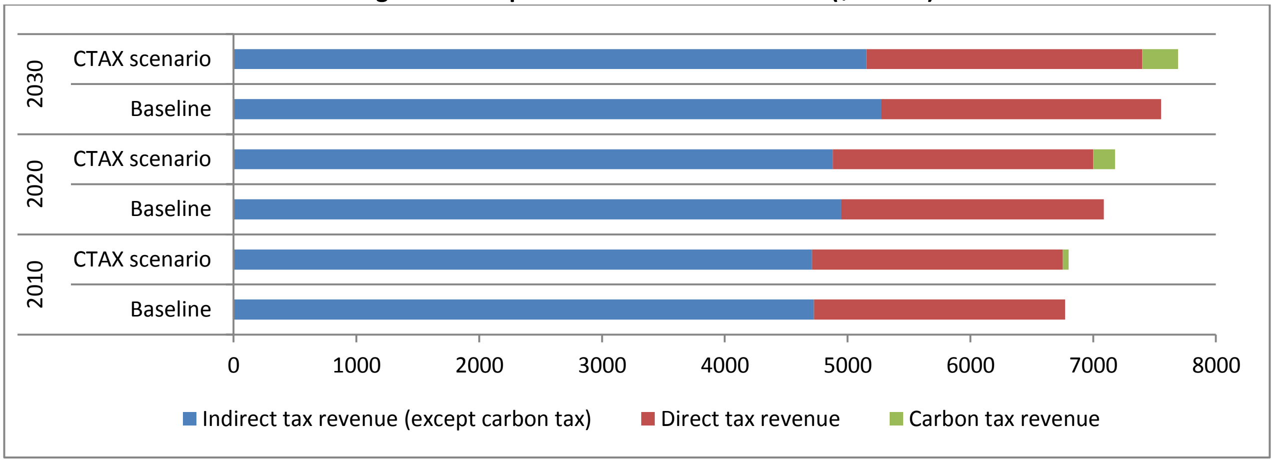
[1] Macroeconomic data are provided in real terms

The reduction of GDP due to the carbon tax is within the range of the five studies cited previously. The economy is affected by a price effect. Pollutant commodities face a higher final price in the market. This affects both the production and the consumption side. From a producing point of view, fossil fuel commodities are more expensive as intermediates, thus all sectors reduce their demand. Therefore, polluting sectors lower their production. Final consumers face a higher market price so that they also reduce their consumption. This is one of the basic features of the carbon tax itself: it changes consumption behaviour in the economy. Exports and imports decline because of a contemporaneous reduction in total regional production and final demand.

The net effect on investment is negative because the negative effect on GDP prevails over the positive effect on the differential between regional and world rates of return of capital. Indeed, raising a carbon tax with endogenous government deficit allows the government to increase its income and lower the deficit level. Consequently, regional savings are higher than in the reference scenario. Increasing regional savings lower the price of saving also lowering the regional rate of return of capital.

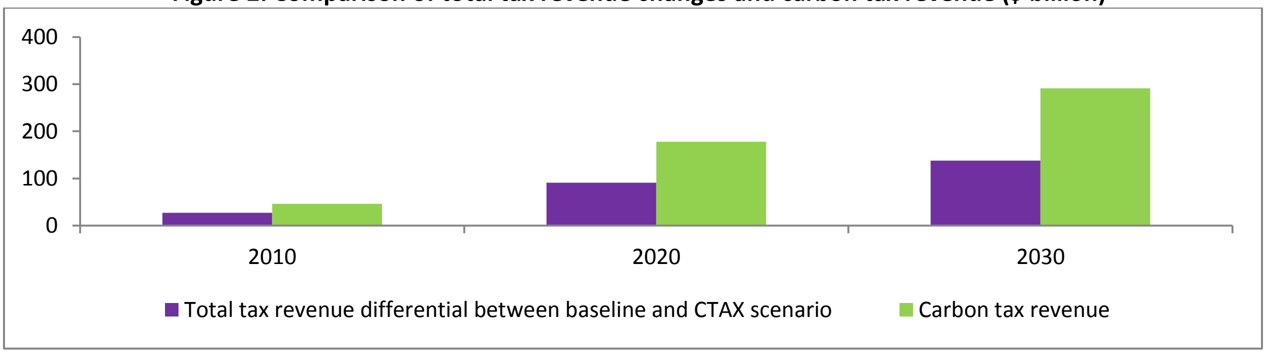
Another crucial element to analyse is how tax revenue changes over time considering the base erosion principle. Figure 1 shows the tax revenue decomposition in its three main components-direct, indirect and carbon tax revenues in 2010, 2020 and 2030.

Figure 1: Composition of total tax revenue ($ billion)



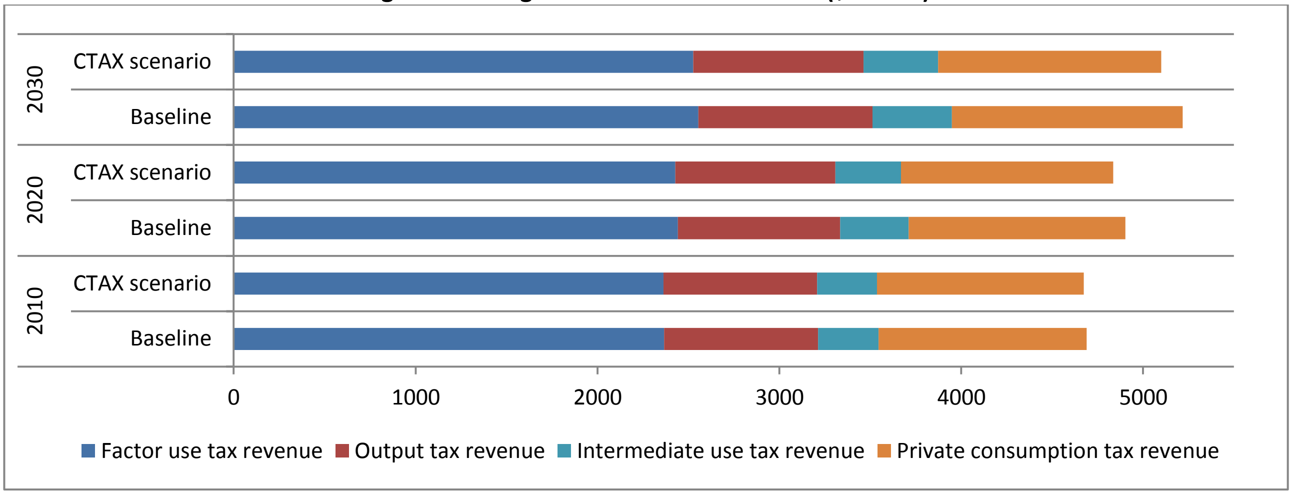
When the carbon tax is implemented, tax revenues increase along the time period. However total tax revenues increase less than the carbon tax revenue. Indeed, this tax has a negative consequence since it erodes its tax base. Comparing variations on total tax revenue and the carbon tax revenues, the total increase in tax is lower than the carbon tax revenue as Figure 2 depicts. In other words, in 2010 nearly 42% of carbon tax revenue is eroded by other tax revenue drop; the percentage erosion increases to 52% in 2030.

Figure 2: Comparison of total tax revenue changes and carbon tax revenue ($ billion)



To better understand the causes of this phenomenon, we decompose indirect tax revenues to highlight which taxes changes as a consequence of the new carbon tax (see Figure 3). The main changes affect three producer taxes (tax on output, factor use and intermediate use) and the private consumption tax.

Figure 3: Changes in selected tax revenue ($ billion)

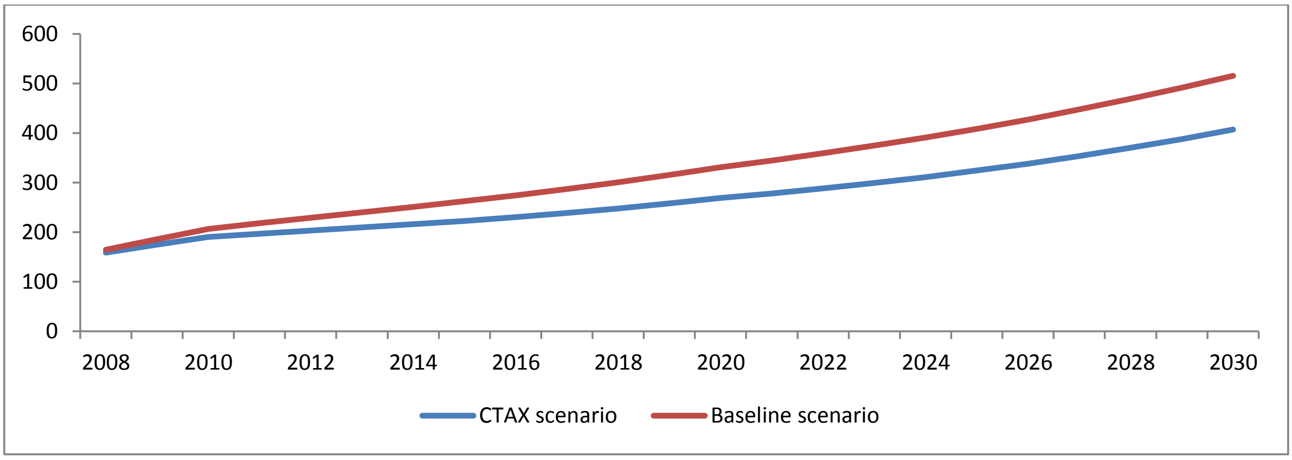


The factor use tax drop is caused by the reduction in production of the polluting commodities which has to pay a higher output tax on final products and in the substitution in the nest energy-capital. This tax does not decline uniformly among producing factors but the highest reduction is in the labour and capital use taxation. In 2030 their reductions respect to the same year in the baseline scenario count for 48% and 45%, respectively. Finally, this tax counts for 23% in total indirect revenues reduction. The output tax reduction is limited to the fossil fuel sectors (coal, oil, gas and oil products) which count for 65% of the output tax reduction, while the energy intensive industry, other industry and services, and construction sectors account for the remaining 35%. The output tax is the smallest contributor respect to the other indirect tax revenue falls, counting for only 19%. The intermediate use tax diminishes because of the reduction in fossil fuel intermediates use due to their higher prices. Its relative weight in total indirect taxation revenue is nearly the same of the factor use tax drop (22%), suggesting a clear link between the two tax performances. Finally, private consumption tax revenue drastically reduces because of the tax base erosion of the carbon tax. The sole reduction in this tax revenue counts for 35% on the total change in the CTAX scenario in 2030 compared with the same year in the baseline scenario.

Results on tax revenue after the introduction of the carbon tax do not contradict Böhringer and Rutherford (2013). They suggest an interaction effect of raising a new tax in a distorted tax system which exacerbates the negative interactions in the economy.

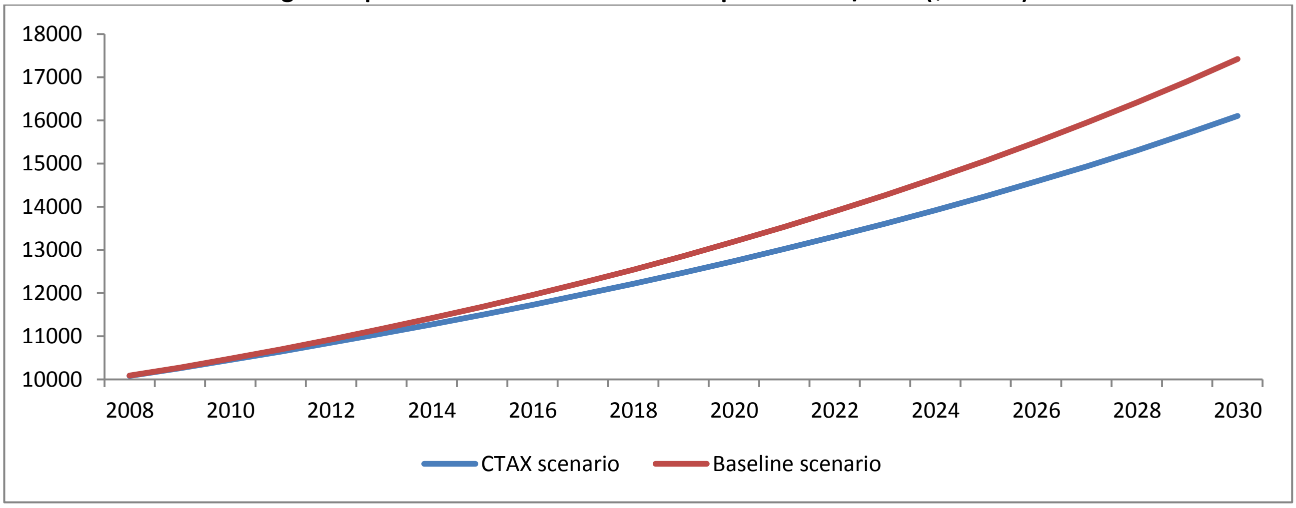
As already described, carbon tax revenues lower the deficit level and the borrowing needs of the government (see Figure 4). In the CTAX scenario public deficit is lower than in the reference scenario by 21% (or 109 $ billions) in 2030.

Figure 4: public deficit evolution in the period 2008/2030 ($ billion)



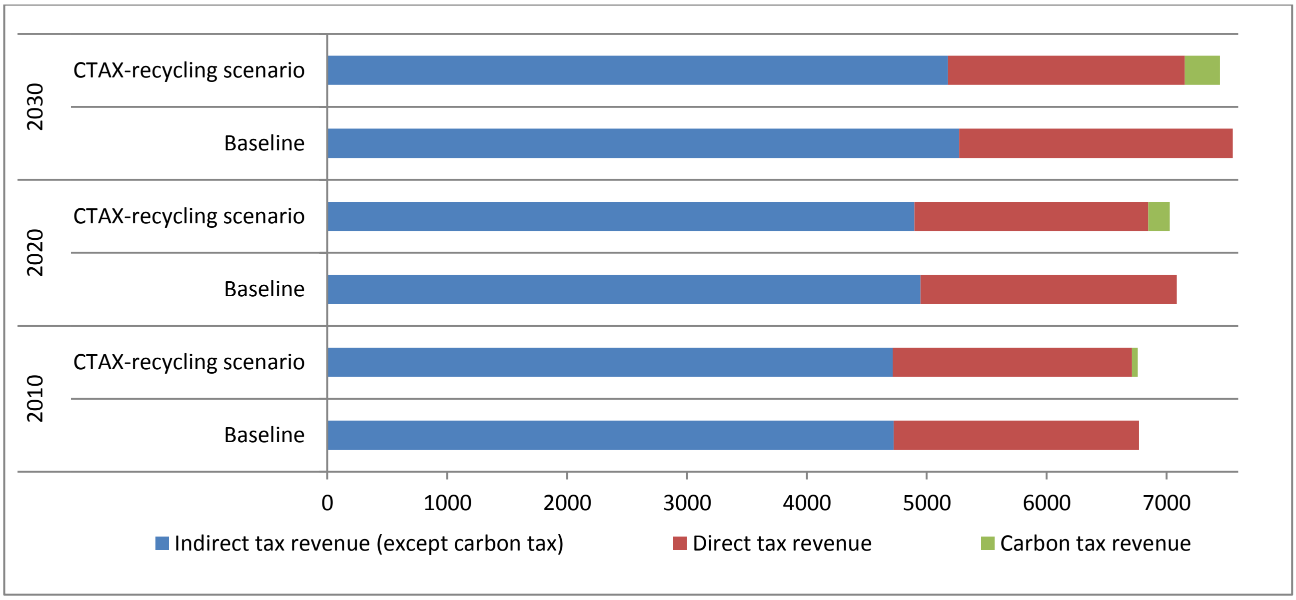
Therefore, the government debt accumulation is lower in the CTAX scenario than in the reference case (see Figure 5). In 2030 public debt reduces by 7.5% respect to the reference scenario (1319 $ bllions). The slope of the government debt accumulation in the baseline scenario is steeper than in the counterfactual.

Figure 5: public debt accumulation in the period 2008/2030 ($ billion)



Since in ICES-XPS the government closure is relevant, it is also important to see what happens with the same carbon tax but considering a different closure rule. Here, we assume that the government targets its deficit level fixing it as in the baseline scenario. So the carbon tax revenue is not used to lower public deficit but to alleviate distortionary taxation in the economy, such as the labour income tax. In this case results are not so different respect to the previous one. The economy faces a decline in GDP growth mainly caused by a more evident reduction in investment demand. Private consumption increase respect to the previous experiment because of the higher level of disposable income for the private household. Figure 6 depicts the composition of total tax revenue and its breakdown in its main components. In the CTAX- recycling scheme total tax revenue decreases by 59 $ billion in 2010 and by 399 $ billion in 2030.

Figure 6: Composition of total tax revenue in the baseline and CTAX recycling scenarios ($ billion)



This scenario shows the same effect on final tax revenues but with a more evident reduction in direct taxation than in the indirect tax rate because of the recycling scheme. In fact, the share of carbon tax eroded by indirect tax revenue reduction ranges between 21% in 2010 and 32% in 2030. Comparing the CTAX scenario and the CTAX-recycling scenario there is a different pattern in indirect tax revenues. The decline in intermediate uses and output taxes is equal in both scenarios, since they are solely a consequence of the carbon tax introduction. Conversely, private consumption tax and factor use tax are higher than in the previous exercise. Table 6 below compares the changes in indirect tax revenues in the two counterfactuals respect to the baseline scenario.

Table 6: Changes in indirect tax revenues in CTAX and CTAX-recycling scenarios respect to baseline scenario ($ billion)

	CTAX scenario			CTAX- recycling scenario		
	2010	**2020**	**2030**	**2010**	**2020**	**2030**
Factor use tax revenue	-2	-10	-20	-3	-15	-27
Output tax revenue	-2	-12	-23	-2	-12	-23
Export subsidies	0	0	0	0	0	0
Import duties	0	0	0	0	0	-1
Intermediate uses tax revenue	-3	-15	-27	-3	-15	-27
Private consumption tax revenue	-3	-13	-23	-6	-24	-41
Public consumption tax revenue	0	0	0	0	0	0

Overall, the reduction in indirect tax inlays in the CTAX recycling scenario ranges between 64.5% and 78.6% of CTAX scenario. In this last exercise total carbon tax revenues are used to compensate the reduction in labour income tax rate and this demonstrates the final effect on total tax revenue. Considering only income tax, its revenues decline more than the carbon tax revenue.

Although the drop in labour income tax counts for 94.5% of total income tax decline, there is a slight decrease in capital income tax and taxes from fossil fuels' natural resources as well. The recycling scheme allows the government to lower the labour income tax rate from 35% to 28%. Because of the closure rule, both public deficits and debt stocks are equal to the baseline scenario.

8. Conclusions

This paper describes an extended version of the ICES model, the ICES-XPS model with an improved description of the public sector. After reviewing literature on different approaches to incorporate a public sector in CGE models, we present both the base data and the equations of the ICES-XPS. The base data requires including a detailed public budget with additional outlays and receipts. Satellite statistics and other external sources are necessary for this. The mathematical statement of the model is provided with a description of the flexibility in public sector closures. The extension of the implies different stages: (i) the elimination of the regional household assumption, (ii) the introduction of an enhanced public budget with intra- and inter- regional transactions involving the government, and (iii) the definition of the yearly deficit and accumulation of government debt stock.

Finally to test the extended ICES-XPS model, we run some illustrative numerical examples. Firstly, in a static framework we highlight the advantages of the enhanced version respect to the standard model. The outcomes of ICES-XPS show that this version allows the possibility to analyse the effects of changes in direct taxation, as a consequence of the elimination of the assumption of the representative regional household. The reduction in labour use tax rate in both model versions shows results with the same sign in terms of GDP and private consumption, while they differ in terms of investment and trade balance. This is a consequence of the changes in the saving-investment balance because of the introduction of government savings and private savings as outcomes of different behaving agents.

Finally, in a recursive dynamic framework, we compare a climate policy following two different closure rules to analyse the flexibility of ICES-XPS. Both experiments show results close to existing studies about the GDP costs of implementing a carbon tax. The experiments show that within the same model and framework it is possible to consider a carbon tax either as an instrument to lower the burden of public deficit or as additional revenues to subsidise labour income.

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