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Abstract:

Climate change impacts and public adaptation have manifold effects on public budgets both on the expenditure and revenue side, which calls for instruments to mitigate these effects such that the provision of fundamental public services such as health or education can remain at the same level as without climate change. This paper therefore compares different instruments to counterbalance expenditure cuts induced by climate change impacts and adaptation within a CGE framework. When comparing the climate change scenario to the baseline scenario, we find that revenues – and thus expenditures – decline. When adding different instruments to counterbalance this effect, we find that there are large differences in budgetary and macroeconomic consequences across instruments. While an increase in capital or output taxes reduces the welfare losses of climate change, higher labor taxes amplify welfare losses. Also increased foreign lending has positive macroeconomic effects but leads to a higher deficit.

JEL codes: Q54; Q58; H23; C68.

Keywords: climate change adaptation; public finance; tax policy; policy analysis; CGE

1. Introduction

Fiscal sustainability or austerity is an important target for many countries across the world, which requires a balance between tax revenues and public expenditures on the national level. However, climate change impacts and adaptation may lead to higher public expenditures for e.g. disaster relief payments to households, or reconstruction and adaptation of infrastructure (see e.g. Perry and Ciscar, 2014), causing an imbalance in public budgets. But climate change impacts also have adverse effects on the private sector such as tourism or agriculture, curbing output and income (see e.g. Aaheim et al., 2012; Ciscar et al., 2014; Steininger et al., 2015), leading to lower tax revenues via a reduced tax base. This indirect effect amplifies the budgetary imbalance even more. For a comprehensive assessment of climate change impacts and adaptation on public budgets, it is therefore necessary to not only look into the direct effects of increased expenditures but also into the indirect effects of a reduced tax base (Jones et al., 2013; Lis and Nickel, 2010).

Eventually, the interplay of higher climate induced expenditures on the one side, and reduced tax revenue on the other side, leads to less available budget for other public service provision such as health and education. In this paper, we thus analyze the combination of direct and indirect effects on public budgets as well as welfare and explore different fiscal instruments to counterbalance the negative effects on public service provision and on welfare.

The consequences of climate change for public budgets have been mostly addressed for mitigation. Both theoretical and empirical models were used to assess whether a double dividend emerges when a carbon tax or an emissions trading scheme is introduced and when revenues are used for reducing distortionary taxes (Goulder, 1995; Jorgenson and Wilcoxen, 1993; Parry, 1995; Pearce, 1991; Repetto et al., 1992). Whether a double dividend arises or not depends on the relative size of the tax interaction and the revenue recycling effect (for a review, see Bor and Huang, 2010; Goulder, 2013). More recently, the focus has shifted towards fiscal consolidation. Fischer and Fox (2012) analyze how labor tax recycling can be used to reduce carbon leakage in case of a unilateral policy. Rausch (2013) investigates how carbon pricing can be used to reduce government debt, i.e. to achieve fiscal consolidation. Franks et al. (2015) compare a carbon tax to a capital tax as a means to finance public infrastructure and find that a carbon tax allows for capturing resource rents whereas capital taxes cannot be raised due to international tax competition.

For climate change impacts and adaptation, the question of implications of public finance is a comparatively new one. Early estimates are provided by the World Bank (2010) who estimate additional investment requirements by the public sector and by Osberghaus and Reif (2010) who provide back-of the envelope estimates for the direct costs of climate change for public budgets in the European Union. Leppänen et al. (2015) estimate the effects of changes in climatic conditions for Russian regional government expenditures for the period 1999-2005 and find a comparatively small positive budgetary effect due to higher temperatures (milder winters).

A related strand of literature addresses the consequences of natural disasters and extreme events for public budgets. Lis and Nickel (2010) use data from an extreme event database to estimate the impact of extreme events on the change in the budget balance for a panel of 138 countries. Hochrainer-Stigler et al. (2014) assess the vulnerability of public finance to disaster risks by looking into the public sector’s ability to rebuild public infrastructure and to undertake disaster relief payments to the affected population.

One shortcoming of the existing literature on budgetary effects of climate change impacts and adaptation is that they are limited to the direct effects on public expenditures, but that they do not address the indirect impacts via reduced government revenues due to sectoral and macroeconomic effects of climate change (for a qualitative review, see Bräuer et al., 2009). But climate change has manifold impacts on economic sectors and households, e.g. changes in productivity, production cost structures, final demand or investment, affecting sectoral output and disposable income and hence change the tax base.

In this paper, we first analyze both direct and indirect effects of climate change impacts and adaptation on public budgets until mid-century. For that purpose, we use a computable general equilibrium model of the Austrian economy which takes account of climate change impacts in ten climate sensitive sectors as well as public expenditures for disaster relief and reconstruction of public infrastructure (Bachner et al., 2015a, 2015b). Second, as these "forced" expenditures divert public spending from other purposes like education and health, we analyze different fiscal instruments as well as the option of foreign lending which can be used to reestablish these public expenditures to the baseline level without climate change. Third, we compare the effects of these different instruments not only for the budget balance but also for welfare and GDP.

The paper is structure as follows. Section 2 explains the methodology, starting with a non-technical description of the CGE model, followed by the implementation of climate change impacts with an qualitative analysis of the resulting effects on public budgets and finally states the identified and implemented fiscal instruments. Section 3 gives the results of the numerical quantitative analysis. Section 4 wraps up by discussing the results and giving conclusions.

2. Methodology

2.1. Non technical model description

To analyze the budgetary effects of climate change impacts and adaptation, we use a single-country, comparative static computable general equilibrium (CGE) model of Austria (see Appendix for technical details and the algebraic formulation). The model covers 40 economic sectors using intermediate inputs as well as the two production factors labor and capital to create output according to nested constant elasticity of substitution (CES) production functions. There is one representative household, which is endowed with labor and capital. The respective factor income is spent for consumption (modeled as a nested CES function). In addition to the representative household there is a government entity which provides public goods and services, financed solely via the following taxes: sales taxes on output, tax on capital gains, labor tax, value added tax and export tax. Hence, tax income always equals government expenditure. All taxes are initially implemented as fixed rates and thus determine flexible government income, which in turn gives the total amount of available public budget. Regarding the labor market, the model includes unemployment, triggered by a minimum wage. International trade is depicted via the ‘Armington’-assumption; meaning that goods/services coming from abroad or being produced domestically are not perfectly substitutable (Armington, 1969). The foreign balance is fixed at the share of the benchmark year (2008).

Concerning the time horizon we implement a baseline scenario for Austria up to 2050 (representing on average the period 2036-2065), which entails economy wide assumptions about economic growth (1,65% p.a.), climate policy (via an exogenous CO_2 price of 41 €/t), as well as the energy and agricultural sector (Bachner et al., 2015a; König et al., 2015). Since we are interested in the additional effects of climate change, relative to a development without climate change, this baseline scenario serves as a reference to compare a climate change scenario with.

2.2. Climate change impacts and adaptation and their effects on public budgets

Having constructed a baseline scenario as a reference point, climate change impacts, and to a limited degree public planned adaptation, are identified and implemented across ten climate change ‘impact fields’: *Agriculture*, *Forestry*, *Water Supply and Sanitation*, *Buildings*, *Electricity*, *Transport*, *Manufacturing and Trade*, *Cities and Urban Green*, *Catastrophe Management* and *Tourism*. For each of these fields, several ‘impact chains’ – describing stepwise the effects of changes of physical climate parameters to economic materialization – are quantified in separate analyses[1] and then implemented into the macroeconomic CGE model via five different economic mechanisms: changes in production cost structures (e.g. a different production processes in *Agriculture*), changes in productivity (e.g. a lower productivity of the labor force in *Manufacturing and Trade*), changes in final demand (e.g. a shift from winter tourism to summer tourism), changes in investments (e.g. additional gas turbines to cover cooling peaks in *Electricity*) and/or changes in public expenditures (e.g. more relief payments undertaken by the government in *Catastrophe Management*). For details on the implementation by impact chain see Bachner et al. (2015b) and Steininger et al. (2015).

[1] In order to achieve consistency, all of the sectoral models use the same assumptions regarding socio-economic developments and climate change. For details see Steininger et al. (2015).

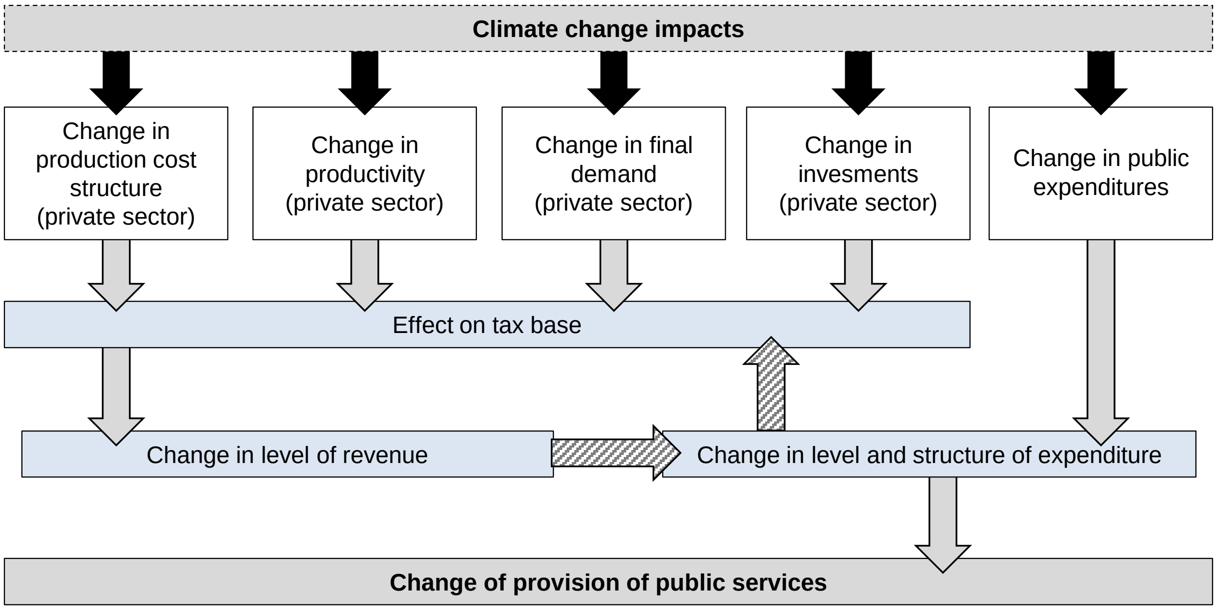


Figure 1: Effects of climate change impacts on the provision of public services via different economic mechanisms. Black arrows show physical climate change impacts, gray arrows show direct effects, dahsed arrows show indirect effects.

Figure 1 shows how the five different mechanisms trigger effects on public budgets: The first four mechanisms affect the level of revenue via a changed tax base (e.g. climate change induced productivity losses reduce sectoral output or labor demand) which in turn indirectly co-determines the level of expenditure (since expenditure has to equal revenues). The last mechanism affects the level and structure of public expenditure directly. The resulting change level and structure of expenditure then again has indirect effects on the tax base (e.g. if the government is confronted with higher payments to replace infrastructure damages due to more extreme events, this triggers construction activity which changes the tax base again). The government is thus confronted with an interplay of climate change triggered reductions of tax revenue and increases of expenditure, leading to a change of the provision of public services.

2.3. Counterbalancing instruments

Since a climate change induced reduction of public services (e.g. health services, education or public infrastructure operation) is not desirable, we aim to keep expenditures on public service provision (i.e. government consumption in the CGE model) at the same value as in the baseline scenario without climate change. This 'counterbalancing' can be done either by raising revenue, decreasing expenditure, or by foreign lending. We thus implement five different instruments for counterbalancing into the CGE model: (i) a uniform production output tax levied on all sectors (OUTTAX), (ii) an increase in labor tax (LABTAX), (iii) an increase in capital tax (CAPTAX), (iv) cuts in non-climate related transfers to private households (CUTTRA), and (v) foreign lending (FORLEN).

To illustrate how the different fiscal instruments work, we start with the analysis of the government balance which is given by:

$$\sum_i p_i^G G_{i,GOV} + UBEN + TRANS = \omega \bar{L} \bar{t}^L + v \bar{K} \bar{t}^K + \sum_i p_i^X X_i \bar{t}_i^X + \sum_i p_i^{EX} EX_i \bar{t}_i^{EX} + FOLE$$

where the left hand side represents government expenditures which consists of government consumption ($WGOV = \sum_i p_i^G G_{i,GOV}$), unemployment benefits (*UBEN*), and transfers to households (*TRANS*). The right hand side represents the government revenues which is the sum of labor tax revenue $\omega \bar{L} \bar{t}^L$, capital tax revenue $v \bar{K} \bar{t}^K$, production tax revenue $\sum_i p_i^X X_i \bar{t}_i^X$, export tax revenue $\sum_i p_i^{EX} EX_i \bar{t}_i^{EX}$, and foreign lending $FOLE$ (i.e. additional foreign lending which is initially set to zero).

With climate change impacts, there are changes both on the left hand side (i.e. a fraction of WGOV is diverted from provision of public services to TRANS as climate induced compensation payments for e.g. disaster relief) as well as on the right hand side (i.e. a reduction in tax income due to a climate change induced reduction of the tax base). To ensure, that the WGOV can be kept at the same level as in the baseline scenario, we now implement different fiscal instruments.

For the fiscal instrument CUTTRA, transfers to households are adjusted endogenously such that more financial resources can be allocated to government consumption (WGOV, which reflects public service provision).

The fiscal instrument FORLEN sets *FOLE* endogenously exactly to the amount to counterbalance the decline in revenue such that the baseline value of public service provision is obtained.

The remaining fiscal instruments are taxes (OUTTAX, LABTAX, CAPTAX). To explain how these taxes emerge in the model, we use sector-specific unit cost functions which are in case of CES functions generally given by (see Appendix for the exact nesting structures):

$$c_j = \left[\sum_i \theta_i {p_i}^{(1-\sigma)}\right]^{1/(1-\sigma)}$$

where c_j are unit costs for production sector j, θ_i is the value share of production input i (intermediate and factor inputs), p_i is the price of input i, and σ is the elasticity of substitution between inputs. With input and output taxes in production, the unit cost function becomes:

$$c_j = \left[\sum_i \theta_i [p_i(1 + \bar{t}_i^{IN})]^{(1-\sigma)}\right]^{1/(1-\sigma)} \frac{1}{1 - \bar{t}_j^{OUT}}$$

where $\bar{t}_i^{IN}$ is the input tax rate on input i and $\bar{t}_j^{OUT}$ is the tax rate on sector j's output. For the fiscal instrument OUTTAX, the tax rate $\bar{t}_i^{OUT}$ is determined endogenously such that government's revenue increases sufficiently for obtaining the same amount of public service provision (WGOV) as in the baseline scenario. In case of the fiscal instruments LABTAX and CAPTAX, the respective tax rate $\bar{t}_i^{IN}$ changes endogenously in a similar manner.[2] As a consequence of all three instruments, unit costs c_j rise, leading to higher output prices and in CAPTAX and LABTAX also to higher factor prices. These effects in turn lead to substitution effects. In production the shares of intermediate and factor inputs are changing across the whole economy, in consumption the composition of final demand changes, but also the absolute level of consumption, since changing factor prices influence the households' disposable income.

For the numerical analysis each instrument is treated as single scenario, being then compared to a case without climate change (BL for Baseline) but also to a case with climate change and without any counterbalancing (scenario NOCNTB) to see the respective effects on government revenue, government expenditure, GDP, welfare, unemployment and sectoral activity.

3. Results

Table 1 summarizes the effects of the different counterbalancing instruments. The first column shows the absolute values for the baseline scenario without climate change (BL) in 2050, whereas the remaining columns show changes due to climate change with respect to BL (indicated by ΔCC) for the NOCNTB case as well as for the five counterbalancing scenarios

[2] Note that all three tax instruments are implemented uniformly across all sectors, hence the same %-point is added to the already existing (sector specific) taxes of the benchmark model.

(i.e. instruments). We see that in NOCNTB total revenue and expenditure are by -0.3% lower than in the BL. On the revenue side, effects comes mainly from lower labor tax revenue (-0.4%) and lower production tax revenue (-0.8%). The lower revenue comes along with more necessary climate induced expenditure for compensation of households (+184%) and more unemployment benefits due to lower aggregate output (+10%). The combination of lower revenue and higher expenditure forces a reduction in the provision of the public services WGOV (-1.4%, or -1.8 billion €), since revenues and expenditures have to be balanced out. Note, that since WGOV is relatively labor intensive, a positive feedback loop emerges, driving labor demand and labor tax revenue further down and leading to an even lower WGOV. This effect explains the relatively strong effect on labor tax revenue. Regarding the macro indicators, both GDP and welfare (measured by Hicksian equivalent variation) are lower compared to the BL (-0.2% and -0.6%) and unemployment is higher by 0.4%-points. Figure 2 illustrates which climate change impact fields contribute most to the total GDP and welfare effect for the NOCTNB scenario. While positive effects are triggered in agriculture and heating & cooling, negative effects emerge from all other impact fields, particularly forestry (due to reduced yields and higher pest infestations), electricity (due to reduced potential from hydro power), tourism (due to reduced winter tourism demand), and catastrophe management (higher expenditures on disaster compensation).

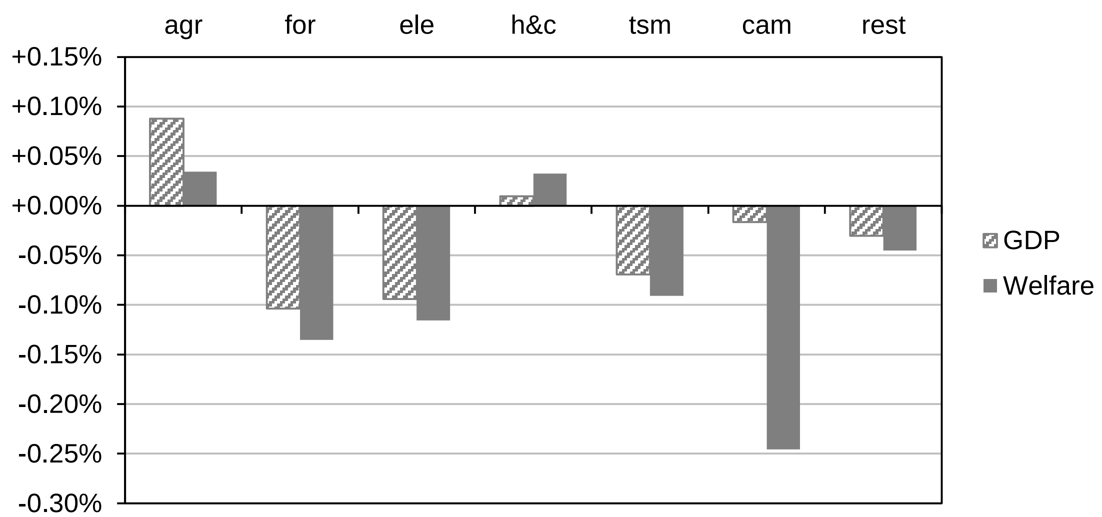


Figure 2: Decomposed effects on GDP (shaded) and welfare (solid) across impact fields for the NOCTNB scenario (relative to BL without climate change) for 2050 (average climate change impacts in period 2036-2065)

Impact fields: Agriculture (agr), Forestry (for), Electricity (ele), Buildings: Heating and Cooling (h&c), Tourism (tsm), Catastrophe Management (cam) and rest: Water, Transport, Manufacturing and Trade, Cities and Urban Green.

Table 1: Changes of revenues, expenditures and macro indicators for the climate change scenario with and without counterbalancing (given for 2050 in million €$_{2008}$).

	BL	ΔCC		ΔCC		ΔCC		ΔCC		ΔCC		ΔCC	
Government Revenues	Baseline	NOCNTB		OUTTAX		LABTAX		CAPTAX		CUTTRA		FORLEN	
Production tax	25,670	-202	-0.8%	+1,739	+6.8%	-294	-1.1%	-158	-0.6%	-157	-0.6%	-150	-0.6%
Labor tax	119,797	-468	-0.4%	-645	-0.5%	+4,599	+3.8%	-255	-0.2%	-256	-0.2%	-244	-0.2%
Capital tax	26,863	-11	-0.0%	-252	-0.9%	-781	-2.9%	+813	+3.0%	-8	-0.0%	+1	+0.0%
Value added tax	39,516	+54	+0.1%	-196	-0.5%	-697	-1.8%	-54	-0.1%	-54	-0.1%	+59	+0.2%
other taxes	14,140	+43	+0.3%	-29	-0.2%	-27	-0.2%	-23	-0.2%	-23	-0.2%	-18	-0.1%
CC induced foreign debt	-	-	-	-	-	-	-	-	-	-	-	+735	+9.2%
Total Government Revenue	**225,986**	**-584**	**-0.3%**	**+617**	**+0.3%**	**+2,799**	**+1.2%**	**+324**	**+0.1%**	**-497**	**-0.2%**	**+383**	**+0.2%**
Government Expenditures													
Government consumption	123,054	-1,750	-1.4%	-547	-0.4%	-547	-0.4%	-547	-0.4%	-547	-0.4%	-547	-0.4%
Climate induced relief payments	297	+547	+184.0%	+547	+184.0%	+547	+184.0%	+547	+184.0%	+547	+184.0%	+547	+184.0%
Transfers to households	96,776	+1	+0.0%	-34	-0.0%	+1	+0.0%	+1	+0.0%	-821	-0.8%	+3	+0.0%
Unemployment benefits	5,859	+618	+10.6%	+651	+11.1%	+2,799	+47.8%	+323	+5.5%	+324	+5.5%	+380	+6.5%
Total Government Expenditures	**225,986**	**-584**	**-0.3%**	**+617**	**+0.3%**	**+2,799**	**+1.2%**	**+324**	**+0.1%**	**-497**	**-0.2%**	**+383**	**+0.2%**
Macro indicators													
GDP	554,771		-0.2%		-0.4%		-1.1%		-0.2%		-0.2%		-0.1%
Welfare	412,291		-0.6%		-0.6%		-1.7%		-0.5%		-0.5%		-0.3%
unemployment rate (change in %-points)	3.5%		+0.4%		+0.4%		+1.7%		+0.2%		+0.2%		+0.2%
additional debt (in % of GDP)	-		-		-		-		-		-		+0.1%

Coming to the effects of the different counterbalancing instruments, we see that the effect on *WGOV* is now less pronounced, but by construction not zero because they have to be equal to climate induced compensation payments (547 million €) which are displayed as an extra line. When summing up the changes in *WGOV* and climate induced compensation payments they add up to zero, meaning that the counterbalancing instruments meet exactly their targets.

Since we are interested in the effect of the different counterbalancing instruments we now compare the effects of the respective counterbalancing scenarios to the NOCNTB scenario. Figure 3 and Figure 4 show the effects on the revenue and expenditure side respectively, given as differences in %-points between NOCNTB (relative to BL) and the counterbalancing scenarios (relative to BL). Figure 5 shows the changes for GDP, welfare, unemployment and foreign debt.[3]

In OUTTAX the endogenously determined additional output tax $\bar{t}_j^{OUT}$ to counterbalance *WGOV* is 0.2%. On the revenue side, this leads to higher production tax revenue of +8%-points, whereas all other tax income items show moderately negative effects. On the expenditure side, we see a positive effect on *WGOV* (the desired counterbalancing becomes visible here). Since economic activity is taxed at a higher rate, production and employment are lower (GDP and welfare: -0.1%-points). Thus, the stimulating effect of more labor demand via the counterbalancing of *WGOV* is overcompensated by the negative scale effect of the tax. Hence also necessary unemployment benefit payments are slightly higher.

In LABTAX the necessary additional input tax $\bar{t}_i^{IN}$ on labor is 4.7%. This relatively strong effect is driven by the previously described feedback loop. As expected, we see an increase in

[3] Note that the change of foreign debt is given relative to the annual debt in the baseline scenario without climate change.

labor tax revenue (4%-points higher), however, since economic activity is negatively affected via strong labor market effects, the government faces a lower tax base and thus lower revenues from capital and value added taxes (-3 and -2%-points respectively). The strong labor market effect becomes clearly visible on the expenditure side, where unemployment benefits are by +37%-points higher (+2.2 billion €), but also when looking at GDP, welfare and unemployment (-0.8, -1.1 and +1.3%-points respectively).

In CAPTAX, the required increase in the capital tax rate $\bar{t}_i^{IN}$ is 0.5%. On the revenue side the additional tax leads to higher tax revenue from capital of +3%-points with only small effects on other tax revenues. Note that the effect on production and labor tax revenue is slightly positive, since production sectors shift from capital input to more labor input, leading to more labor demand. In addition, the stimulating effect of higher *WGOV* via the labor market becomes effective, leading to reduced unemployment (-0.2%-points) and lower unemployment benefit payments (-5%-points). GDP and welfare are affected positively.

Using instrument CUTTRA, transfers to households (*TRANS*) need to be cut by -0.8%. On the revenue side only the small indirect effects of this instrument become visible: There is slightly higher tax revenue coming from production and labor tax (due to the stimulating effect of higher *WGOV*), but lower revenue from value added tax, since there is less consumption possibility for households in this case. On the expenditure side *WGOV* increases (i.e. the counterbalancing) and transfers are cut. Unemployment benefit payments are lower, since unemployment is lower as well (-0.2%-points). GDP and welfare are higher by +0.1%-points.

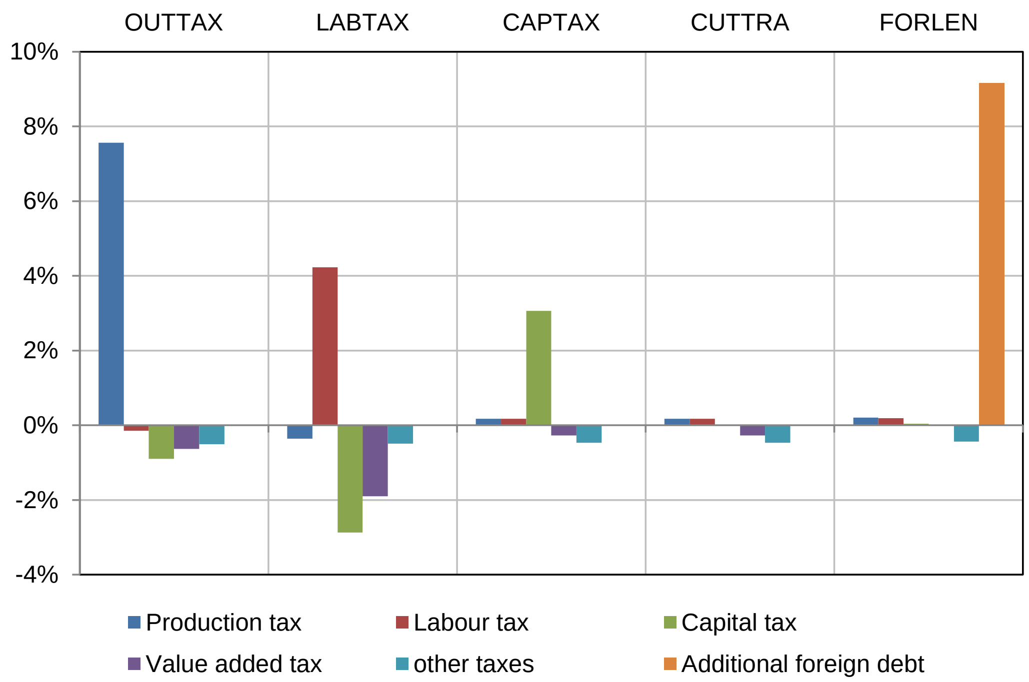


Figure 3: Effects on different tax revenues, for the five counterbalancing scenarios relative to the non-counterbalancing scenario. Percentages are expressed relative to the respective value in the Baseline scenario. Note that the change of additional foreign debt is given relative to the annual debt in the baseline scenario without climate change.

In FORLEN, additional necessary foreign lending (*FOLE*) for counterbalancing is € 735 million. This means that annual debt in 2050 is higher by about +9%. Treating these debts as temporary additional income, again a positive stimulating effect emerges from higher *WGOV*. This leads to lower unemployment (-0.1%-points). GDP as well as welfare are positively affected (+0.1 and 0.3%-points respectively). However, when putting the additional debts into perspective, the positive GDP effect vanishes, since the additional debt is about the same magnitude (0.1% of GDP in 2050).

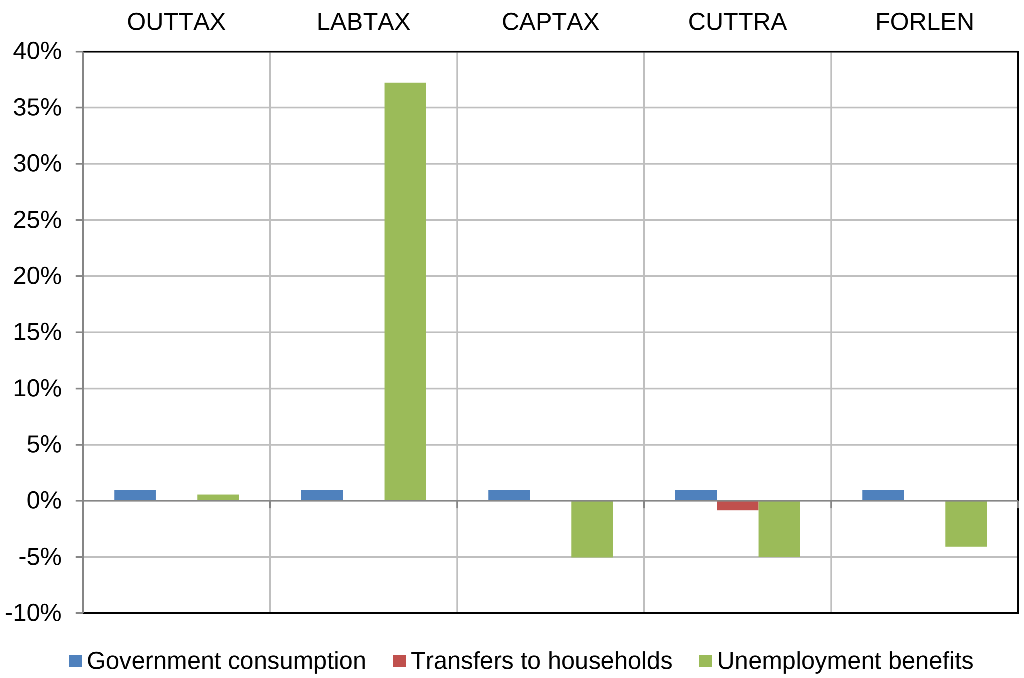


Figure 4: Effects on the expenditure side, for the five counterbalancing scenarios relative to the non-counterbalancing scenario.

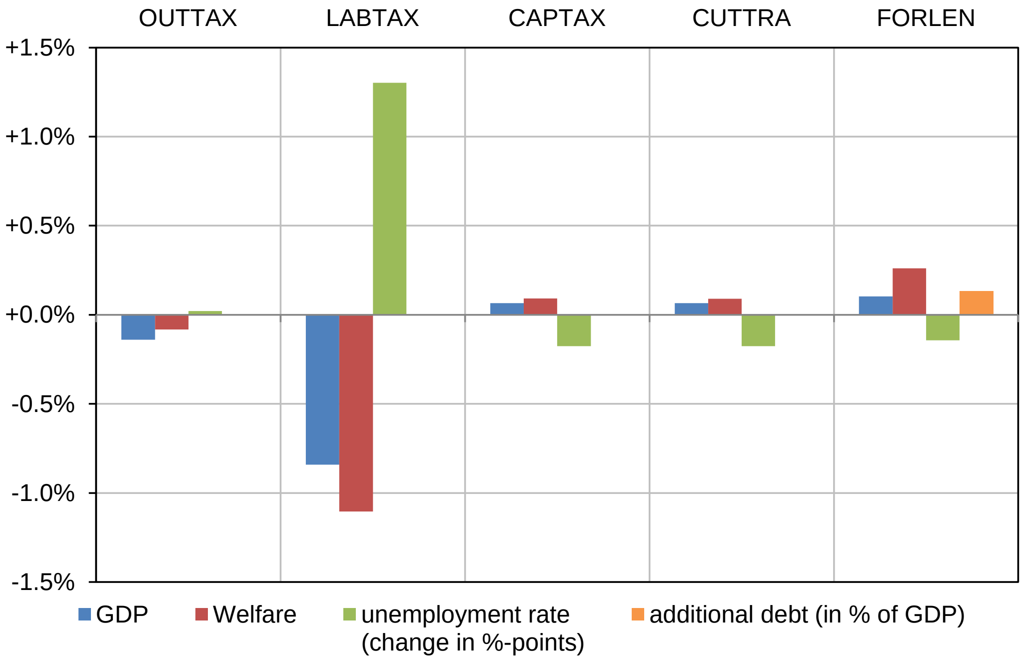


Figure 5: Effects on selected macro indicators, for the five counterbalancing scenarios relative to the non-counterbalancing scenario.

Table 2: Effects on sectoral activity, for the five counterbalancing scenarios relative to the non-counterbalancing scenario

	OUTTAX	LABTAX	CAPTAX	CUTTRA	FORLEN
primary sectors	-0.1%	+0.4%	-0.1%	-0.1%	-0.2%
manufacturing	-0.4%	-0.8%	-0.0%	-0.0%	-0.2%
construction	-0.2%	-0.4%	-0.0%	-0.0%	-0.0%
trade	-0.3%	-1.0%	-0.1%	-0.1%	-0.1%
transport	-0.4%	-1.1%	-0.0%	-0.0%	-0.1%
services	**-0.2%**	**-0.9%**	**+0.1%**	**+0.1%**	**+0.1%**
pharmaceuticals	-0.4%	-0.9%	-0.0%	-0.0%	-0.2%
Real estate	-0.3%	-0.6%	-0.1%	-0.1%	+0.0%
Public adminstration	**+1.0%**	**+0.1%**	**+1.1%**	**+1.1%**	**+1.0%**
health	**+0.6%**	**-0.5%**	**+0.7%**	**+0.7%**	**+0.7%**
Entertainment, culture, and sports	**-0.0%**	**-0.7%**	**+0.1%**	**+0.1%**	**+0.2%**

Note: for sectoral aggregation see Table 3 in the appendix.

The effects of the different counterbalancing instruments on sectoral activity (quantity effect) are given in Table 2 (note that the model features 40 sectors, however for presentation of results we aggregated them to 10. See Table 3 in the appendix for details.). In CAPTAX, CUTTRA and FORLEN the successful counterbalancing becomes visible when looking at the positive effect on service sectors, public administration, health, and entertainment, culture and sports, since these four sectors cover about 95% of *WGOV*. In OUTTAX, however, these positive effects are less pronounced, or even getting negative, since output is taxed, which curbs economic activity slightly. Looking more closely on LABTAX, we see that service sectors, health, and entertainment, culture and sports show negative effects and public administration only a slight positive effect. Thus, although *WGOV* is balanced out successfully in terms of allocated budget (i.e. monetary absolute value) as indicated in Table 1, the actual provision of public services is below the baseline level. This is due to strong price increases in LABTAX such that the government spends the same amount for public service provision, but only can afford (and thus provide) less is terms of quantities. The same is true for OUTTAX, but to a less strong extent.

4. Discussion and conclusions

While climate change induced impacts and adaptation have both positive and negative consequences for GDP and welfare, we find that the overall effect on both macro indicators is clearly negative for Austria in 2050. Because of a reduced tax base the impact on public revenues and hence also on expenditures is therefore negative too. Moreover, due to higher government expenditures on disaster management and compensation, the scope for the provision of other public services is strongly diminished (by -1.4%). It is therefore a legitimate question for national governments whether fiscal instruments such as tax increases, cuts in transfers or foreign lending can mitigate these unfavorable side-effects.

In this paper, we addressed therefore two research questions: What options do governments have to counterbalance climate change induced additional expenditures and revenue losses in the long term? And what are the macroeconomic effects of these options?

In answering these questions, we find that it depends on the type of the instruments how the macroeconomy is affected. While a rise in the capital tax, a cut in transfer and foreign lending reduce GDP and welfare losses, a rise in the labor tax and output tax increases GDP and welfare losses. The reasons for this unfavorable effect in case of a labor tax is that unemployment and hence expenditures on unemployment benefits increase which reduces the scope for government demand and has overall strong negative consequences for GDP and welfare. Furthermore the labor tax scenario revealed that the fiscal instrument should be chosen with great care, as it may trigger increases in relative prices, lowering the purchasing power of the government’s budget, leading in turn also to lower actual public service provision as originally intended when implementing the instrument.

We find little difference between the cut in transfers and a rise in capital tax. Both scenarios increase revenues or reduce expenditures, thus triggering additional government demand. We did not look however into distributional impacts which such a cut in transfer might have for certain income groups. Similarly, due to our small open economy setting in which other countries are only reflected via their trade flows, we cannot address the question of international tax competition and hence cannot investigate how strongly capital might be relocated abroad in response to an increase in the capital tax. If this effect is strong, a rise in the tax rate might lead to a reduction in capital tax revenues instead of the increase which we find in our model.

Finally, increasing foreign lending has important long term impacts when it comes to debt service. While we accounted for the increase in debt service due to the increase in foreign lending (corresponding to a 9% increase in the primary deficit which translates to an increase in the debt to GDP ratio by 0.1%), we did not consider potential increases in interest rates due to a worsened debt rating of the government and we also ignored that higher interest payments reduce the future scope for public expenditures.

5. Appendix

5.1. General model description

The production structure of domestic production *X* is shown in Figure 6. A nested constant elasticity of substitution (CES) production function is applied: On the top level of production of commodity *i* a capital-labor-energy composite (*(KL)E*) can be substituted for an intermediate composite (*INT*) with the sector specific elasticity of substitution *top*. On the second level of the nesting structure there are two branches: First, *(KL)E* is produced by a capital-labor composite (*KL*) and an energy composite *E* which can be substituted with a sector specific elasticity *kle*. Second, *INT* is produced by intermediate inputs coming from an 'Armington-aggregate' (including domestically produced commodities and imports), capturing all types of commodities, except COKE and ELEC (G_i to G_k). The intermediate inputs can be substituted against each other with the sector specific elasticity *int*. On the third nesting level the composite *KL* is composed by *K* and *L*, whereas the composite *E* is composed by inputs from the sectors COKE and ELEC, respectively, with an elasticity of substitution of *kl* and *ene*.

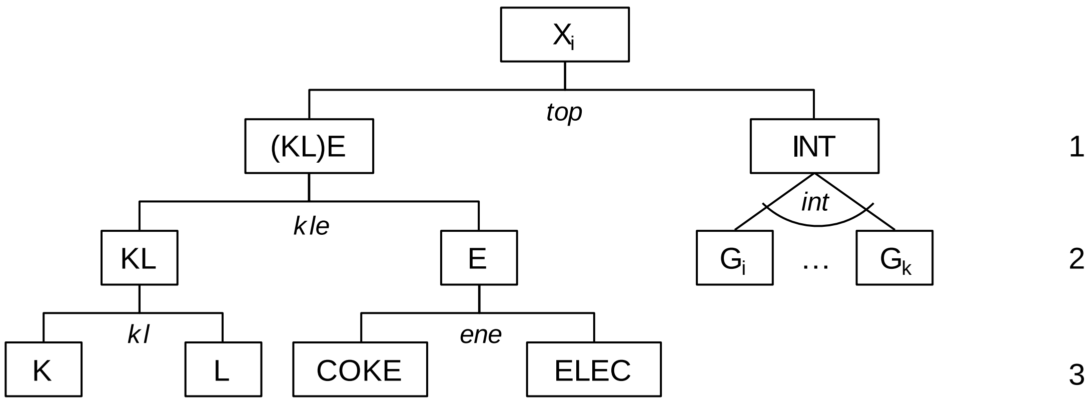


Figure 6: Production structure of domestic production with 3 nesting levels.

Concerning final demand of private households and the government the welfare function is depicted in Figure 7. On the top level a non-energy composite (*NE*) can be traded off for the energy composite *E* with an elasticity of substitution of *s*. Similar to the production structure of domestic production the *NE* composite is produced using commodities G_i to G_k but with a different elasticity of substitution (*nene*). The energy composite *E* is produced in the same manner as in domestic production.

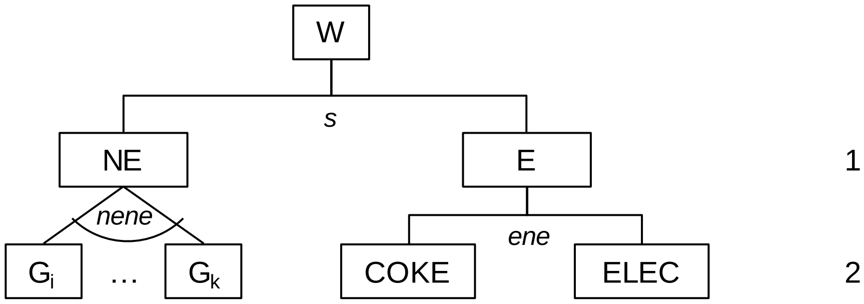


Figure 7: Final demand structure of private households and government with 2 nesting levels.

5.2. Algebraic model formulation

The CGE model is formulated as a system of non-linear inequalities. More precisely the Arrow-Debreu economic equilibrium can be stated as a mixed complementarity problem (MCP) where three inequalities must be satisfied (Mathiesen, 1985): (i) zero profit condition, (ii) market clearance condition and (iii) income balance condition. The first condition is determining activity levels, the second price levels and the third defines income levels. In the algebraic model formulation the unit profit function π_i^Z is used for notation. *Z* is the regarded activity of sector (or commodity) *i*. The unit profit function is based on the constant elasticity of substitution (CES) production function in calibrated share form (see for example Böhringer and Wiegard, 2002). Initial benchmark data refers to the year of 2008.

5.2.1. Zero profit conditions

The zero profit condition requires that any production activity which produces positive quantities must earn zero profits. Thus, the value of inputs must be greater or equal than the value of outputs. Therefore either a positive amount is produced and profits are zero or profits are negative and the output is zero.

<u>Production of X_i</u>

Unit profits π of domestic production *X* of sector *i* (π_i^X) are determined by two parts: Revenue per unit and unit costs. The former part is the domestic price p of good *i* (p_i^D) net of the sector specific domestic benchmark output tax $\bar{t}_i^D$. The latter part is determined by $\bar{C}_i^X$ (benchmark costs of item *i* in domestic production *X*) which is divided by $\bar{X}_i$ (benchmark production of sector *i*). The resulting benchmark unit costs are then multiplied by sector specific relative prices of inputs or input aggregates (equilibrium price p_i divided by the benchmark price $\bar{p}_i$) which are weighted with sector specific value shares θ_i of inputs or input aggregates. Note that in the benchmark case the whole term in curly brackets is equal to 1. Substitution elasticities between inputs or input aggregates are reflected by σ.

(1) $$\pi_i^X = p_i^D * \left(1 - \bar{t}_i^D\right) - \frac{\bar{C}_i^X}{\bar{X}_i} * \left\{\theta_i^{KLE}\left(\frac{p_i^{KLE}}{\bar{p}_i^{KLE}}\right)^{1-\sigma_i^{top}} + \left(1-\theta_i^{KLE}\right)\left(\frac{p_i^{INT}}{\bar{p}_i^{INT}}\right)^{1-\sigma_i^{top}}\right\}^{\frac{1}{1-\sigma_i^{top}}}$$

≤ 0 with $\perp\ X_i$

Sector specific capital-labor-energy aggregate

$$(2)\qquad \pi_i^{KLE} = p_i^{KLE} - \frac{\overline{C}_i^{KLE}}{\overline{KLE}_i} * \left\{\theta_i^{KL}\left(\frac{p_i^{KL}}{\overline{p}_i^{KL}}\right)^{1-\sigma_i^{kle}} + (1-\theta_i^{KL})\left(\frac{p_i^{E}}{\overline{p}_i^{E}}\right)^{1-\sigma_i^{kle}}\right\}^{\frac{1}{1-\sigma_i^{kle}}}$$

≤ 0 with $\perp\ KLE_i$

Sector specific capital-labor aggregate

$$(3)\qquad \pi_i^{KL} = p_i^{KL} - \frac{\overline{C}_i^{KL}}{\overline{KL}_i} * \left\{\theta_i^{K}\left(\frac{p_i^{K}}{\overline{p}_i^{K}}\,(1+\overline{t}_i^{K})\right)^{1-\sigma_i^{kl}} + \theta_i^{L}\left(\frac{p_i^{L}}{\overline{p}_i^{L}}(1+\overline{t}_i^{L})\right)^{1-\sigma_i^{kl}}\right\}^{\frac{1}{1-\sigma_i^{kl}}}$$

≤ 0 with $\perp\ KL_i$

Sector specific energy aggregate

$$(4)\qquad \pi_i^{E} = p_i^{E} - \frac{\overline{C}_i^{E}}{\overline{E}_i} * \left\{\theta_i^{COKE}\left(\frac{p_i^{G,COKE}}{\overline{p}_i^{G,COKE}}\right)^{1-\sigma_i^{ene}} + \theta_i^{ELEC}\left(\frac{p_i^{G,ELEC}}{\overline{p}_i^{G,ELEC}}\right)^{1-\sigma_i^{ene}}\right\}^{\frac{1}{1-\sigma_i^{ene}}}$$

≤ 0 with $\perp\ E_i$

Sector specific intermediate aggregate

$$(5)\qquad \pi_i^{INT} = p_i^{INT} - \frac{\overline{C}_i^{INT}}{\overline{INT}_i} * \left\{\sum_i^k \theta_i\left(\frac{p_i^{G}}{\overline{p}_i^{G}}\right)^{1-\sigma_i^{int}}\right\}^{\frac{1}{1-\sigma_i^{int}}}$$

≤ 0 with $\perp\ INT_i\ for\ i\ \neq COKE\ and\ ELEC$

Armington aggregate:

(6) $$\pi_i^G = p_i^G - \frac{\overline{C}_i^G}{\overline{G}_i} * \left\{\theta_i^D \left(\frac{p_i^D}{\overline{p}_i^D}\right)^{1-\sigma_i^{armi}} + (1-\theta_i^D)\left(\frac{p_i^{IM}}{\overline{p}_i^{IM}}\right)^{1-\sigma_i^{armi}}\right\}^{\frac{1}{1-\sigma_i^{armi}}}$$

≤ 0 with $\perp\ G_i$

Welfare of private household:

(7) $$\pi^W = p^W - \frac{\overline{C}^W}{\overline{\overline{W}}} * \left\{\theta^{NE}\left(\frac{p^{NE}}{\overline{p}^{NE}}\right)^{1-\sigma^S} + (1-\theta^{NE})\left(\frac{p^E}{\overline{p}^E}\right)^{1-\sigma^S}\right\}^{\frac{1}{1-\sigma^S}}$$

≤ 0 with $\perp\ W$

Household non-energy consumption[4]:

(8) $$\pi^{NE} = p^{NE} - \frac{\overline{C}^{NE}}{\overline{\overline{NE}}} * \left\{\sum_i^k \theta_i \left(\frac{p_i^G}{\overline{p}_i^G}\right)^{1-\sigma_i^{nene}}\right\}^{\frac{1}{1-\sigma_i^{nene}}}$$

≤ 0 with $\perp\ NE$

Welfare of government:

(9) $$\pi^{WGOV} = p^{WGOV} - \frac{\overline{C}^{WGOV}}{\overline{\overline{WGOV}}} * \left\{\theta^{NE}\left(\frac{p^{NE}}{\overline{p}^{NE}}\right)^{1-\sigma_i^S} + (1-\theta^{NE})\left(\frac{p^E}{\overline{p}^E}\right)^{1-\sigma_i^S}\right\}^{\frac{1}{1-\sigma_i^S}}$$

≤ 0 with $\perp\ WGOV$

[4] Household energy consumption is equivalent to sector specific energy aggregate

Aggregate imports and exports:

Exports are used to create foreign exchange (*FX*) which is used to purchase imports (*IM*). In the benchmark SAM there are positive net exports. The resulting excess *FX* is assumed to be spent for investment (i.e. foreign investment).

(10) $\pi^{EX} = p^{EX} - \frac{\overline{C}^{EX}}{\overline{\overline{EX}}} * \left\{\sum_i \theta_i^{EX} \left[\frac{p_i^{EX}}{\overline{p}_i^{EX}}\left(1 + \overline{t}_i^{EX}\right)\right]\right\} \leq 0 \text{ with } \perp EX$

(11) $\pi^{IM} = p^{IM} - \frac{\overline{C}^{IM}}{\overline{\overline{IM}}} * \left\{\sum_i \theta_i^{IM} \left(\frac{p_i^{FX}}{\overline{p}_i^{FX}}\right)\right\} \leq 0 \text{ with } \perp IM$

Domestic supply:

Domestic supply *D* is modeled as a constant elasticity of transformation (CET) function. Domestic production *X* is either allocated to domestic supply *D* (which is then used as input in the Armington aggregate *G*) or to exports *EX*).

(12) $X_i = \{\theta_i D^\rho + (1-\theta_i) EX^\rho\}^{\frac{1}{\rho}}$

$with\ \rho = \frac{1-\sigma^{armi}}{\sigma^{armi}}$

Investment:

(13) $\pi_{INV} = p_{INV} - \frac{\overline{C}_{INV}}{\overline{\overline{INV}}} * \left\{\prod_i^n \left(\frac{p_i^G}{\overline{p}_i^G}\right)^{\theta_i}\right\}$

$\leq 0 \text{ with } \perp INV$

5.2.2. Market clearance conditions

The market clearance conditions require that all goods with a positive price must have a balance between demand and supply. Any goods in excess supply must have zero prices. Derivation of unit profit functions π_i^Z with respect to prices gives the respective compensated demand quantities which must be smaller or equal to supply (Shephard's Lemma).

<u>Labor market:</u>

Aggregate labor endowment $\overline{L}$ has to be larger or equal labor demand, which is the sum of all labor demand by all sectors. Labor demand of sector *i* is calculated by derivation of the unit profit function of domestic production of this sector π_i^X with respect to the wage rate ω (price for labor) and multiplying it by the activity level of domestic production X_i. We allow for unemployment in equilibrium by applying a minimum wage ω which has to be equal or greater than the price of the welfare good p^W. $\overline{L}$ is rationed or expanded by an endogenous parameter such that this constraint is met. The change in this parameter then gives the change of unemployment.

(14) $\overline{L} \geq \sum_i X_i \frac{\partial \pi_i^X}{\partial \omega} \ with \perp \omega$

(15) $\omega \geq p^W$

<u>Capital market:</u>

(16) $\overline{K} \geq \sum_i X_i \frac{\partial \pi_i^X}{\partial v} \ with \perp v$

Sector specific energy aggregate:

(17) $\overline{E}_i \geq X_i \frac{\partial \pi_i^X}{\partial p_i^E} \text{ with } \perp p_i^E$

Sector specific capital-labor aggregate:

(18) $\overline{KL}_i \geq X_i \frac{\partial \pi_i^X}{\partial p_i^{KL}} \text{ with } \perp p_i^{KL}$

Sector specific capital-labor-energy aggregate:

(19) $\overline{KLE}_i \geq X_i \frac{\partial \pi_i^X}{\partial p_i^{KLE}} \text{ with } \perp p_i^{KLE}$

Sectoral domestic output (for Armington aggregate and export markets):

(20) $\overline{X}_i \geq D_i \frac{\partial \pi_i^G}{\partial p_i^D} + IM_i \frac{\partial \pi_i^{IM}}{\partial p_i^D} \text{ with } \perp p_i^D$

Import aggregate:

(21) $\overline{IM}_i \geq G_i \frac{\partial \pi_i^G}{\partial p_i^{IM}} \text{ with } \perp p_i^{IM}$

Armington aggregate:

(22) $\overline{G}_i \geq X_i \frac{\partial \pi_i^X}{\partial p_i^G} + W \frac{\partial \pi^W}{\partial p^G} + WGOV \frac{\partial \pi^{WGOV}}{\partial p^G} \text{ with } \perp p_i^G$

Household non-energy consumption:

(23) $\overline{NE} \geq W \frac{\partial \pi^W}{\partial p^{NE}} \; with \perp p^{NE}$

Sector specific material consumption:

(24) $\overline{INT}_i \geq X_i \frac{\partial \pi_i^X}{\partial p_i^{INT}} \; with \perp p_i^{INT}$

Welfare of household:

(25) $\overline{W} \geq \frac{IHH}{p^W} \; with \perp p^W$

Welfare of government:

(26) $\overline{WGOV} \geq \frac{IGOV}{p^{WGOV}} \; with \perp p^{WGOV}$

5.2.3. Income balance conditions

Income balance condition requires that every agent's income must equal the value of endowments.

Household income:

Household income IHH equals the total value of labor and capital income of private households (wage rate ω times benchmark labor endowment $\overline{L}$ plus rental rate v (price of capital) times benchmark capital endowment $\overline{K}$) plus unemployment benefits (*UBEN*) and other transfers (*TRANS*) from the government.

(27) $IHH = \omega\overline{L} + v\overline{K} + \overline{UBEN} + \overline{TRANS} = \overline{W}$

In addition the private household is endowed with annual savings $\overline{SAVE}$ and depreciation $\overline{DEPR}$, which drive the extent of annual investment. The composition of investments however is flexible. Hence the household does not decide whether to consume or invest, since investment is given exogenously.

(28) $p_{INV}\overline{INV} = \overline{DEPR} + \overline{SAVE}$

Government income:

(29) $IGOV = TAX + FOLE$

with *FOLE* being foreign lending.

(30) $TAX = \omega\overline{L}\overline{t}^{L} + v\overline{K}\overline{t}^{K} + \sum_i p_i^X X_i \overline{t}_i^X + \sum_i p_i^{EX}\overline{EX}_i\overline{t}_i^{EX}$

(31) $\overline{WGOV} = IGOV - UBEN - TRANS$

(32) $IGOV = \omega\overline{L}\overline{t}^{L} + v\overline{K}\overline{t}^{K} + \sum_i p_i^X X_i \overline{t}_i^X + \sum_i p_i^{EX}\overline{EX}_i\overline{t}_i^{EX} + FOLE$

5.3. Economic sectors

Table 3: Description of economic sectors, model codes and aggregation for displaying results

NACE code	Sector description	Sector model code	Aggregation for displaying results
V01	Crop and animal production, hunting and related service activities	AGRI	prim
V02	Forestry and logging	FORE	prim
V86	Human health activities	HEAL	heal
V87_88	Residential care activities; Social work activities without accommodation	RECA	serv
V36	Water collection, treatment and supply	WATE	serv
V37_39	Sewerage; Waste collection, treatment and disposal activities; materials recovery; Remediation activities and other waste management services	WAST	serv
V35	Electricity, gas, steam and air conditioning supply	ELEC	manu
V19	Manufacture of coke and refined petroleum products	COKE	manu
V28_29	Manufacture of machinery and equipment n.e.c.; Manufacture of electrical equipment	MACH	manu
V41_43	Construction of buildings; Civil engineering; Specialised construction activities	CONT	cont
V68	Real estate activities	REAL	real
V71	Architectural and engineering activities; technical testing and analysis	ARCH	serv
V45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	MOTO	manu
V49	Land transport and transport via pipelines	LTRA	trans
V50	Water transport	WTRA	trans
V51	Air transport	ATRA	trans
V52_53	Warehousing and support activities for transportation; Postal and courier activities	STRA	trans
V10, V12	Manufacture of food products; Manufacture of tobacco products	FOOD	manu
V11	Manufacture of beverages	BEVE	manu
V16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	WOOD	manu
V17	Manufacture of paper and paper products	PAPE	manu
V20	Manufacture of chemicals and chemical products	CHEM	manu
V21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	PHAR	phar
V22_23	Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products	PLAS	manu

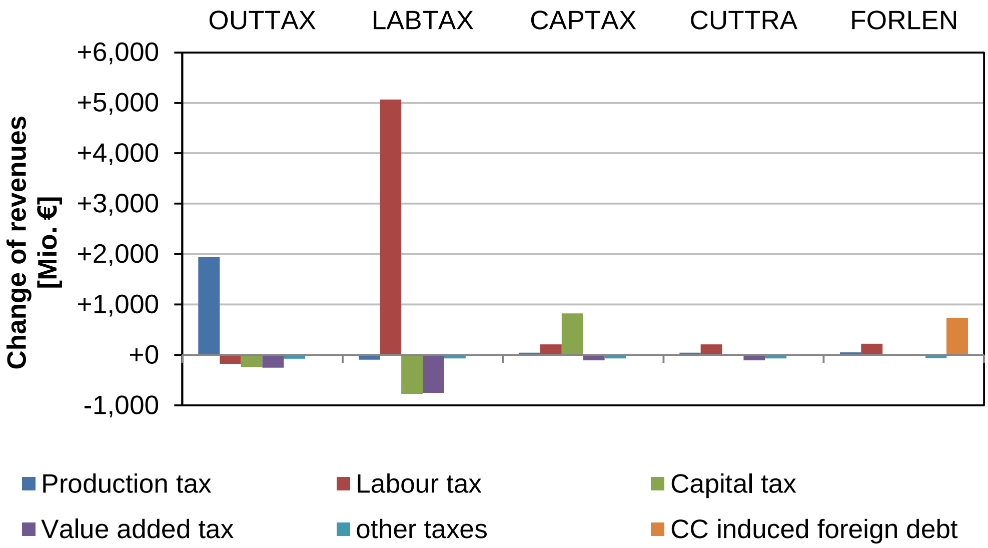
NACE code	Sector description	Sector model code	Aggregation for displaying results
V24_25	Manufacture of basic metals; Manufacture of fabricated metal products, except machinery and equipment	META	manu
V13_15; V18, V26, V27, V30_V33	Rest of manufacturing (Manufacture of textiles; Manufacture of wearing apparel; Manufacture of leather and related products; Printing and reproduction of recorded media; Manufacture of computer, electronic and optical products; Manufacture of electrical equipment; Manufacture of other transport equipment; Manufacture of furniture; Other manufacturing; Repair and installation of machinery and equipment)	RMAN	manu
V46_47	Wholesale trade, except of motor vehicles and motorcycles; Retail trade, except of motor vehicles and motorcycles	TRAD	trad
V64	Financial service activities, except insurance and pension funding	FINA	serv
V65	Insurance, reinsurance and pension funding, except compulsory social security	INSU	serv
V66	Activities auxiliary to financial services and insurance activities	AFIN	serv
V84	Public administration and defence; compulsory social security	PUBL	publ
V55_56	Accommodation; Food and beverage service activities	ACCO	serv
V79	Travel agency, tour operator and other reservation service and related activities	TRAV	serv
V90	Creative, arts and entertainment activities	ENTE	ecus
V91	Libraries, archives, museums and other cultural activities	CULT	ecus
V93	Sports activities and amusement and recreation activities	SPOR	ecus
V03, V05_09	Fishing and aquaculture; Mining of coal and lignite, Extraction of crude petroleum and natural gas, Mining of metal ores, Other mining and quarrying, Mining support service activities	REXT	prim
V58	Publishing activities	RECR	serv
V59_60	Motion picture, video and television programme production, sound recording and music publishing activities; Programming and broadcasting activities		
V92	Gambling and betting activities		
V69_70	Legal and accounting activities; Activities of head offices, management consultancy activities	SCIE	serv
V72	Scientific research and development		
V73	Advertising and market research		

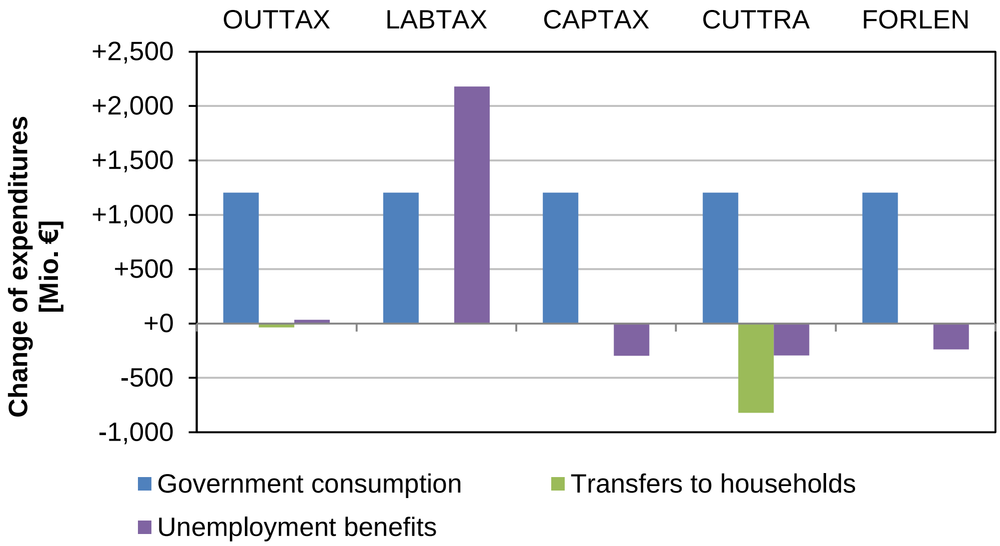
NACE code	**Sector description**	**Sector model code**	**Aggregation for displaying results**
V74_75	Other professional, scientific and technical activities; Veterinary activities		
V61	Telecommunications	TELE	serv
V62_63	Computer programming, consultancy and related activities; Information service activities		
V95	Repair of computers and personal and household goods		
V77	Rental and leasing activities	RSER	serv
V78	Employment activities		
V80_82	Security and investigation activities; Services to buildings and landscape activities; Office administrative, office support and other business support activities		
V85	Education		
V94	Activities of membership organisations		
V96	Other personal service activities		
V97_98	Activities of households as employers of domestic personnel; Undifferentiated goods- and services-producing activities of private households for own use		
V99	Activities of extraterritorial organisations and bodies		

5.4. Elasticities of substitution

Table 4: Elasticities of substitution (based on Okagawa and Ban, 2008)

	kl	kle	int	top
AGRI	0.023	0.516	0	0.392
FORE	0.087	0.456	0.115	0.695
REXT	0.139	0.553	0.309	0.729
FOOD	0.328	0.395	0	0.329
RMAN	0.046	0.529	0.309	0.406
PLAS	0.358	0.411	0.191	0.306
META	0.22	0.644	0.253	1.173
MACH	0.295	0.292	0.459	0.13
CONT	0.065	0.529	0	1.264
TRAD	0.316	0.784	0.132	0.902
STRA	0.31	0.281	0.331	0.352
RECR	0.316	0.784	0.132	0.902
TELE	0.37	0.518	0.711	0.654
SCIE	0.316	0.784	0.132	0.902
RSER	0.316	0.784	0.132	0.902
BEVE	0.046	0.529	0.309	0.406
WOOD	0.046	0.529	0.309	0.406
PAPE	0.381	0.211	0	0.187
COKE	0.334	0	0.082	0.848
CHEM	0.334	0	0.082	0.848
PHAR	0.046	0.529	0.309	0.406
ELEC	0.46	0.256	0.391	0
WATE	0.46	0.256	0.391	0
WAST	0.46	0.256	0.391	0
MOTO	0.316	0.784	0.132	0.902
LTRA	0.31	0.281	0.331	0.352
WTRA	0.31	0.281	0.331	0.352
ATRA	0.31	0.281	0.331	0.352
ACCO	0.316	0.784	0.132	0.902
FINA	0.264	0.32	0	0.492
INSU	0.264	0.32	0	0.492
AFIN	0.264	0.32	0	0.492
REAL	0.316	0.784	0.132	0.902
ARCH	0.316	0.784	0.132	0.902
TRAV	0.316	0.784	0.132	0.902
PUBL	0.316	0.784	0.132	0.902
HEAL	0.316	0.784	0.132	0.902
RECA	0.316	0.784	0.132	0.902
ENTE	0.316	0.784	0.132	0.902
CULT	0.316	0.784	0.132	0.902
SPOR	0.316	0.784	0.132	0.902


OUTTAX
LABTAX
CAPTAX
CUTTRA
FORLEN
+6,000
+5,000
+4,000
+3,000
+2,000
+1,000
+0
-1,000
Change of revenues [Mio. €]
Production tax
Labour tax
Capital tax
Value added tax
other taxes
CC induced foreign debt


OUTTAX
LABTAX
CAPTAX
CUTTRA
FORLEN
+2,500
+2,000
+1,500
+1,000
+500
+0
-500
-1,000
Change of expenditures [Mio. €]
Government consumption
Transfers to households
Unemployment benefits

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