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Analyzing the coordinated impacts of climate policies for financing adaptation and development actions

Elisa Delpiazzi^{1,2}, Ramiro Parrado³

Preliminary draft version

Abstract

This paper explores the public budget and environmental consequences of establishing an “adaptation fund” in favor of Developed to Least Developed Countries (LDCs). The exercise assumes that the EU uses carbon tax revenues from a unilateral mitigation policy to finance coastal protection investments in LDCs. Assuming that each region self-finances its coastal protection investments leads to an increase in public deficit while the introduction of a fund to monetize could eliminate the negative effect on public deficit, making SLR adaptation more sustainable for LDCs. The EU carbon tax revenues channeled into the fund are higher than LDCs additional investments in the period 2007-2014 while in the next decades investments approximately double total revenues.

JEL classification: C68, Q01

Keywords: Computable General Equilibrium, mitigation, adaptation, climate change

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¹ Euro-Mediterranean Center for Climate Change Fundation (CMCC).

² Corresponding author: Elisa Delpiazzi, Isola di San Giorgio Maggiore 8, 30124 Venezia (Italia). Email address: elisa.delpiazzi@feem.it

³ Euro-Mediterranean Center for Climate Change Fundation (CMCC) and Fondazione Eni Enrico Mattei.

1. Introduction

Climate change might be seen as a remote issue compared with more urgent problems such as poverty, disease and economic stagnation. However, it can directly affect the efficiency of resource investments and eventually hinder the achievement of many development objectives. Hence, linking climate change considerations with development priorities should be considered as a crucial matter for economic planning, with adaptation opportunely “mainstreamed” within a wide range of development activities (Agrawala and van Aalst, 2008). Considerable research has already been done on climate change mitigation, but much less attention has been paid to make development strategies more resilient to climate change impacts. The lack of awareness of climate change within the development community (i.e. knowledge constraint) and the limitations on resources to implement response measures (i.e. economic and financial constraints) are the most frequently cited explanations (Agrawala and van Aalst, 2008, Klein *et al.*, 2014). Mainstreaming climate policies could also prove to be particularly difficult because of the perceived direct trade-offs between development priorities and the actions required to deal with climate change. For instance, governments and donors, confronting challenges such as poverty and inadequate infrastructure have few incentives to divert scarce resources to investments that do not pay off until climate change impacts fully manifest. In addition, short-run economic benefits often accrue to a few in the community and can crowd out long-run investment decisions like those characterizing adaptation that benefit societies as a whole and in the longer term. Finally, several economic activities, that create employment, boost income, and foster economic development, may also induce maladaptation and increase climatic vulnerability.

In principle official flows (grants and loans) to finance climate change adaptation investments in Least Developed Countries (LDCs), as well as countries in the low- and middle-income categories, are significant. In practice a low fraction of them addresses adaptation directly while there is still a considerable gap between the resources which are pledged and those effectively disbursed. Moreover, tight budgetary constraints in many potential donor countries could hinder their commitment to fight climate change and to foster development. Against this background, this paper, developing a CGE analysis, focuses on the need for financing adaptation actions in a framework of development for LDCs, considering a particular climate change impact (Sea level rise - SLR). Here, we evaluate the use of a coordinated climate policy as an instrument to raise revenues and recycle them to finance domestic adaptation actions in developed countries or to pool them into an “adaptation fund” to finance investment against SLR in LDCs.

The paper is structured as follows. Section 2 provides a brief overview of mitigation and adaptation in the international context, while section 3 offers a brief literature review about CGE modeling and the establishment of international climate funds. Section 4 deals with a description of the modeling framework. Section 5 describes the main scenarios simulated, and section 6 discusses the main results. Finally, section 7 concludes.

2. Mitigation and adaptation in the international context

Like climate change itself, many of the proposed coping strategies are closely intertwined with development choices and pathways. There are two broad categories of responses to climate change: mitigation and adaptation. While mitigation aims to reduce the causes of climate change by slowing GHG emissions; adaptation reduces the impact of climate stresses on human and natural systems.

Both mitigation and adaptation interact with development activities in a dynamic cycle often characterized by significant delays. Mitigation and adaptation actions themselves can have implications on future development in the form of: (i) direct benefits of avoided climate damage on development prospects, (ii) ancillary benefits of mitigation and adaptation development, (iii) direct costs of mitigation or adaptation, which might hinder development; and (iv) positive or negative spillover effects on other regions through international trade. Conversely, development policies may affect both adaptation and mitigation capacity. Development trends as well as sector policies pursuing non-climate objectives can potentially increase or decrease greenhouse emissions.

Adaptation has emerged on an equal footing with mitigation in climate policy circles only since 2001 when during COP7 in Marrakesh the United Nations Framework Convention on Climate Change (UNFCCC) adopted a comprehensive framework to capitalize adaptation needs in LDCs. The so called “Marrakesh funds” consisted of two distinct funds whose aim, among others, is the monetization of adaptation measures. Subsequently, the Special Climate Change Fund (SCCF) and the Least Developed Countries Fund (LDCF) managed by the Global Environment Facility (GEF), were established in 2006, to address specifically short and long term adaptation needs in Least Developing and Small Islands and Developing States. The 2007 COP13 in Bali, established the Adaptation Fund (AF) as an instrument of the Kyoto Protocol, partially capitalized through a 2% share of the proceeds of certified emission reductions from projects under the Clean Development Mechanism (CDM). This share is completely independent of the willing of donor countries and it only depends on carbon price volatility.

Table 1: The UNFCC Adaptation Funds and their income magnitude

Fund	Total income*		
	Pledged	Deposited	Approved
Least Developed Countries Fund (LDCF)	\$ 964 Million	99.7%	\$ 795 Million
Special Climate Change Fund (SCCF-A)	\$350 Million	98.3%	\$ 278 Million
Adaptation Fund (AF)	\$ 487 Million	99.4% of which: 39.8% from sales of CERs and 60.2% from voluntary national contributions	\$ 325 Million

* Updated data on total income November 2015.

Source: Climate Funds Update

Another step forward, in the establishment of international funds for adaptation needs in LDCs, was the Developed countries' commitment to adapt to the effects of climate change in developing countries and to mobilize financial instruments to support their investments in the Copenhagen Agreement (2009). They promised to provide \$30 billion for the period 2010-2012, and to gather long-term finance (public and/or private) of a further \$100 billion a year by 2020⁴. Even the Paris Agreement, signed in December 2015, recognizes the urgency of an adequate finance to fight climate change and the establishment of a concrete roadmap to achieve the Copenhagen goal of jointly providing \$100 billion annually by 2020.

Assisting the most vulnerable countries in their efforts to adapt to climate change has become a priority for the EU in the last decades. In 2015 the EU participated for 90% of the cumulative contributions to the AF, for nearly 80% of the LDCF cumulative funding, and about 80% of the SCCF (European Commission, 2015). Moreover, as set by the 2014- 2020 multiannual financial framework (MFF) at least 20% of the entire EU budget from 2014 to 2020 should be spent on climate-related actions (EC, 2013), and climate action should be integrated into all major EU policies (EC, 2011). The 20% climate-spending target applies also to spending outside the EU through development and external action instruments. This funding will be considered both for mitigation and adaptation actions according to a 50-50 distinction.

Against the multiplicity of instruments to finance climate change adaptation in the international context, there are no unique estimates of future funding to be capitalized. Over the past decade, understanding climate change impacts and its associated costs have improved considerably, and with that estimates of adaptation finance needs. In 2007, a UNFCCC assessment put adaptation needs in developing countries at \$28 billion annually by 2030 (UNFCCC, 2007). Later on, in 2010, the World Bank estimates costs around \$70 to \$100 billion per year between 2010 and 2050 (Margulis and Narain, 2010). The most recent appraisal suggests adaptation costs could be at least two to three times higher. The costs of climate change for LDCs alone could be in the range of \$50 billion per year by 2025/2030, but it could be double by 2050 (UNEP, 2014). For all developing countries, estimates amount to \$150 billion per year by 2025/2030, and \$250 billion to \$500 billion per year by 2050. The Africa's Adaptation Gap 2 report (UNEP, 2015) estimates that the short- term cost of adaptation in Africa at \$7- \$15 billion per year by 2020, of which so far, roughly \$1- \$2 billion a year is estimated to have been flowing to Africa for adaptation. By 2050, Africa's adaptation costs could rise to \$50 billion per year if temperatures stay below 2°C and up to \$100 billion per year by 2050 in a 4°C scenario. Oxfam (2015) suggests that the specific financial need for adaptation before COP-21 is between \$2.5 to \$4.2 billion according to the first UNFCCC biennial reports, which count for Developed countries outflows to address adaptation issues, and OECD DAC statistics, which take track of climate- specific bilateral flows for adaptation.

⁴ Recent estimates from an OECD and CPI report (OECD, 2015) suggest that the target is more than half reached; the 2014 figures show that developed countries have mobilized \$62 billion.

As the uncertainty on the estimates of the total adaptation financing needs, even estimates on total costs of coastal protection are not clear and they are derived from the use of models based on the comparison of costs and benefits of adaptation policies. The costs reported by the UNFCCC for coastal adaptation (Nicholls, 2007) shows according to different sea-level-rise scenarios the adaptation cost for 2030. If we assume that all flood defenses anticipate conditions in 100 years, the annual costs in 2030 (assuming the investment occurs over 50 years) could be as high as \$13 billion per year. However, in their critique, Parry *et al.* (2009) conclude that these numbers are significant underestimates. Focusing on Africa, Watkins *et al.* (2010) considered the potential costs of adaptation for coastal zones in Africa. Under the A1B scenario, they are estimated at approximately \$2 billion per year over the time period 2030 - 2100. These costs rise significantly, with higher sea level scenarios, up to \$5 to \$8 billion per year by 2100. Finally, Nicholls *et al.* (2010) compare adaptation investments for coastal protection in a scenario without SLR and a medium scenario. In the first case, investments rise from \$10.4 billion in 2010s to \$9.5 billion in 2040s, while in the medium scenario they are four times higher in 2010s and nearly six times higher in 2040s (\$43.4 billion and \$59.5 billion, respectively).

3. Literature review

Several papers discuss the issue of financially supporting less developed countries in coping with climate change, but few of them address the issue by means of a computable general equilibrium model.

Antimiani *et al.* (2014) focuses on the creation of the Green Climate Fund (GCF) and its role in strengthening developing countries' growth in a green growth strategy, by linking a mitigation policy (global carbon tax) and investments in mitigation. The GCF fund is redistributed among developing countries to finance these green growth measures. The introduction of the Fund and its use in energy efficiency investment is a pro-poor strategy. In this way the negative effects of the mitigation policy is minimized and its beneficial spillovers are evident also in donor countries. Eisenack (2011) focuses on the capitalization of the Green Climate Fund, but considering its role respect to an adaptation levy in a partial equilibrium framework. The paper suggests that a linkage between mitigation and adaptation, in a way similar to what the clean development mechanism and the adaptation levy jointly do, is inappropriate to raise enough funds to close the adaptation deficit. A better financial mechanism should consider either auctioning emission permits or adaptation funding mechanisms with no link to mitigation. In fact, linking adaptation funding to mitigation efforts seems to be counterintuitive; the mechanism finances more adaptation when climate protection is more effective, and less adaptation if more global warming is admitted.

Altamirano-Cabrera *et al.* (2010) consider the introduction of a fund devoted to finance global climate change adaptation damages and investments costs. The structure of the fund is close to Antimiani *et al.* (2014) considering two options: a global carbon tax or a carbon tax levied only

on industrialized countries (i.e. OECD countries). Moreover, the fund revenues could be used either for adaptation to climate change or for damage recovery. A general conclusion from this study is that this financial scheme would not be feasible when the whole burden is put on industrialized countries. The unequal distribution of the tax burden would not encourage industrialized countries to engage in significant abatement strategies. It is more likely that industrialized countries accept to finance adaptation because it causes a lower burden.

4. Modeling framework

For this assessment, we use an extended version of the ICES recursive dynamic computable general equilibrium model (Eboli *et al.*, 2010; Parrado and De Cian, 2014) enriched with a more realistic description of the public sector in order to better capture the relations between public expenditure in adaptation and public budget sustainability (Delpiazzi *et al.*, forthcoming).

Differently from the original ICES model in which the government is part of the representative household, in the ICES-eXtended Public Sector (ICES-XPS) version the government is a separate actor with its own budget constraint⁵. Furthermore, the model now includes different transfers between the government and households such as social transfers, and interest payments on debt stock. There are also transfers among governments in form of international aid. Thus, government income is used for consumption, transfers, and savings. At the regional level, investments are function of private and public investments with a Cobb-Douglas formulation. The gap between public savings and public investments represent the government's financial needs (borrowing). This gap is financed by private households' savings, since both domestic and foreign households supply a homogenous saving commodity. Investment is internationally mobile and regional savings (private plus public) from all regions are pooled in a global bank. Subsequently investment is allocated to equalize expected rates of return to capital in the long-run.

Savings and investments are equalized at the world, but not at the regional level. Therefore, each region could have an imbalance between disposable savings and investment demand. This imbalance is closed by a surplus/deficit in foreign transactions (considered as the sum of trade surpluses/deficits and the net inflows of international transfers). In this context, government borrowing reduces the availability of regional savings with a consequent increase in saving prices which are negatively correlated to the rate of return to capital.

(i) Modeling public planned adaptation investments

According to the literature on SLR impacts, coastal protection expenditures mainly consist of infrastructure expenditures which are primarily financed by public funds (CEPS and ZEW, 2010; Nicholls *et al.*, 2010). In CGE modeling, however, there are few works dealing with planned strategies for adaptation (Bachner, 2015). Most of the literature relates to "autonomous

⁵ The detailed description of the public sector in the ICES-XPS is in Appendix A.

adaptation”, as the spontaneous adjustment mechanism which occurs as a response to climate change because of changes in relative prices (Bosello and Parrado, 2014).

In our set up, public expenditure in coastal protection is modeled as an increase in public sector demand addressed to the building sector. There is firstly an investment component of this expenditure.

In the model, regional investment net of depreciation ($NETINV_r$) is split into public ($GOVINV_r$) and private investments ($PRIVINV_r$) according to fixed shares:

$$NETINV_r = GOVINV_r + PRIVINV_r$$

Where: $GOVINV_r = \varepsilon_r \cdot NETINV_r$ and $PRIVINV_r = (1 - \varepsilon_r) \cdot NETINV_r$.

Introducing additional adaptation infrastructure investments $\Delta GOVINV_{CNST,r}$ public investments become:

$$GOVINV_r = \varepsilon_r \cdot NETINV_r + \Delta GOVINV_{CNST,r}$$

This implies that the new public investments in coastal protection are crowding out private investments.

Furthermore, coastal protection expenditures have also a recurrent component consisting of operation and maintenance costs. To accommodate this additional costs, we increase sector specific government expenditures in construction services ($QG_{CNST,r}$), and at the same time we also increase total government expenditures ($QGOV_r$). In this way we should not be altering the initial government expenditures on the remaining sectors of the economy. Therefore, the government spends its income in goods and services in all sectors while for the construction sector there is an additional shock ($\Delta QG_{CNST,r}$) which is exactly the amount of operation and maintenance costs for adaptation investments against SLR. This means that the government will increase its borrowing to cover for the additional costs. Formally, total government expenditures are:

$$PGOV_r \cdot QGOV_r = \sum_i PG_{i,r} \cdot QG_{i,r}$$

The summation on the right-hand side of the equation could be split into the following equations according to each sector. In the construction sector ($i = CNST$), the demand is equal to:

$$PG_{CNST,r} \cdot QG_{CNST,r} = PG_{CNST,r} \cdot QG_{CNST,r} + \Delta QG_{CNST,r}$$

while in the other sectors ($i \neq CNST$):

$$PG_{i,r} \cdot QG_{i,r} = PG_{i,r} \cdot QG_{i,r} \cdot (1 - b_r)$$

Where b_r is a shifting parameter for expenditures in sectors different from construction which ensures to respect the budget constraint for each year. Formally, b is defined as:

$$b_r = \frac{\Delta QG_{CNST,r}}{PGOV_r \cdot QGOV_r - PG_{CNST,r} \cdot QG_{CNST,r}}$$

(ii) Modeling the “Adaptation Fund”

Each region r can collect the revenues of a carbon tax and decide to pool all or a fraction of them into the Adaptation Fund. In the first step, each can raise a carbon tax on CO₂ emissions ($CO2TOT_r$) according to a tax rate ($RCTAX_r$) such that total revenues ($VCTAX_r$) from carbon tax are:

$$VCTAX_r = RCTAX_r \cdot CO2TOT_r$$

Then country r can participate or not as a donor to the Fund according to a binary variable α_r , which could have value either zero (the country does not participate to the Fund) or one (the country is a donor).

Donors decide how much of their revenues contribute to the Adaptation Fund for developing countries according to share β_r ranging between 0 and 1. Thus, the total amount of money available in the Fund is:

$$FUND = \sum_r \alpha_r \cdot \beta_r VCTAX_r$$

All resources of the Fund are distributed among beneficiary countries in shares according to parameter γ_r . If the country is a beneficiary, δ_r assumes the value 1, 0 otherwise. Thus, the total disposable income of the Fund equals the sum of each contribution to beneficiaries:

$$FUND = \sum_r \delta_r \cdot \gamma_r \cdot FUND$$

Such that: $\sum_r \gamma_r = 1$

Parameter γ_r represents the allocation rule. In this paper we assume that the Fund is allocated in proportion to the share of national land lost to SLR by beneficiary countries. This approach represents a “vulnerability approach”, since countries with higher vulnerability to SLR would receive more. We assume a 1-year lag for allocating resources because there is no instant adjustment of the Fund that decides to allocate:

$$\gamma_r = \frac{LandLoss_{t-1,r}}{\sum_r LandLoss_{t-1,r}}$$

(iii) Main input data and sources

Data on economic flows in the benchmark year are provided by the extended GTAP database version 8 (Narayanan *et al.*, 2012). Table 1 summarizes the regional and sector aggregations. In this analysis we assume an aggregated regional breakdown since the objective of the paper is the evaluation of the policy and the feasibility of the “Adaptation Fund” as an instrument to capitalize adaptation investments in LDCs. Further future research could include a more detailed regional aggregation to capture effects on single countries.

Table 2: Sectoral and regional aggregation in the ICES-XPS model

Aggregation	Acronym	Extended name	
Regional Aggregation	EU	European Union	DONOR
	FSU	Former Soviet Union	
	OCEANIA	Australia, New Zealand and Oceania	
	NORTH AMERICA	USA, Canada	
	MENA	Middle East and North Africa	
	LACA	Mexico, Latin America and the Caribbean	
	ASIA	Asia	BENEFICIARIES
	SSA	Sub- Saharan Africa	
Sectoral Aggregation	Agriculture		Primary sector
	Coal, Oil, Gas, Oil_pcts,		Energetic commodities
	Ely_nuclear, Ely_renewables, Ely_other,		Electricity
	En_int_ind, Oth_ind_ser, Construction, Pub_serv		Secondary sector and services

For the business as usual (BAU) , the model replicates GDP and population growth rates of the SSP2 scenario from the Shared Socio- Economic Pathways (SSPs) in the “OECD version” (Van Vuuren and Carter, 2014). It is a “middle of the road” scenario with a combination of both adaptation and mitigation intermediate challenges.

Input data on SLR impacts and adaptation expenditures come from the Dynamic Interactive Vulnerability Assessment (DIVA) model (Dinas Coast Consortium, 2006) when SRES scenario B2 is imposed.⁶ Following previous research efforts,⁷ we model SLR impacts as negative shocks on capital and land stocks. The main information used regards land loss (column 2 in table 2), and we assume there is productive capital installed on it. However, since there is no available data

⁶ The data for this study comes from an earlier version of the DIVA model providing data only with respect to the IPCC’s SRES scenarios. We acknowledge this as a limitation of this approach and will update our scenarios when new data will be available. For this study we follow the close correspondence between SSP2 and the SRES B2 scenario (Van Vuuren and Carter, 2014).

⁷ Bigano *et al.* (2008), Bosello *et al.* (2012a), Bosello *et al.* (2012b), Bosello *et al.* (2007), Eboli *et al.* (2010).

about the share of capital installed on the land lost, we assume a 1 to 1 correspondence for capital loss. We use a “full adaptation” scenario for investments in dike and seawalls construction as well as beach nourishment. This means that this level of regional investments allows the region to have zero residual damage for SLR. Table 2 summarizes the land loss as well as the cumulated adaptation investments.

Table 3: Input data on land and capital loss, adaptation expenditures and residual damage

	SLR scenario	SLR_ADAPT scenario
	% land loss (cumulated in 2007/2030)	Adaptation investments (cumulated in 2007/2030) \$ billion
EU	-0.030	11332
FSU	-0.036	11287
MENA	-0.007	2626
ASIA	-0.100	9823
OCEANIA	-0.012	4537
LACA	-0.024	11474
NORTH AMERICA	-0.079	16998
SSA	-0.135	3856

Source: Authors' calculation based on DIVA output

These data give an aggregated value for adaptation investments in each year. We then assume that it consists of both new investments in protective infrastructure as well as operation and maintenance costs (O&M) to increase the lifetime for the infrastructure itself, as described in Nicholls *et al.* (2010). We suppose that 1% of the annual investments are destined to O&M costs, while the remaining amount is new productive investment in infrastructure (Nicholls *et al.*, 2010).

5. Simulation scenarios

To perform this analysis, we set up six different scenarios in order to consider step-by-step the effects of SLR impacts along with the selected mitigation and adaptation policies.

1. **Business as usual (BAU).** Demographic and economic growth according to the SSP2 projections for the period 2007/2030. SLR impacts or adaptation expenditures are not considered.
2. **SLR.** The BAU is perturbed by the negative impacts of sea-level rise on land and capital stock (see table 2). The outcome of the scenario is the indirect or GDP cost of SLR impacts.
3. **SLR_ADAPT.** SLR Impacts are completely avoided thanks to full coastal protection, but expansion of government investment and recurrent expenditures in protective infrastructure (e.g. dikes, sea walls) is imposed. This setting allows us to evaluate the indirect benefits and costs of SLR adaptation expenditure.
4. **CTAX.** Here, we estimate the cost of the unilateral climate policy in EU (i.e. EU- ETS) and its indirect effects on other macro regions through international trade linkage effects.

Emission reduction targets are adapted to follow the EU 2020 and 2030 Climate and Energy Policy framework (CO₂ emission reductions of 20% in 2020, and 40% in 2030, compared to 1990 levels) .

5. **CTAX_ADAPT.** In this scenario we assess whether a unilateral climate policy in EU is a suitable instrument to finance a domestic adaptation expenditures (in this case for the EU), while the rest of the world use their own resources to finance adaptation investments also domestically. Ultimately, this scenario wants to assess if the introduction of a carbon tax is useful to reduce public deficit and foster GDP when we use it to finance domestic adaptation investments.
6. **Adaptation Fund.** Introduction of the EU financed “Adaptation Fund” as a means to finance SLR adaptation investment in LDCs. The aim is to compare the establishment of the Fund respect to the SLR_ADAPT scenario for LDCs. For EU, instead, we can compare this scenario with the CTAX_ADAPT to evaluate if the establishment of the Fund has a cost (in terms of GDP or worsening public budget position).

Scenarios 5 and 6 represent two extremes in the case of how much of the carbon tax revenues are used to finance adaptation against SLR in EU and LDCs. In the first case we assume total revenues accrue to EU to finance adaptation investments, while in the second case all revenues are channeled via “Adaptation Fund” to LDC. We do not consider intermediate cases, such as EU firstly uses revenues for its expenditures and only the remaining fraction is mainstreamed into the Fund, because we assume that each of these combinations are middle of the road points and we focus only on the extremes where either EU or LDCs completely benefit.

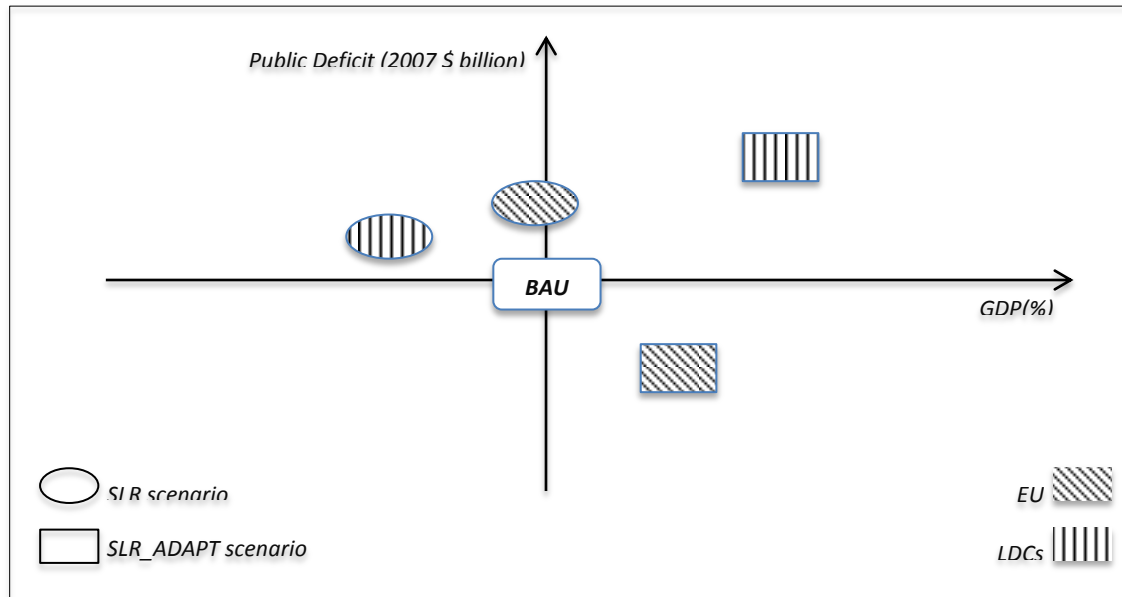
6. Simulation results

Our analysis concentrates on four issues. First, we evaluate the budgetary effects of impact and adaptation scenarios to identify if there is a trade-off between adaptation and development in terms of economic growth and public borrowing. Secondly, we focus on the costs of an EU unilateral mitigation policy with leakage effects on LDCs, by comparing mitigation policy revenues to the adaptation financing needs. Then, we analyze the costs and benefits of an adaptation fund considering two extremes where the EU uses revenues to finance adaptation domestically or abroad. Finally, we show the positive effect of such fund for LDCs.

(i) Impact indirect costs versus adaptation benefits

Figure 1 summarizes the outcomes in 2030 comparing the impact (SLR) with the adaptation (SLR_ADAPT) scenario showing deviations from the BAU taken as reference. The idea is to compare a short-run indicator as GDP (horizontal axis) with an indicator that has long term implications for public budget sustainability such as the public borrowing level (vertical axis). This is consistent with the theoretical structure of the CGE model. The model considers the “perpetual notion of debt”. This means that if a country increases its public deficit it has to pay more interests and consequently worsens its public fiscal position, since there is no repayment of government debt.

Figure 1: The GDP- public borrowing gap in the SLR and SLR_ADAPT scenarios in 2030



SLR impacts lower GDP growth with the corresponding implications on economic development. The final effect is directly dependent of the input shocks. This explains why the GDP loss is consistently different between EU and LDCs. While EU loses only 0.03% of its land, the LDC country group loses more than 0.26% as a whole (with more than 50% of the loss concentrated in the SSA region). Therefore, the final effect on EU GDP is negligible, while the LDC region as a whole loses nearly 0.12% of GDP respect to BAU. Regarding the public borrowing dimension, SLR impacts increase public borrowing in both regions (\$0.62 billion and \$0.06 billion, respectively). This effect is mainly driven by a reduction in tax revenues consequent the GDP contraction partially compensated by the assumption that transfers are a fixed share of government income. Thus, a reduction in taxes lowers the income of the government which deteriorates transfers both domestically and abroad.

When adaptation is carried out, there is a positive effect on economic growth for both regions. EU increases its GDP by 0.1% and LDCs by 1.8%. However, the final effect for public borrowing is different; while the EU lowers its level respect to BAU (\$529 billion), LDCs increase their public borrowing by \$109 billion. This highlights a potential trade-off between adaptation and development policies in those countries. Taking adaptation measures to protect from SLR may increase the public burden because on the financing needs associated to cover those investments.

A more in-depth analysis shows a differentiated situation within LDCs. In the SLR scenario LACA, SSA and ASIA report a GDP loss ranging from 0.04% to 0.08% in 2030; while MENA slightly increases its GDP. This outcome derives from the lower land loss in MENA compared to other

LDCs which ultimately gives the region a comparative advantage over its competitors. Considering public borrowing, all but ASIA increase their public financial needs (between \$268 and \$6 billion). When adaptation is domestically financed, GDP increases in LACA and SSA, by nearly 5% respect to the BAU. MENA now loses as its comparative advantage is eliminated. ASIA also loses slightly more with than without coastal protection (around 1%). Public deficit increases in each sub-region (between \$230 and \$23 billion).

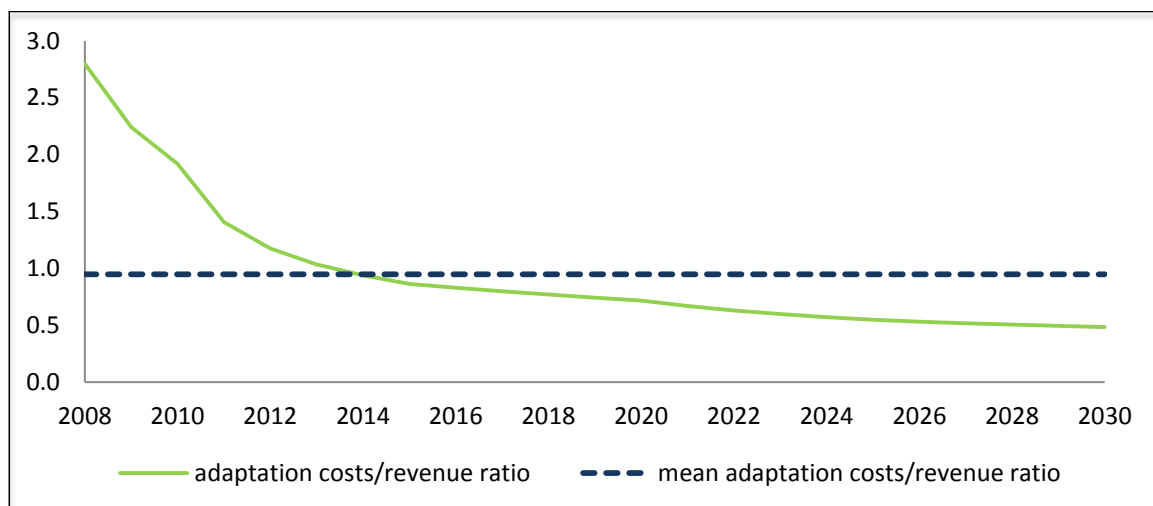
(ii) Mitigation policy revenues in EU versus adaptation needs in LDCs

The mitigation policy costs nearly 6.9% of GDP respect to BAU in 2030. However it allows also to reduce EU's public borrowing by \$552 billion in 2030, since revenues accrue to public budgets and reduce public deficit.

The combined mitigation and adaptation policy scenario (CTAX_ADAPT) shows the expected carbon leakage outside the EU. LDCs countries increase their GDP by 2.5%. This is the result would not only be the loss of competitiveness in the EU, but also the combination of the adaptation investments that stimulate GDP growth. Although mitigation policy funds are used domestically in EU, and LDCs cover their adaptation investments by themselves the lower production costs in LDCs pushes their GDPs through international trade. But there is another effect which is not so positive for LDCs, given that their public borrowing increases (around \$120 billion).

In figure 2 the thick line represents the ratio of total adaptation costs in LDCs over total revenues from the EU mitigation policy. At the beginning revenues would not cover the adaptation needs in LDCs, but in the second half of the simulation period revenues are higher than costs (nearly 48% of revenues are necessary to monetize SLR adaptation investments). The dotted line shows the mean value of the ratio adaptation costs in LDCs/revenues throughout the entire time span (90%).

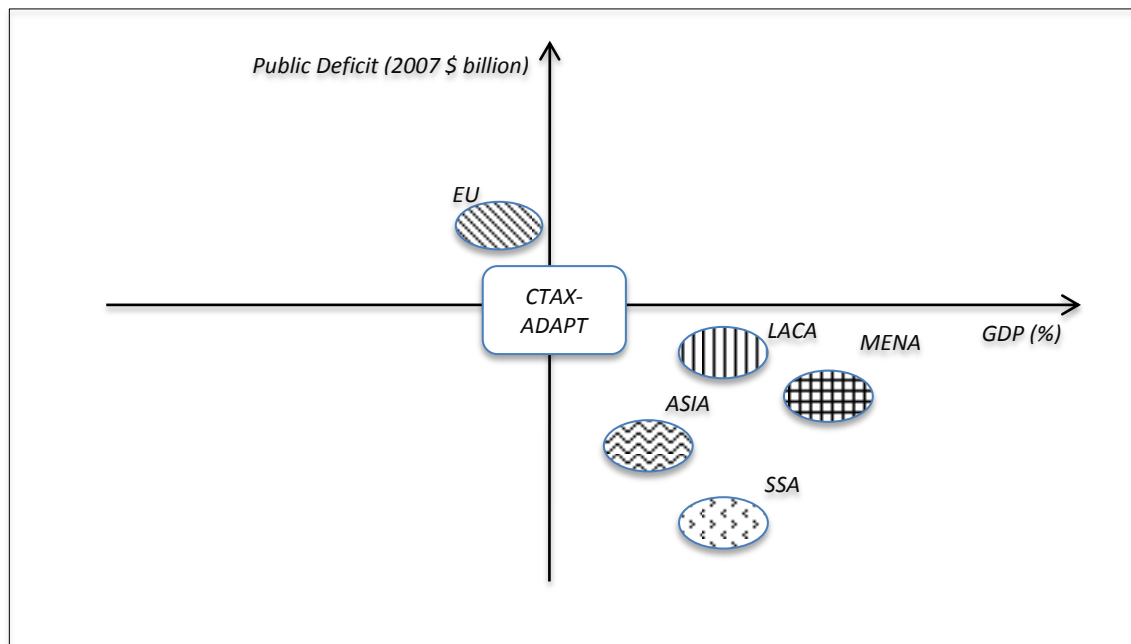
Figure 2: The adaptation costs in LDCs/ climate policy revenues ration in the period 2008/2030



(iii) Cost and benefits of an Adaptation Fund

For illustrative purposes, we assume that in the last scenario, the EU collects all revenues from the climate policy in the “Adaptation Fund” for LDCs. Figure 3 summarizes the results compared to the mitigation scenario (CTAX-ADAPT). In other words, the reference is when the EU decide to use the ETS revenues domestically, while the deviations shows what happens when the EU channels the revenues into the “Adaptation Fund”. Using the revenues to finance adaptation measures domestically or abroad has nearly no impact on GDP. The EU GDP loss is lower than 0.01% with a small increase in public borrowing (\$ 586 billion). The effect on GDP suggests that the revenues from a unilateral mitigation policy could provide a good source of funds for international adaptation cooperation.

Figure 3: The GDP- public borrowing gap in the CTAX-ADAPT and FUND scenarios



When the mitigation policy revenues are channeled to LDCs, there is a positive effect on GDP respect to the CTAX scenario ranging between 0.23% (ASIA) and 0.35% (SSA). There is also a contemporaneous decline in public borrowing varying between \$124 billion (LACA) and \$630 billion (SSA). This means that the reduction completely offsets the increase in public borrowing in the CTAX-ADAPT scenario.

(iv) Positive effects on LDCs

Comparing Figures 1 and 3 highlights one clear result: LDCs are better off when implementing adaptation policies to deal with SLR, and when they receive financial support to do so. Table 4 shows the GDP growth rate and the difference in public borrowing respect to BAU for the cases

in which there is adaptation either financed domestically (SLR_ADAPT) or when is it financed abroad (Adaptation Fund).

Table 4: GDP growth and public borrowing in 2030 (Deviations from BAU)

	SLR_ADAPT		Adaptation Fund	
	GDP % change	Public deficit \$ billion change	GDP % change	Public deficit \$ billion change
MENA	4.58	59	0.50	-3
LACA	4.58	121	5.52	-83
SSA	5.50	23	6.55	-616
ASIA	-1.83	233	-0.99	-188

With the exception of MENA, financing adaptation through an international fund increases GDP in LDCs. In fact, since land loss is lower in MENA all adaptation benefits would also be lower. The effect on public borrowing is uniform for all LDCs, since the Adaptation fund improves their public financial positions. Adaptation can be an expensive policy when the country has to self-finance it and public finance sustainability could be compromised.

Conclusions

In a context where governments of developing countries must decide among different priorities because of limited resources, the availability of financial resources to adopt adaptation measures is crucial. Using a computable general equilibrium model we quantitatively assessed the impacts of SLR including the consequent adaptation scenarios to address this issue.

In order to properly include in the analysis the budgetary effects of climate policies we have extended the representation of the public sector in the CGE model. In this way we can control the effects on the public budget of an increasing expenditure covering adaptation needs. The analysis concentrates on two measures: GDP and public borrowing as two strategic dimensions to understand the interactions of short and long run goals in a context of mainstreaming adaptation in development policies. Firstly, GDP is regarded as an economic development indicator useful to measure economic performance and the indirect costs of climate change. Secondly, public borrowing is interpreted as a measure of governments' burdens posed on future expenditure policies. The fact that a government has scarce resources is crucial in budget planning, and increasing today's deficit is likely to affect the possibilities of the government to pursue other expensive policies in the future. This is particularly relevant in LDCs. These two variables allow us summarizing the trade-off in spending for climate change adaptation and development, which could be one of the main causes of inaction in mainstreaming adaptation to climate change in development policies.

Supposing the establishment of an EU unilateral mitigation policy following the 2020 and 2030 climate and energy packages, we consider whether these revenues are used domestically or abroad to increase resilience to SLR in Least Developed Countries. When EU raises revenues

through a mitigation policy and uses them domestically, the possibility to have an additional source of funding reduces the need of public borrowing, thus lowering the future public finance burden. If the EU sets an Adaptation Fund for developing countries with those resources, LDCs' governments could eventually have greater room for other development policies besides adaptation needs. Pooling all revenues in an Adaptation Fund to finance LDCs does not reduce EU GDP drastically respect to the sole climate mitigation policy. Our results suggest that the establishment of the Fund is almost costless for the donor respect to when only climate policy takes place.

There seems to be a trade-off between economic growth and public finance when LDCs consider mainstreaming adaptation investments into their policies using public borrowing as a financing instrument. Supporting adaptation investments through an international financing mechanism allows LDCs to increase their ability in coping with SLR and to become more resilient. This is a strategic outcome to stimulate developed countries to contribute in strengthening an integrated climate policy framework in international finance, because of additional positive externalities of mitigating climate change, even in the case of a unilateral climate policy.

Appendix A: Overview of the ICES-XPS model

The model uses a Walrasian perfect competition paradigm to simulate market adjustment processes. Industries are modeled through a representative price-taker firm that minimizes its production costs. Output prices are given by average production costs. The production functions are specified via a series of nested Constant Elasticity of Substitution (CES) functions. Domestic and foreign inputs are imperfect substitutes, according to the Armington assumption.

A private representative consumer in each region receives income (YH_r), defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically, but immobile internationally. Land and natural resources, on the other hand, are industry-specific.

In mathematical terms, equation (1) describes private income respect to sources. It is composed of four main elements according to sources: (i) factor use remuneration (divided into labour and capital income, YHL_r , YHK_r respectively); (ii) social transfers from the government ($YHTR_r$); (iii) the net of other transfers between private households and government ($YHOGI_r$, $YHOGE_r$) which is functional to the balancing of the base year; (iv) income from interest on public debt (YHI_r).

$$YH_r = YHL_r + YHK_r + YHTR_r - YHOGI_r + YHOGE_r + YHI_r \quad (1)$$

Where:

$$YHTR_r = \alpha_{TR,r} \cdot YG_r \quad (2)$$

$$YHOGI_r = \alpha_{OGI,r} \cdot YH_r \quad (3)$$

$$YHOGE_r = \alpha_{OGE,r} \cdot YG_r \quad (4)$$

$$YHI_r = INTD_r + INTI_r \quad (5)$$

Transfers are fixed shares of the income of the agent paying out the transfer. For instance, social transfers from government to the private household (equation (2)) are a fixed share ($\alpha_{TR,r}$) of the government income. Similarly, other expenditures (equations (3)-(4)) are respectively fixed shares of government and household income (according to shares $\alpha_{OGE,r}$ and $\alpha_{OGI,r}$). Interest income to households (equation (5)) is the sum of interest paid from the domestic government and interest from abroad.

This income is used to finance aggregate household consumption ($PRIV_EXP_r$) and household savings ($PRIV_SAV_r$). The expenditure and saving shares are fixed ($\beta_{PEXP,r}$ and $(1 - \beta_{PEXP,r})$, respectively), which means that the top-level utility function has a Cobb-Douglas specification. Formally, equation (6) defines the private income equation respect to uses; equations (7) and (8) isolate the Cobb-Douglas structure between consumption and savings.

$$YH_r = PRIV_EXP_r + PRIV_SAV_r \quad (6)$$

$$PRIV_EXP_r = \beta_{PEXP,r} \cdot YH_r \quad (7)$$

$$PRIV_SAV_r = (1 - \beta_{PEXP,r}) \cdot YH_r \quad (8)$$

Then, private consumption is split in a series of alternative composite Armington aggregates. The functional specification used at this level is the Constant Difference in Elasticities (CDE) form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods. In mathematics, equation (9) represents the identity between regional private expenditure and its decomposition into prices and quantities, while equation (10) states that total regional private consumption is nothing else than the sum of private consumption by goods.

$$PRIV_EXP_r = PPRIV_r \cdot QPRIV_r \quad (9)$$

$$PPRIV_r \cdot QPRIV_r = \sum_i PP_{i,r} \cdot QP_{i,r} \quad (10)$$

The government is a separate actor, and the model enriches the representation of public expenditures.

It receives income from four main sources: (i) tax revenues ($TTAX_r$); (ii) the net transfers with private households ($YHOGI_r - YHTR_r - YHOG E_r$); (iii) net interest payments to resident and non- resident households (YGI_r); (iv) net foreign transfers among governments ($AIDI_r - AIDO_r$). Government income is used for consumption (GOV_EXP_r) and savings (SAV_GOV_r). Equations (11) and (12) represent the government income respect to sources and uses.

$$YG_r = TTAX_r - YHTR_r + YHOGI_r - YHOG E_r - YGI_r + AIDI_r - AIDO_r \quad (11)$$

$$YG_r = GOV_EXP_r + SAV_GOV_r \quad (12)$$

Where:

$$YGI_r = INTD_r + INTO_r \quad (13)$$

$$AIDO_r = \alpha_{AIDO,r} YG_r \cdot aidout_r \quad (14)$$

$$AIDI_r = \overline{AIDI_r} \cdot aidin_r \quad (15)$$

Equations (13)-(15) show the definition of the new variables. YGI_r is the total amount of interest paid from a government (so it is the sum of payment to residents ($INTD_r$) and non-residents ($INTO_r$)). Outflows of grants ($AIDO_r$) 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 ($AIDI_r$), are simply rescaled considering the initial level.

Since there is no bilateral matrix to track international transfers (i.e. grants), we use the approach described in McDonald and Sonmez (2004), where an artificial accounting agent (named "Globe") collects all outflows and distribute them to the countries. This leads to a clearing condition (equation (16)) in the global market of aid of this kind:

$$\sum_r \overline{AIDI_r} \cdot aidin_r = \sum_r \overline{AIDO_r} \cdot aidout_r \quad (16)$$

Government income is used to consume and save according to equation (12). Regional real government expenditures are a fixed share of real regional GDP (equation (18)), while nominal expenditures are the sum of the single commodity consumption (equation (19)).

$$GOV_EXP_r = PGOV_r \cdot QGOV_r \quad (17)$$

$$QGOV_r = \beta_{GEXP,r} \cdot QGDP_r \quad (18)$$

$$PGOV_r \cdot QGOV_r = \sum_i PG_{i,r} \cdot QG_{i,r} \quad (19)$$

Total regional investments are modeled through a Cobb-Douglas function of private and public investments. Formally, regional investment net of depreciation ($NETINV_r$) is split into public (GOV_INV_r) and private investments ($PRIV_INV_r$) according to fixed shares (equation (20)).

$$NETINV_r = GOV_INV_r + PRIV_INV_r \quad (20)$$

Where:

$$GOV_INV_r = \varepsilon_r \cdot NETINV_r + \Delta GOVINVCNST,r \quad (21)$$

$$PRIV_INV_r = (1 - \varepsilon_r) \cdot NETINV_r \quad (22)$$

and ($\Delta GOVINVCNST,r$), are additional adaptation infrastructure investments.

The gap between public savings and public investments is the amount of borrowing the government requires. This gap is financed by private households. Both domestic and foreign households supply a homogenous saving commodity. Therefore, equation (23) is satisfied in each time period of the simulation:

$$I_GOV_r = SAV_GOV_r + GBOR_r \quad (23)$$

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.

Investment is internationally mobile: regional savings (private plus public) from all regions are pooled and subsequently investment is allocated to achieve equality of expected rates of return to capital in the long term. Savings and investments are equalized at the world, but not at the regional level. Therefore, each region could have an imbalance between disposable savings and investment demand, which is closed by a surplus/deficit in foreign transactions (considered as the sum of trade surpluses/deficits and the net inflows of international transfers). An important role is played by government borrowing since it reduces the availability of regional savings with a consequent increase in saving prices which are negatively correlated to the rate of return to capital. Therefore, a country can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of the other countries, or its government necessitates a lower level of borrowing.

The ICES-XPS model 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:

$$GDEBT_{t,r} = GDEBT_{t-1,r} + GBOR_{t,r} \quad (24)$$

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 (24) becomes:

$$GDDEBT_{t,r} = GDDEBT_{t-1,r} + (1 - fdshr_r) \cdot GBOR_{t,r} \quad (25)$$

$$GFDEBT_{t,r} = GFDEBT_{t-1,r} + fdshr_r \cdot GBOR_{t,r} \quad (26)$$

Interest payments on government's domestic and foreign debt stocks ($INTD_{t,r}, INTF_{t,r}$) are defined as an exogenous interest rate (ir_r) multiplied by the related previous year debt stock (equations (27)- (28)). This means that interest payments are a consequence of the level of indebtedness (Lemelin and Decaluwé, 2007)

$$INTD_{t,r} = ir_r \cdot GDDEBT_{t-1,r} \quad (27)$$

$$INTF_{t,r} = ir_r \cdot GFDEBT_{t-1,r} \quad (28)$$

Similarly to the case of international grants, there is a clearing condition (equation (29)) also in the world market for interest payments. This condition ensures that the total amount of interests governments pay to non- residents equals the total amount of interest payments from abroad. This does not mean that there is a balance in outflows and inflows of foreign interest payments but each country could face a positive or negative net value.

$$\sum_r INTI_{r,t} = \sum_r INTF_{r,t} \quad (29)$$

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 30), and on a scaling parameter ($psavshr_{r,t-1}$) which represents the country contribution to world private investment in the previous year.

$$psavshr_{r,t-1} = \frac{SAV_PRIV_{r,t-1}}{\sum_r SAV_PRIV_{r,t-1}} \quad (30)$$

This share reflects by how much private households in each country contribute 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:

$$INTI_{r,t} = INTAVI_r \cdot psavshr_{r,t-1} \quad (31)$$

Government closure rule choice for ICES-XPS model

When the public agent is introduced in a Computable General Equilibrium model, the modeler has to choose how to close the sector, in other words, he has to decide the causality among income, expenditures and savings (Robinson, 2003). There are essentially two alternatives: (i) endogenous government savings and the other components exogenous, or (ii) the other way round with exogenous government savings. Since, in this deliverable we want to use the ICES-XPS model to assess the budgetary effects of impacts and adaptation expenditures we follow the first approach. Therefore, taxes have exogenous tax rate, expenditures (both recurrent and investments) are fixed exogenously and as a consequence the model calculates the final savings (or public borrowing) as the gap between revenues and expenditures. However, there are no projections for government expenditures up to 2050. Some estimates are in IMF's World Economic Outlook (IMF, 2016) up to 2020 but there is no clear and unique correspondence between its aggregate "general government total expenditures" and the ICES-XPS variables. Therefore, to project these variables in the baseline we apply two different approaches: (i) real recurrent expenditures are a fixed share of real GDP (Chateau *et al.* 2014); (ii) real government investments are a fixed share of total regional investments, so that public and private investments are a Cobb-Douglas function respect to total (depreciated) regional investments.

Considering fixed government expenditures is as to assume that the government has a sort of "minimum" level of expenditures it wants to maintain even in other scenarios, when, for instance, impacts or adaptation occur. Moreover, this choice allow us to have a more clear link between inputs and the final outcomes. In fact, in this framework impacts act on the supply side of the economy, as they are modeled as changes in stocks and productivity. As a consequence, the most obvious result is a change in tax revenues. When additional adaptation investments are considered the final effect on the public budget depends solely on the additional expenditures and eventually on the effects on revenues due to residual impacts.

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