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

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SUMMARY This research investigates the effects on GDP and public budget of developed and developing countries of a coastal protection expenditure aimed to offset completely land lost to sea-level rise. First, adaptation action is considered in isolation, then the parallel implementation of the EU mitigation targets for 2020 and 2030 by means of carbon taxation is assumed, finally an “adaptation fund” from the EU in favor of Least Developed Countries (LDCs) financed by carbon tax revenues is considered. Coastal protection is beneficial especially for developing countries, however, in face of GDP benefits that turn to be higher than the costs, the additional expenditure required worsens public deficits. When the EU implements unilaterally its carbon energy package, GDP in developing countries increase because of the presence of a non-negligible carbon leakage, however their public borrowing still deteriorates. Against this background, the adaptation fund could be particularly important. The revenues from the EU carbon tax would be more than sufficient to cover the full coastal protection expenditure in LDCs and allow them to lower their deficit and increase further their GDP. As expected, the deficit in the donor developed countries increases, however, the total deficit cut in developing countries would be even higher, while GDP in the donor will decrease only marginally.

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

JEL Classification: C68, Q01

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1. INTRODUCTION

Climate change might be seen as a remote issue compared with more urgent problems such as poverty, ill health and economic stagnation. However, it can directly affect the efficiency of resource use 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. In particular, climate change adaptation should be 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 increase the resilience of development strategies to climate change impacts. The, at least initial, lack of awareness of climate change threats within the development community (i.e. knowledge constraint) and the limited 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 infrastructures 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, especially when accrue to a few in the community, 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 (Nakooda et al. 2013). 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. ADAPTATION IN THE INTERNATIONAL CONTEXT, A BACKGROUND

Like climate change itself, many of the proposed coping strategies are closely intertwined with development choices and pathways. As anticipated, 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 from avoided climate damage on development prospects, (ii) ancillary benefits of mitigation and adaptation on 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 mobilize financial instruments towards developing countries stated in the Copenhagen Agreement (2009). The goal is 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 2020[1]. Even the Paris Agreement, signed in December 2015, recognizes the urgency of an adequate finance to fight climate change and strengthened the Copenhagen goal of providing $100 billion annually by 2020, extending it to 2025 and conceiving the possibility to increase it before 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 this multiplicity of instruments to finance climate change adaptation, there are no unique estimates of future funding to be capitalized. Nonetheless, over the past decade, understanding climate change impacts and its associated costs, and with that estimates of adaptation finance needs, improved enough to offer at least some orders of magnitude. For instance, according to the UNFCCC, adaptation needs in developing countries are $28 billion annually by 2030 (UNFCCC, 2007). The World Bank estimates costs around $70 to $100 billion per year between 2010 and 2050 (Margulis and Narain, 2010). More 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, and double by 2050 according to 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 the short-term cost of adaptation in Africa at $7- $15 billion per year by 2020, of which so far, only $1- $2 billion a year have been covered by international support. 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 temperature increase scenario. Oxfam (2015) suggests that the specific financial need for adaptation

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[1] 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.

(before COP-21 commitment) is between \$2.5 to \$4.2 billion. This could be however, an underestimation, as it is based on official figures form the first UNFCCC biennial reports which records Developed countries outflows to address adaptation issues, and OECD DAC statistics, which take track of climate- specific bilateral flows for adaptation, which are not necessarily fully representative of actual adaptation needs.

Estimating adaptation costs in the different sectors is equally problematic. In the specific case of coastal protection for instance, particularly relevant for the current analysis, they are often derived from the use of engineering models proposing the comparison of costs and benefits of different adaptation measures. The UNFCCC reports estimates from Nicholls (2007) quantifying global flood defense costs in 2030 as high as \$13 billion per year, assuming protection against events with a 100 year return period. However, Parry et al (2009) suggest that these numbers are significant underestimates. Watkins at al. (2010) quantify the potential costs of adaptation in African coastal zones in approximately \$2 to 8 billion per year over the period 2030 – 2100 depending on the climate change scenario considered. Finally, Nicholls et al. (2010) compare adaptation investments for coastal protection in a scenario without and with (medium) SLR. In the first case, investments remain roughly constant at around \$10 billion per year from 2010 to 2040s. In the latter case, they can reach \$59.5 billion in 2040.

Several papers then address the issue of financial support to climate change adaptation in less developed countries, but relatively few of them use computable general equilibrium models.

Antimiani et al. (2014) analyze the creation of the Green Climate Fund (GCF) and its role in strengthening developing countries' green growth in the context of a mitigation policy pursued with carbon taxation. The study shows that the introduction of the Fund and its use to promote energy efficiency investment in developing countries is a pro-poor strategy, which minimizes the negative effects of the mitigation policy and brings beneficial spillovers also in donor countries. Eisenack (2011) discusses the capitalization of the Green Climate Fund as currently done by the Adaptation Fund which links the clean development mechanism to an adaptation levy. His partial equilibrium analysis concludes that this mechanisms is inappropriate to rise enough funds to close the adaptation deficit. A better financial mechanism should consider either auctioning emission permits or an adaptation funding with no link with mitigation. In fact, the linkage seems inefficient: it will produce more funding to adaptation when climate action is more effective, and less if more global warming were admitted. Altamirano-Cabrera et al. (2010) analyze two different options to finance an adaptation fund: a global carbon tax, or a carbon tax levied only on industrialized countries. The general conclusion is that, when the whole burden is put on industrialized countries, this would in fact discourage them to engage in significant abatement strategies, with negative implications either for mitigation and adaptation effort. It is more likely that industrialized countries accept to finance adaptation when it is associated to a lower tax burden.

3. 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 (Delpiazzo *et al.*, forthcoming).

Differently from the original ICES model in which the government ultimately behaves as the representative household, in the ICES-eXtended Public Sector (ICES-XPS) version, the government is a separate actor with its own budget constraint[2]. 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 the 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, that could be both domestic and foreign. Investment is internationally mobile, and regional savings (private plus public) from all regions are initially pooled and then redistributed to countries in order to equalize expected rates of return to capital in the long-run.

[2] The detailed description of the public sector in the ICES-XPS is in Appendix A.

Accordingly, savings and investments are equalized at the world, but not at the regional level. Imbalances are "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 IN COASTAL PROTECTION

According to the literature on SLR impacts, coastal protection expenditures 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 public-planned strategies for adaptation (Bachner, 2015). Most of the literature relates to "autonomous adaptation", defined as the spontaneous reaction of agents/markets to changes in relative prices induced by climate shocks (Bosello and Parrado, 2014).

In our set up, on the contrary, public expenditure in coastal protection is modeled as an increase in public sector demand addressed to the building sector. This expenditure has firstly an investment component.

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 ($\mathrm{QG_{CNST,r}}$), keeping the initial government expenditures on the remaining sectors of the economy unaltered. This means that total government expenditure will expand, without crowding out other public expenditure items. The additional public funds needed are supported by additional borrowing from the households, thus using private savings. 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 ≠ 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 CO_2 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 $\gamma_r$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 used in the study.

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

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

The model business as usual (BAU) 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 presenting "intermediate challenges" for both adaptation and mitigation.

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.[3] Following previous research efforts,[4] we model SLR impacts as negative

[3] 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

shocks on capital and land stocks. The information available is on land loss (column 2 in table 2). Since there is no available data about the share of capital immobilized on that land we assume a 1 to 1 correspondence land/capital losses. We consider a "full adaptation" scenario. This means that the related regional protection investments allow zero residual damage. 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 expenditure in each year[5]. 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).

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).

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

[5] Data on Adaptation expenditures provided by the DIVA model are results of a partial equilibrium analysis and do not take into account indirect effects on the economic system.

4 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.** Estimates 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 (CO_2 emission reductions of 20% in 2020, and 40% in 2030, compared to 1990 levels) .
5. **CTAX_ADAPT.** Assesses the effects of coupling mitigation and adaptation focusing especially on the policy interaction triggered on GDP and public deficit.
6. **Adaptation Fund.** Introduces the EU financed "Adaptation Fund" as a means to finance SLR adaptation 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 the two extremes cases of international support to adaptation in LDCs. In the first, the EU uses total revenues from the tax to finance its adaptation needs; in the second 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 for the Fund, because we assume that each of these combinations will produce outcomes within these extremes.

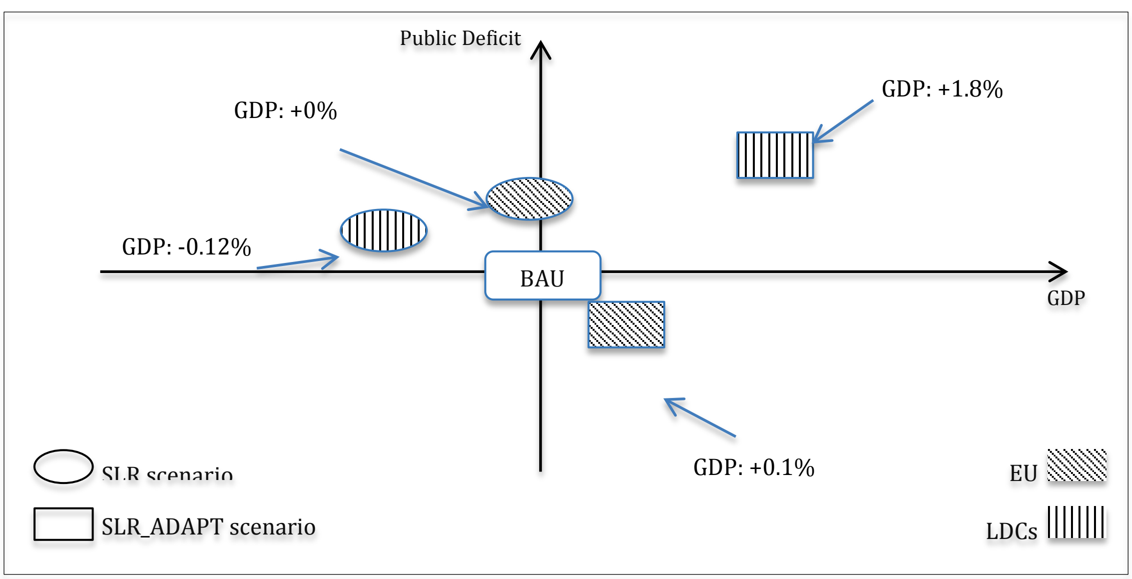
5 SIMULATION RESULTS

Our analysis concentrates on four issues. First, we evaluate the budgetary effects of the 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 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 indicator chosen for the comparison are GDP (horizontal axis) and public borrowing (vertical axis) shedding light on implications for public budget sustainability.

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



Note: the boxes and circles in the figure provide a qualitative immediate visual representation of results without respecting the quantitative proportions

SLR impacts lower GDP according to the different input shocks: while the 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. 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, the EU increases its GDP by 0.1% and LDCs by 1.8%. However, the final effect on public borrowing is different; while the EU lowers its deficit respect to the BAU ($529 billion), LDCs increase their public borrowing ($109 billion). This highlights a potential trade-off between adaptation and development policies in these countries. Adaptation measures (in this case for coastal protection) may increase the public finance burden because additional financing needs can turn to be higher than the higher tax revenues consequent the lower GDP losses.

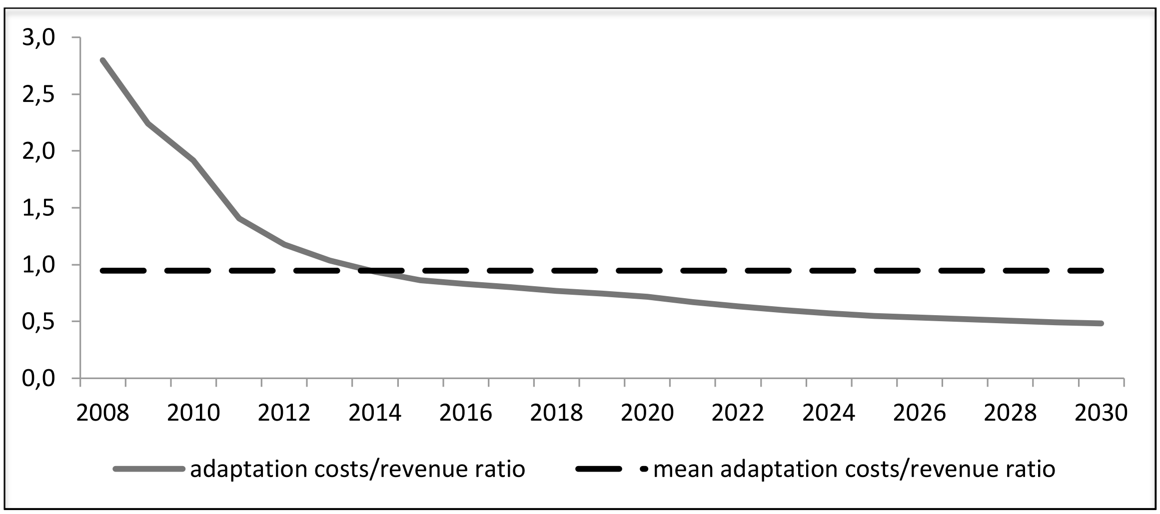
A more in-depth analysis shows the further differentiation within LDCs. In the SLR scenario LACA, SSA and ASIA report a GDP loss ranging from 0.04% to 0.08% in 2030; while MENA slightly increases its GDP. This outcome derives from the lower land loss in MENA compared to other LDCs which ultimately gives 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 unilateral mitigation policy in the EU costs nearly 6.3% of its GDP respect to BAU in 2030. However it allows also to reduce EU's public borrowing by $144 billion in 2030, since carbon tax revenues accrue to public budgets and reduce public deficit. LDCs countries increase their GDP by 2.5% as a consequence of a non-negligible leakage effect, nonetheless, their public deficit also increase slightly (0.03%). This outcome, that is the aggregated result of the LDCs group, but that does not characterize each LDCs, depends upon the partially pro-cyclical modelling of taxes. They tend to increase less than GDP during expansions and contract less during contractions.

Figure 2 compares total coastal protection costs in LDCs with the revenues from the EU mitigation policy. It shows that since 2014 revenues are higher than the 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%).

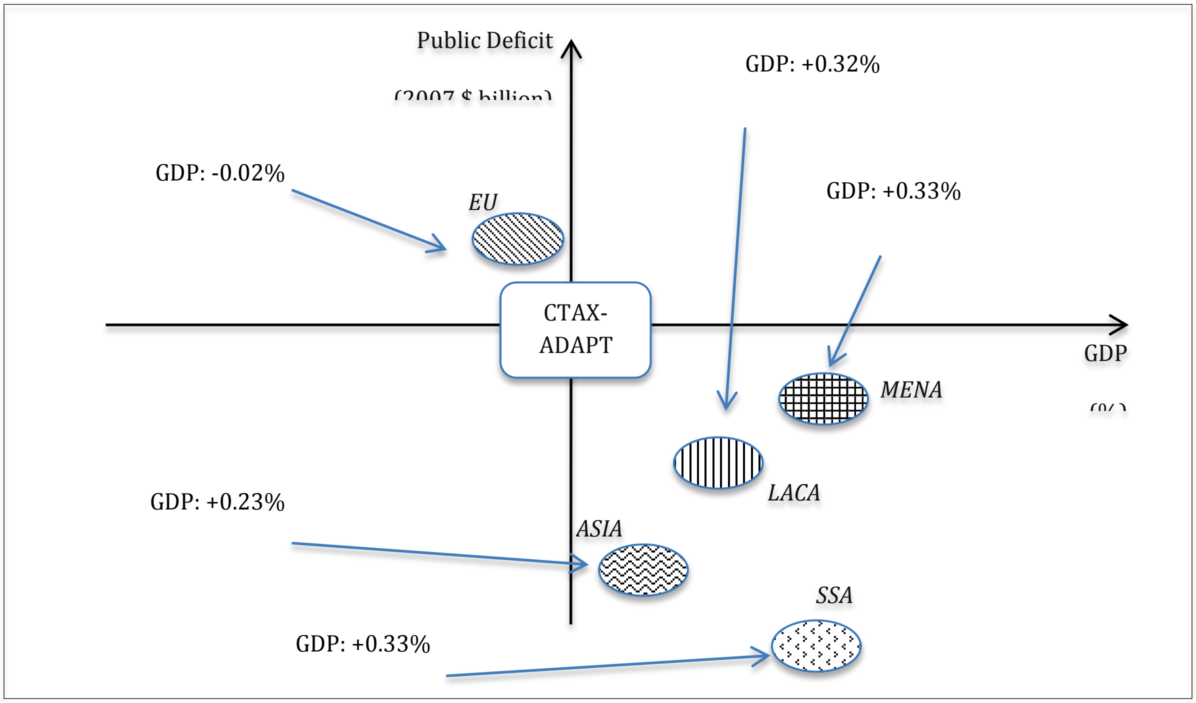
Figure 2: The adaptation costs in LDCs/ climate policy revenues ration in the period 2008/2030



(III) COST AND BENEFITS OF AN ADAPTATION FUND

Figure 3 reports the effects of the adaptation fund using as reference the mitigation with adaptation scenario (CTAX-ADAPT). Impacts on the EU are negligible: its additional GDP loss is lower than 0.01%, public borrowing however increase slightly more than the fund ($ 586 billion).

Figure 3: The GDP- public borrowing gap in the CTAX-ADAPT and FUND scenarios in 2030



Note: the boxes and circles in the figure provide a qualitative immediate visual representation of results without respecting the quantitative proportions

When the mitigation policy revenues are channeled to LDCs, there is a positive effect on GDP respect to the CTAX-ADAPT scenario ranging between 0.23% (ASIA) and 0.33% (SSA and MENA). There is also a contemporaneous decline in public borrowing varying between $16 billion (MENA) and $624 billion (SSA). This means that the reduction completely offsets the increase in public borrowing in the CTAX-ADAPT scenario.

Considering as a whole the Fund partners, the establishment of the Fund has a positive effect both on GDP and public deficit. Indeed, GDP increases by 0.13%, with the reduction in EU GDP ($ -2.8 billion) completely offset by SSA increase ($ + 2.9 billion). Furthermore, public deficit declines as a whole by $ 318 billion.

In summary: adaptation (to SLR) is worthwhile especially in LDCs. With few exceptions, GDP costs are lower than GDP benefits[6] (Table 4). Nonetheless, the additional expenditure worsens their public budget deficits. In the long term, this can feedback negatively on their growth perspectives considering especially their tight budget constraints. Against this background, support from developed country could be particularly important. For instance, the revenues from a carbon tax raised to achieve the EU mitigation targets for 2030, would be more than sufficient to cover the full coastal protection expenditure in LDCs and allow them to lower their deficit. As expected, the deficit in the donor developed countries increases, however, the deficit cut in developing countries would be higher, while GDP in the donor will decrease only marginally.

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

	SLR_ADAPT		**CTAX_ADAPT**		**Adaptation Fund**	
	GDP %	Public deficit $ billion change	GDP %	Public deficit $ billion	GDP %	Public deficit $ billion
MENA	4.58	59	0.16	73	0.50	-3
LACA	4.58	121	5.17	128	5.52	-83
SSA	5.50	23	6.20	31	6.55	-616
ASIA	-1.83	233	-1.22	258	-0.99	-188

6 CONCLUSIONS

Developing countries are particularly vulnerable to climate change impacts. They feature, accordingly, high adaptation needs which often conflict with other development priorities in a context of particularly stringent public budget constraints.

This research investigates the effects on GDP and public budget of developed and developing countries of a coastal protection expenditure aimed to offset completely land lost to sea-level rise. First, adaptation action is considered in isolation, then the parallel implementation of the EU mitigation targets for 2020 and 2030 by means of carbon taxation is assumed.

[6] Consider that we are analyzing the particular case of full protection. Partial protection could still produce benefits larger than the costs also in those LDCs in which full protection is not economically justifiable.

Coastal protection is beneficial especially for developing countries, however, in face of GDP benefits that turn to be higher than the costs, the additional expenditure required worsens public deficits.

When the EU implements unilaterally its carbon energy package, GDP in developing countries increase because of the presence of a non-negligible carbon leakage, however their public borrowing are anyway deteriorated by the coastal protection expenditure. Against this background, the support from developed country could be particularly important. In particular, the revenues from the carbon tax raised to achieve the EU mitigation targets, channeled to developing countries through an Adaptation Fund, would be more than sufficient to cover the full coastal protection expenditure in LDCs and allow them to lower their deficit and increase further their GDP. As expected, the deficit in the donor developed countries increases, however, the total deficit cut in developing countries would be even higher, while GDP in the donor will decrease only marginally.

REFERENCES

Agrawala S. and van Aalst M. (2008). Adapting development cooperation to adapt to climate change, *Climate Policy*, vol. 8(**2**), pp.183-193.

Altamirano-Cabrera J.C., Biccheti D., Drouet L.,Thalmann P., and Vielle M. (2010). *A global carbon tax to compensate damage and adaptation costs*. Working Paper-2009-004. National Centers of Competence in Research Climate (NCCR Climate): Bern.

Antimiani, A., Costantini, V., Markandya, A., Martini, C., Palma, A., and Tommasino, M.C. (2014). *A dynamic CGE modelling approach for analyzing trade-offs in climate change policy options: the case of Green Climate Fund.* SEEDS Working Paper 16/2014. Sustainability Environmental Economics and Dynamics Studies (SEEDS).

Bachner G. (2015). *Land Transport Systems under Climate Change: A Macroeconomic Assessment of Adaptation Measures for the Case of Austria*. Graz Economic Papers GEP 2015-01. University of Graz.

Bigano A., Bosello F., Roson R. and Tol R. S. J. (2008). Economy-wide impacts of climate change: a joint analysis for sea level rise and tourism. *Mitigation and Adaptation Strategies for Global Change*, vol. 13(**8**), pp.765-791.

Bosello F., Eboli F., and Pierfederici R. (2012). *Assessing the Economic Impacts of Climate Change*. FEEM Note di Lavoro no. 2012/002.

Bosello F., Nicholls R. J., Richards J., Roson R., and Tol R. S. J. (2012). Economic impacts of climate change in Europe: Sea-level rise. *Climatic Change*, vol. 112(**1**), pp. 63-81.

Bosello F., Roson R., and Tol R. S. J. (2007). Economy-Wide Estimates of the Implications of Climate Change: Sea Level Rise. *Environmental and Resource Economics*, vol. 37(**3**), pp. 549-571.

Bosello, F. and R. Parrado (2014). Climate change impacts and market driven adaptation: The costs of inaction including market rigidities. Working Papers 2014.64, Fondazione Eni Enrico Mattei.

Chateau J., Dellink R., Lanzi E. and Magné B. (2012). *The ENV - Growth model: global reference scenarios for future economic growth*. OECD Working Paper no. ENV/EPOC/WPCID(2012)6.

CEPS and ZEW (2010). *The fiscal implication of climate change adaptation*. Final report of the ADAM project. Centre for European Policy Studies (CEPS) and Centre for European Economic Research (ZEW).

Climate Fund Update dataset (2015). Available at: http://www.climatefundsupdate.org

Dinas Coast Consortium (2006). *DIVA 1.0*. Potsdam Institute for Climate Impact Research, Potsdam, Germany, CD-ROM.

Eboli F., Parrado R., and Roson R. (2010). Climate-change feedback on economic growth: Explorations with a dynamic general equilibrium model. *Environment and Development Economics*, vol. 15(**5**), pp. 515-533.

Eisenack K. (2011). *Adaptation financing as part of a global climate agreement: is the adaptation levy appropriate?* Discussion Paper no. V-334-11. Carl von Ossietzky University: Oldenburg.

European Commission (2011). *A Budget for Europe 2020 - Part II: Policy fiches*. European Commission: Bruxelles

European Commission (2013). *An EU budget for low-carbon growth*. Press Release: Warsaw.

European Union (2015). Climate Funding for Developing Countries, 2015. European Commission.

Harmeling S., Burck J., and Bals C. (2007). *Adaptation to Climate Change in Africa and the European Union's Development Cooperation*, GermanWatch.

Hertel, T.W. (Ed.). (1997). *Global trade analysis: Modeling and applications*. Cambridge and New York: Cambridge University Press.

Margulis S., Narain U. (2010). The costs to developing countries of adapting to climate change : new methods and estimates - the global report of the economics of adaptation to climate change study. Washington, DC: World Bank.

Nakooda, S., T. Fransen, T. Kuramochi, A. Caravani, A. Prizzon, N. Shimizu, H. Tilley, A. Halimanjaya, and B. Welham (2013), "Mobilising International Climate Finance: Lessons from the Fast-Start Finance Period", ODI, WRI, IGES. http://www.wri.org/sites/default/files/mobilising_international_climate_finance.pdf

Narayanan B. G., Aguiar A., and McDougall R. (*Eds.*) (2012). *Global Trade, Assistance, and Production: The GTAP 8 Data Base*. Center for Global Trade Analysis, Purdue University

Nicholls R., Brown S., Hanson S., and Hinkle J. (2010). *Economics of Coastal Zones Adaptation to Climate Change*. Discussion Paper no.10. The World Bank: Washington.

OECD (2014). OECD DAC Statistics Climate related Aid. Available at: www.oecd.org/dac/stats/rioconventions.htm

OECD (2007), *Policy Observer*. Policy brief. August 2007.

Oxfam (2015). *The Right to Resilience*. Oxfam Briefing on Adaptation Finance in the Post-2020 Paris Agreement.

Parrado R., and De Cian E. (2014). Technology Spillovers Embodied in International Trade: Intertemporal, regional and sectoral effects in a global CGE framework. *Energy Economics*, vol. 41(**1**), pp. 76-89.

IIASA (2015). SSP IIASA database. Available online at: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

UNEP (2014). *The Adaptation Gap Report 2014*. United Nations Environment Programme (UNEP): Nairobi

UNEP (2015*). Africa Adaptation Gap Technical Report: Climate-change impacts, adaptation challenges and costs for Africa*. United Nations Environmental Programme (UNEP): Nairobi.

UNFCCC (2007). *Investments and Financial Flows to Address Climate Change*. United Nations Framework Convention on Climate Change (UNFCCC) Secretariat: Bonn.

Van Vuuren D. P., and Carter T. R. (2014). Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. *Climatic Change*, vol. 122 (**3**), pp. 415-429.

Watkiss, P., Downing, T., Dyszynski, J. (2010) AdaptCost *Project: Analysis of the Economic Costs of Climate Change Adaptation in Africa*. United Nations Environmental Programme (UNEP): Nairobi.

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 ($\mathrm{YH_r}$), 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, $\mathrm{YHL_r}, \mathrm{YHK_r}$ respectively); (ii) social transfers from the government ($\mathrm{YHTR_r}$); (iii) the net of other transfers between private households and government ($\mathrm{YHOGI_r}, \mathrm{YHOGE_r}$) which is functional to the balancing of the base year; (iv) income from interest on public debt ($\mathrm{YHI_r}$).

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

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.

$$YH_r = PRIV\_EXP_r + PRIV\_SAV_r \qquad (6)$$

$$PRIV\_EXP_r = \beta_{PEXP,r} \cdot YH_r \qquad (7)$$

$$PRIV\_SAV_r = (1-\beta_{PEXP,r}) \cdot YH_r \qquad (8)$$

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.

$$PRIV\_EXP_r = PPRIV_r \cdot QPRIV_r \qquad (9)$$

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

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 ($YHOGI_r - YHTR_r - YHOGE_r$); (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.

$$YG_r = TTAX_r - YHTR_r + YHOGI_r - YHOGE_r - YGI_r + AIDI_r - AIDO_r \qquad (11)$$

$$YG_r = GOV\_EXP_r + SAV\_GOV_r \qquad (12)$$

Where:

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

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

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

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:

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

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)).

$$GOV\_EXP_r = PGOV_r \cdot QGOV_r \qquad (17)$$

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

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

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:

$$GOV\_INV_r = \varepsilon_r \cdot NETINV_r + \Delta GOVINV_{CNST,r} \quad (21)$$

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

and ($\Delta GOVINV_{CNST,r}$), 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:

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

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:

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

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

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)

$$INTD_{t,r} = ir_r \cdot GDDEBT_{t-1,r} \tag{27}$$

$$INTF_{t,r} = ir_r \cdot GFDEBT_{t-1,r} \tag{28}$$

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.

$$\sum_r INTI_{r,t} = \sum_r INTF_{r,t} \tag{29}$$

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.

$$psavshr_{r,t-1} = \frac{SAV\_PRIV_{r,t-1}}{\sum_r SAV\_PRIV_{r,t-1}} \tag{30}$$

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:

$$INTI_{r,t} = INTAVI_r \cdot psavshr_{r,t-1} \tag{31}$$

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, 2015) 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 the effects on revenues due to residual impacts.