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Abstract

In response to anthropogenic climate change, developed countries have committed themselves to raise 100 billion USD a year from 2020 onwards for addressing the needs of developing countries. In this paper, we investigate the economic and CO_2 emission impacts of four alternative options for raising climate funds from public sources in developed countries: CO_2 emission prices, wires charges on electricity consumption, a tax on international transport services, and the removal of fossil fuel subsidies. We find that these four options do not only induce very different global costs to raise given amounts of climate funds but have quite diverging implications for the cost incidence between developed and developing countries. Likewise, the global CO_2 emission impacts of alternative fund-raising policies differ a lot.

Keywords: climate finance; computable general equilibrium; green climate fund
JEL classifications: C68, Q58

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1. Introduction

At the United Nations Climate Change Conference in Copenhagen in 2009, political leaders confirmed their strong will to combat climate change in accordance with the principle of common but differentiated responsibilities and respective capabilities. In this context, developed countries – as listed in Annex 2 of the United Nations Framework Convention on Climate Change (UNFCCC) – committed themselves to the goal of jointly mobilizing 100 billion USD a year from 2020 onwards for addressing the needs of developing countries.

The Secretary-General of the United Nations established the so-called High-level Advisory Group on Climate Change Financing in February 2010 with the mandate to identify and discuss potential sources of finance. The Advisory Group classified these sources into four categories (UN, 2010): public sources, development bank instruments, carbon market finance, and private capital. Regarding public sources, the ten options have been listed (see Section 3 for an overview) .

In this paper, we focus on the three most promising public sources for climate finance identified by the UN Advisory Group, namely an international price on CO_2 emissions, a wires charge on electricity consumption, and the removal of fossil fuel subsidies. These policies are estimated to promise the highest revenues that could be used for climate finance. We use a multi-region, multi-sector computable general equilibrium model (CGE) to complement the assessment of the UN Advisory Group in two ways. First, we provide a comprehensive quantification of the global and regional economic costs associated with raising revenues in Annex 2 countries via the three above mentioned public sources. Second, we assess the impacts of those different climate finance options on global CO_2 emissions, acknowledging that climate finance policies still pursue the objective of curbing global CO_2 emissions in a cost-efficient manner.

We find that the three instruments exhibit quite differing and important economic and environmental effects. They not only differ in their cost-effectiveness of raising climate funds, but they also have very diverse implications for the cost incidence among developed and developing countries. CO_2 pricing or a tax on electricity consumption in Annex 2 countries induce significant cost on Non-Annex 2 countries through changes in international prices, the so-called terms of trade. By contrast, the removal of fossil fuel subsidies within Annex 2 lead to welfare gains for Non-Annex 2 compared to the business-as-usual. The economic incidence of raising climate funds must be considered when it comes to a more comprehensive appraisal of alternative funding instruments.

The implementation of the three instruments has furthermore quite different implications for global CO_2 emission levels. Obviously, the climate effectiveness of instruments does not only depend on the change in emissions within Annex 2 countries, but also on the emission changes triggered in Non-Annex 2 countries. While a CO_2 price and an electricity consumption tax trigger emission increases in Non-Annex 2 countries, the removal of fossil fuel subsidies even leads to emission abatement. As the provision of climate funds should not overlap in a counterproductive manner with carbon abatement policies, it is important to monitor the emission impacts of alternative instruments for raising climate funds.

The remainder of the paper is organized as follows. In Section 2 we lay out the data and model used for our impact assessment of raising revenues for climate finance. In Section 3 we describe how alternative public sources for climate finance are devised into policy scenarios that we can simulate in our numerical model. In Section 4 we report and discuss the simulation results. In Section 5 we conclude.

2. Framework of assessment: model and data

2.1 Model

To assess the economic and CO_2 emission impacts of different climate finance options we use a standard, static multi-region multi-sector computable general equilibrium (CGE) model of the global economy. The particular virtue of CGE models is their rigorous microeconomic foundation in Walrasian equilibrium theory which accommodates the coherent welfare accounting of market supply and demand responses to policy shocks. In this section, we provide a brief, non-technical model summary. A detailed algebraic model description is given in Böhringer et al. (2015).

Our model features a representative agent in each region who receives income from three primary factors: labor, capital, and specific fossil fuel resources for coal, natural gas, and crude oil. Labor and capital are inter-sectorally mobile within a region but immobile between regions. Fossil resources are specific to fossil fuel production sectors in each region.

Fossil fuel production is represented by a constant elasticity of substitution (CES) cost function, where the demand for the specific resource trades off with a Leontief composite of all other inputs. The elasticities of substitution in the fossil fuel sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham et al., 1999; Krichene, 2002; Ringlund et al., 2008).

All other commodities are produced according to a six-level nested CES cost function. At the top level, a CES composite of transport services trades off with a CES composite of intermediate material demands, energy, capital, and labor. At the second level, a CES function describes the substitution possibilities between the different transport services: air transport, water transport, and other transport. At the same level, intermediate material demand trades off with a CES composite of energy and primary factor demands. The third level represents the substitution between an energy aggregate and primary factors. At the fourth level, capital and labor inputs trade off according to a CES function; likewise, within the energy aggregate, electricity trades off with the composite of fossil fuels (coal, natural gas, and refined oil). At the fifth level, a CES function describes the substitution possibilities between coal and the composite of refined oil and natural gas. The sixth level describes substitution between refined oil and natural gas.

Final consumption demand in each region is determined by the representative agent who maximizes welfare subject to a budget constraint with fixed investment and exogenous government provision of public goods and services. Consumption demand of the representative agent is given as a CES composite that combines consumption of composite energy and an aggregate of other consumption goods and is specified with a similar functional form as the production of commodities.

Bilateral trade is modeled following Armington's differentiated goods approach, where domestic and foreign goods are distinguished by origin (Armington, 1969). A balance of payment constraint incorporates the base-year trade deficit or surplus for each region. CO_2 emissions are linked in fixed proportions to the use of coal, refined oil and natural gas, with CO_2 coefficients differentiated by fuels and sector of use.

2.2 Data

For model parameterization, we use the most recent GTAP data set (version 9) which includes detailed balanced accounts of production, consumption, bilateral trade flows as well as data on physical energy consumption and CO_2 emissions for the base year 2011 in 140 regions and 57 sectors of the economy (Narayanan et al., 2016). As is customary in applied general equilibrium analysis, base year data together with exogenous elasticities determine the free parameters of the functional forms. Elasticities in international trade (Armington elasticities) as well as factor substitution elasticities are directly provided by the GTAP database.

For our simulation analysis, we aggregate the GTAP dataset towards the specific requirements of our research question (Table 1).

Table 1: Model sectors and regions

Sectors and commodities	***Countries and regions***
Energy	Annex 2
Coal	Non-Annex 2
Crude oil	
Natural gas	
Refined oil products	
Electricity	
Energy-intensive and trade-exposed sectors	
Energy-intensive and trade-exposed sectors*	
Transport sectors	
Air transport	
Water transport	
Other transport	
Other industries and services	
All other manufactures and services	

* Included are iron and steel; non-metallic minerals; chemical, rubber, and plastic products; paper products, publishing;

At the regional level, we aggregate all Annex 2 countries into one composite region and all Non-Annex 2 countries into one composite region, as our analysis in not concerned on the allocation of costs or emissions on the country-level, but focuses on the aggregate economic impacts of raising public funds on developed and developing regions. At the sectoral level, we explicitly represent sectors that are directly targeted by the implementation of policy instruments: primary and secondary energy sectors (coal, crude oil, natural gas, refined oil, and electricity), an aggregate of energy-intensive and trade-exposed sectors, and international air transport, water transport, and other transport services. All remaining sectors are aggregated into one composite.

Acknowledging that Annex 2 countries committed themselves to raise 100 billion USD per year for financing climate action in developing countries from 2020 onwards, we do a forward calibration of the model's 2011 base year to a business-as-usual situation in 2020. The model forward projection employs data from the US Energy Information Agency (EIA, 2013). Details for the forward-projection technique are described in Böhringer et al. (2009).

Additionally, we use data from the OECD's online database of measures supporting fossil fuels (OECD, 2015) on volumes of fossil fuel production subsidies. The OECD provides subsidy data for 36 different energy carriers – particularly coal and coal products, crude oil and oil products, natural gas, and electricity – categorized into "consumer support estimates", "producer support estimates", and "general services support estimates" for the years 2000-2014. We aggregate the data on "producer support estimates" on the sectoral and regional level towards the fossil fuel sectors and regions in our model (Table 1), so that we include subsidies to crude oil, refined oil, coal, and gas production. To avoid misrepresentations due to larger fluctuations of annual regional subsidies we average the values over the time period of 2000-2014 for our analysis. The OECD data is reported in current local currencies. We use data from World Development Indicators (World Bank, 2017) and the implicit price deflators for GDP from the Bureau of Economic Analysis (BEA, 2016) to translate local currencies into 2011 USD that correspond to GTAP 9.

3. Policy instruments, scenarios, and business-as-usual statistics

The UN Advisory Group identified ten sources of public climate finance:

(i) Revenues from the international auctioning of emission allowances (such as assigned amount units (AAU) under the Kyoto Protocol): this would involve retaining some allowances from developed countries and then auctioning them to raise revenues.

(ii) Revenues from the auctioning of emission allowances in domestic emissions trading schemes: this would involve the auctioning of domestic credits (as in the European Union Emission Trading Scheme phase III) and allocating some part of associated revenues.

(iii) Revenues from offset levies: this would involve withholding a share of offset revenues as a global source, as currently done in the Clean Development Mechanism (CDM).

(iv) Revenues generated from taxes on international aviation and shipping: this would either involve some levy on maritime bunker/aviation jet fuels for international voyages or a separate emissions trading scheme for these activities, or a levy on passenger tickets of international flights.

(v) Revenues from a wires charge: this involves a small charge on electricity generation, either on kWh produced or linked to carbon emissions per kWh produced.

(vi) Revenues generated by removing fossil energy subsidies in developed countries: this comprises budget commitments freed by the removal of fossil energy subsidies, which can be diverted towards climate finance.

(vii) Revenues from fossil fuel extraction royalties/licenses: these could be allocated in part to international climate finance.

(viii) Revenues from carbon taxes: this is based on a tax on carbon emissions in developed countries raised on a per-ton-emitted basis.

(ix) Revenues from a financial transaction tax: this builds on existing proposals on a global financial transaction tax (with a focus on foreign exchange transactions).

(x) Direct budget contributions: this involves revenues provided through national budgetary decisions.

In our simulation analysis, we quantify the economic costs of raising revenues from public sources via three different instruments suggested by the UN Secretary-General's High-level Advisory Group on Climate Change Financing (UN 2010): (i) an international price on CO_2 emissions, (ii) a wires charge on electricity consumption, and (iii) the removal of fossil fuel subsidies.

These instruments are implemented in our CGE model through endogenous taxes or subsidies on the respective goods to yield exogenous levels of revenues. Since the focus of our analysis is on the impact of fund raising, we attribute the revenues to the respective representative agents in the implementing countries, and do not further investigate allocation possibilities of these revenues across Non-Annex 2 countries.

For each of the three instruments we employ the revenues estimates of the UN Advisory Group as an orientation for the upper bound. In the following, we describe our business-as-usual scenario and lay out in more detail how we translate the three policy instruments for raising climate funds into our CGE framework.

3.1 Business-as-usual

Acknowledging that Annex 2 countries committed themselves to raise 100 billion USD per year for financing climate action in developing countries from 2020 onwards, we do a forward calibration of the model's 2011 base year to a business-as-usual situation in 2020. The business-as-usual structure of our model regions in 2020 reflects the US Energy Information Agency's projections for energy input demands across sectors, future GDP levels, and the international price for crude oil. We assume an existing CO_2 price of 25 USD in Annex 2 countries in the business-as-usual, which is in line with the UN Advisory Group's medium CO_2 price scenario.[2] With respect to the additional OECD subsidy data, calibration is done in the following way: output taxes or subsidies in the GTAP database are reported as aggregate values, i.e. the sum of taxes and subsidies that apply in the respective sector. In each sector, we split this aggregate rate into a tax and a subsidy using the OECD data. Due to considerable uncertainties about policy choices by governments, we abstain from projecting values on subsidies to the future and use current values as volumes of subsidies in 2020.

3.2 International price on CO_2 emissions

The UN Advisory Group identifies two possible sources for climate finance associated with carbon pricing. The first option is using between 2 and 10 percent of carbon credit revenues from international or national auctions to channel them to climate finance. The second option is an additional charge on carbon emissions in developed countries. Based on their medium CO_2 price scenario of 25 USD per ton of CO_2 and reduction scenarios taken from the low to high range of commitments made under the Copenhagen Accord, the UN Advisory Group estimates potential revenues from a carbon tax of roughly USD 10 billion from an additional 1 USD to be levied in addition to the existing CO_2 price.. We implement this instrument in our scenario *CO2* as an endogenous economy-wide and uniform CO_2 emission price across Annex 2 on top of the CO_2 price of 25 USD in the business-as-usual to raise revenues from USD 1 billion up to USD 40 billion, where we assumed an upper bound of four times the aforementioned charge.

3.3 Wires charge on electricity

The UN Advisory Group calculated the potential revenues from wires charges on electricity based on projections from the as a function of the size of the wires charge and suggests that for every charge of 0.0004 USD per kWh in OECD countries – which is equivalent to 1 USD per ton of CO_2 in developed countries on average – 5 billion USD could be raised for climate finance by 2020. We implement the wires charge on electricity in our scenario *ELE* as an endogenous tax on electricity consumption in Annex 2 countries to raise revenues of up to 20 billion USD, assuming four times the above charge as an upper bound. The CO_2 price in Annex 2 remains at the business-as-usual level of 25 USD per ton of CO_2.

3.4 Removal of fossil fuel subsidies

The UN Advisory Group conclude from different sources that fossil fuel production subsidies in developed countries revenues of 8 to 60 billion USD could be gradually phased out and revenues could completely be used for climate finance. We implement this in our scenario *SUB* by reducing the calibrated producer subsidies in fossil fuel sectors of Annex 2 countries endogenously in order to meet

[2] The UN Advisory Group bases its estimates on CO_2 price scenarios of 15 USD (low), 25 USD (medium), and 50 USD (high) per ton of CO_2.

revenue targets of up to 60 billion USD. The CO_2 price in Annex 2 remains at the business-as-usual level of 25 USD per ton of CO_2.

3.5 Overview of policy scenarios

Table 2 provides an overview of our five central case policy scenarios.

Table 2: Policy scenarios in the numerical analysis

Scenario	Description	Max. revenue
CO2	Uniform CO_2 price across Annex 2 countries in addition to the business-as-usual CO_2 price of 25 USD.	40 billion USD
ELE	Uniform tax on electricity consumption across Annex 2 countries. CO_2 price remains at 25 USD.	20 billion USD
SUB	Uniform output tax in fossil fuel sectors across Annex 2 countries. CO_2 price remains at 25 USD.	60 billion USD

The UN Advisory Group stresses the importance of avoiding negative economic spillovers under these scenarios to developing countries. Thus, we run each policy with the option to compensate Non-Annex 2 countries through income transfers such that they enjoy at least their economic well-being under business-as-usual. Annex 2 countries share the burden of these transfers according to their benchmark consumption levels. In our exposition of results, we refer to the sub-case with compensation through the label "*w/ comp*" and to the sub-case without compensation through the label "*w/o comp*".

4. Simulation results

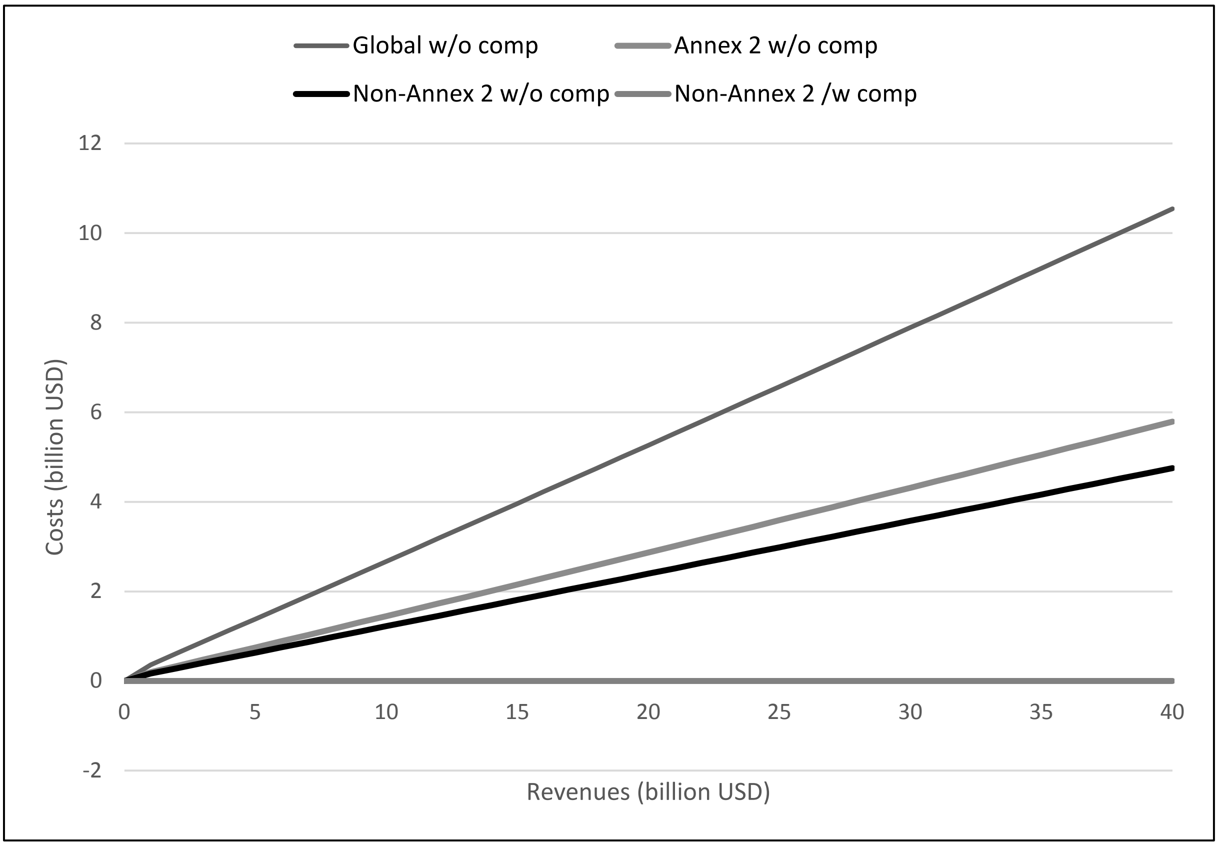
We first investigate the macroeconomic costs of raising revenues from the four public sources under investigation. Macroeconomic costs are reported in terms of compensating equivalent variation in billion USD, i.e., the amount of money that the representative agents would need in the counterfactual situation in order to enjoy the same utility level as in the business-as-usual scenario. Furthermore, we report the implications for global CO_2 emissions.

4.1 Macroeconomic costs

We start with the results for the instrument of an international price on CO_2 emissions. Subsequently, we discuss the cost implications across the two remaining finance instruments.

Figure 1 shows the global costs of raising revenues for climate finance through a uniform CO_2 emissions price across Annex 2 countries (scenario *CO2*). Reflecting the Advisory Group's estimates for upper limits, we report costs for revenues targets of USD 1 billion up to 40 billion USD. Also, we differentiate whether Annex 2 countries compensate Non-Annex 2 countries via direct transfers of income (*w/ comp* and *w/o comp*). Compensation of Non-Annex 2 countries via income transfers has only a minor influence on the global efficiency costs of the CO_2 pricing policy. For the sake of clarity, we have only reported the global costs for the case without compensating income transfers (*w/o comp*).[3]

Figure 1: Global costs of raising revenues via CO_2 emission pricing in Annex-2 countries (scenario *CO2*)



Key: *w/o comp* – no compensation for Non-Annex 2 countries; *w/ comp* – compensation for Non-Annex 2 countries.

Notes: Global w/o comp ≈ Global w/comp; Annex w/o comp ≈ Annex w/comp

Global costs for raising revenues with a uniform CO_2 price rise proportional with the targeted revenues and amount to 10.5 billion USD for the maximum case of 40 billion USD revenues. Regarding the cost incidence between Annex 2 and Non-Annex 2 countries, compensating transfers of income change the picture significantly, as reported in Figure 1. With compensating income transfers (*w/ comp*), by definition no costs are inflicted on Non-Annex 2 countries; thus, the costs for Annex 2 are identical to global costs. In the case without compensation the cost incidence for Non-Annex 2 is quite significant. Non-Annex 2 countries bear roughly 45% of the global cost of raising revenues, which amounts to 2.4 billion USD for revenues of 20 billion USD, and to 4.8 billion USD for revenues of 40 billion USD. The reasoning behind is that unilateral CO_2 emission pricing in Annex 2 countries changes the ratio of export

[3] Likewise, adjustment costs in Annex 2 in the case with compensation (*/w comp*) are identical to global costs, so we only report the case without compensation (*w/o comp*).

to import prices – the terms of trade. Pricing carbon emissions raises production costs in Annex 2 countries. In most sectors, produced goods from Annex 2 are not perfect substitutes for goods from Non-Annex 2.[4] This enables Annex 2 countries at sufficiently low CO_2 prices – depending on import demand elasticities in Non-Annex 2 – to shift parts of the economic adjustment costs from emission pricing to their trading partners. Carbon pricing in that respect is a substitute for exerting market power on export markets, which exists due to limited substitutability of regionally differentiated goods.[5] The substantial burden shifting effect of carbon pricing through international markets is a well-known phenomenon in unilateral climate policy design (see e.g. Böhringer et al., 2012; Branger and Quirion, 2014).

CO_2 emission prices increase linearly with the targeted revenue, as shown in Table 2. In order to collect 1 billion USD in revenues Annex 2 would have to increase their effective CO_2 price by 0.14 USD from the business-as-usual price of 25 to 25.14 USD. With revenues increasing up to 40 billion USD, the required CO_2 price in Annex 2 goes up linearly to 29 USD. This is in line with the suggestion by the UN Advisory Group.

Table 2: CO_2 prices in Annex 2 required to raise revenues under scenario *CO_2*

Revenue (billion USD)	CO2 price (USD/tCO2)
1	25.14
10	26.02
20	27.00
30	27.99
40	28.99

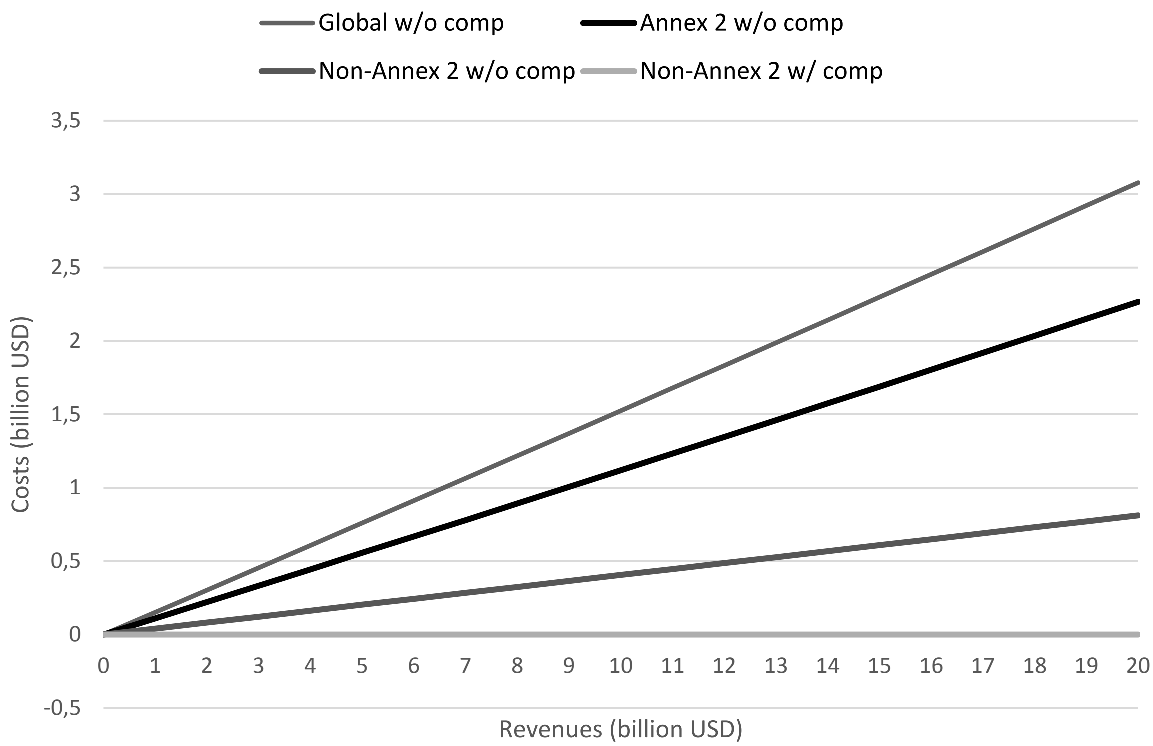
If Annex 2 countries create revenues through a uniform tax on electricity consumption (*ELE*), global economic adjustment costs increase almost linearly up to 3.1 billion USD for a revenue of 20 billion USD (see Figure 2). As for the CO_2 pricing policy, the difference in global costs as to whether Non-Annex 2 countries are compensated or not (*w/ comp* or *w/o comp*) to achieve their business-as-usual welfare level is negligible while the cost incidence across regions differs significantly. Without compensation, Non-Annex 2 countries bear more than one quarter of the global costs. The burden shifting effect is again driven by changes in international prices, where Annex 2 countries are able to

[4] In our model, this is reflected by the Armington assumption of regionally differentiated goods and the application of Armington elasticities, see Section 2.

[5] In theory, the terms-of-trade gains could even more than offset the efficiency cost of domestic emission pricing (note that emission pricing is used here as a source for public revenues rather than a means to correct for climate change externalities).

pass cost increases in production through to (foreign) consumers of their goods and change the terms-of-trade in their favor.

Figure 2: Global costs of raising revenues via electricity wires charges (scenario *ELE*) in Annex-2 countries with and without compensation for Non-Annex 2 countries



Key: *w/o comp* – no compensation for Non-Annex 2 countries; *w/ comp* – Non-Annex 2 countries are compensated such that they achieve their benchmark utility level

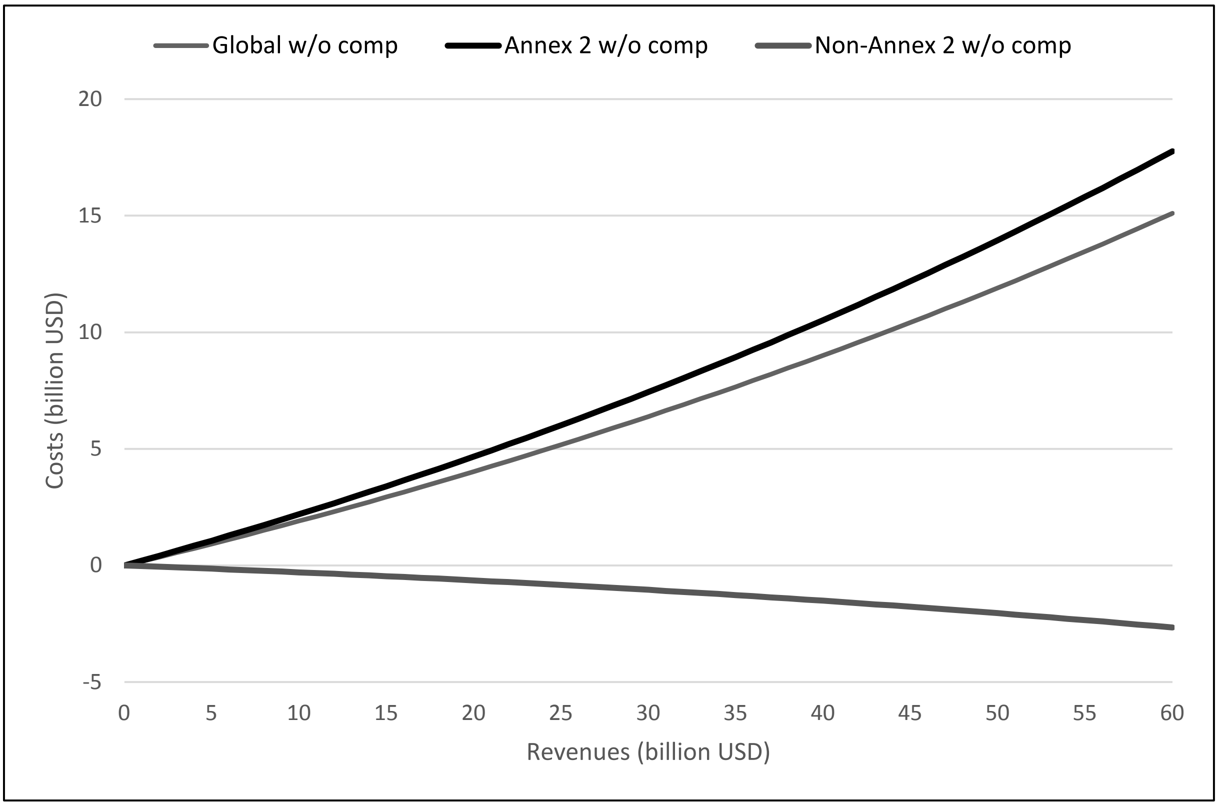
Notes: Global w/o comp ≈ Global w/comp; Annex w/o comp ≈ Annex w/comp

Raising revenues via the removal of fossil fuel production subsidies (*SUB*) has rather different efficiency and incidence implications than the previous policies considered, as reported in Figure 3. Global costs rise roughly proportional to the raised revenues and reach 15.1 billion USD for 60 billion USD in revenues. However, for this policy the cost burden entirely falls on the Annex 2 region, while Non-Annex 2 countries even enjoy significant welfare gains: For 60 billion USD of revenues under *SUB*, Annex 2 countries bear costs of 17.8 USD, while Non-Annex 2 countries gain 2.7 billion USD.

From on a partial single country perspective, the huge difference between *ELE* and *SUB* in the cost incidence seems odd, as both instruments raise costs for certain inputs in a similar manner: electricity in *ELE* and fossil fuels in *SUB*. The crucial difference between electricity and fossil fuels for our analysis is the substitutability of domestic production on international markets. For the removal of fossil fuel production subsidies in Annex 2 (*SUB*) the economic reasoning behind is the following. Fossil fuels –

in particular crude oil and coal – are rather homogenous commodities in international trade. Thus, fossil fuel producers in Annex 2 countries are hardly able to pass through higher cost to consumers such that their production is partly substituted with fossil fuel imports from Non-Annex 2. For a target revenue of 60 billion USD, crude oil output in Annex 2 drops by 2.3% and coal output even by 18.7%. Exports from Non-Annex 2 to Annex 2 countries, on the other hand, increase in all fossil fuel sectors. They boost by 11.7% in the coal sector, and moderately increase by around 1% in crude oil, refined oil, and gas. Electricity, however, is (almost) not internationally substitutable, so that users of electricity face the complete cost increase, which they are in turn able to pass through to a certain extent.

Figure 3: Global and regional adjustment costs of raising revenues under *SUB*



Key: *w/o comp* – no compensation for Non-Annex 2 countries; *w/ comp* – Non-Annex 2 countries are compensated such that they achieve their benchmark utility level.

4.2 Global and regional CO_2 emissions

So far, we have investigated the economic adjustment cost for Annex 2 and Non-Annex 2 regions of raising revenues from alternate public sources. However, the goal of raising revenues for climate finance is to curb CO_2 emissions in developing countries, and ultimately global CO_2 emissions. Obviously, not only the final allocation of climate funds to developing countries will impact on global CO_2 emissions, but also the alternative fund-raising mechanisms. In particular, it would be highly undesirable to implement an instrument for climate finance that actually incentivizes CO_2 emissions in developing countries through price signals.

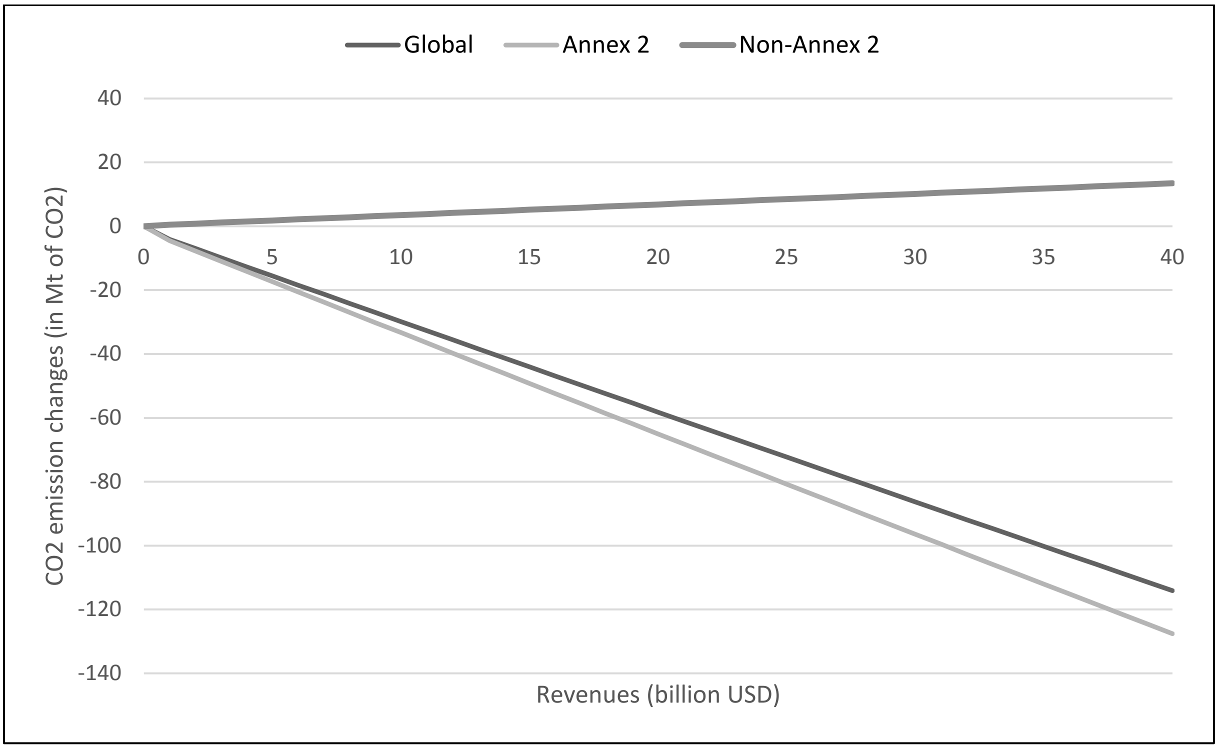
Figures 4, 5, and 6 show the impacts on global CO_2 emission for given revenue targets across our different fund-raising scenarios. The respective emission impacts differ drastically. Note that we focus in our presentation of results on the scenarios without compensating transfers (*w/o comp*) because the changes due to transfers are negligible.

The implementation of each of the three policy instruments reduces global emission levels roughly linearly to the collected revenue. Nonetheless, we see quite substantial differences in magnitudes of emission changes and in their regional distribution.

As a reference point for comparison, we take a closer look at the point where revenues of 10 billion USD are raised. In this case, we observe global CO_2 emission reductions – in descending order – of 49.4 Mt in *SUB*, 29.8 Mt in the *CO2* scenario, and of 9.4 Mt in *ELE*. Comparing the regional changes in emissions reveals more important implications of the instruments. The regional patterns for the scenarios *CO2* and *ELE* look quite similar: Annex 2 countries reduce their emissions as a consequence of the policy while Non-Annex 2 slightly increases emissions compared to the business-as-usual scenario. Under scenario *SUB*, however, Non-Annex 2 countries reduce their emissions almost to the same extent as Annex 2 countries, so that the global emission reduction is by far the greatest among the three policy scenarios.

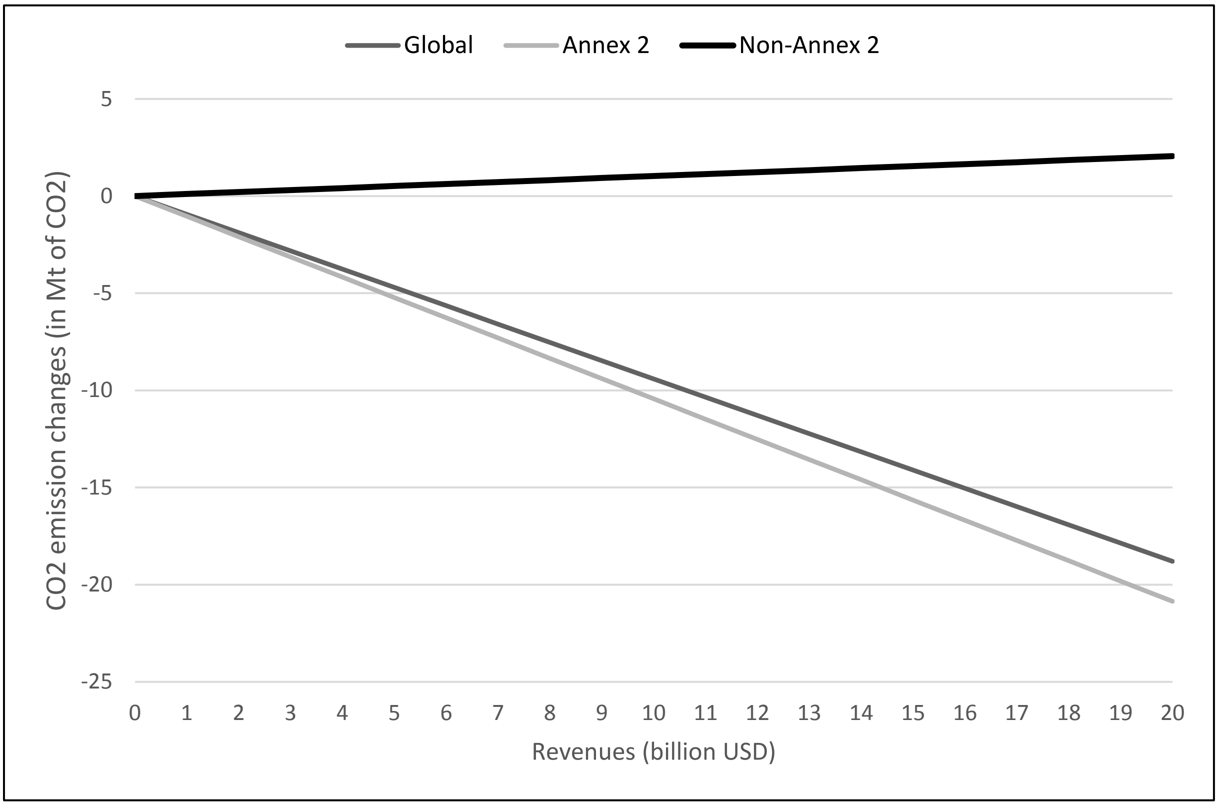
The effectiveness in global and regional patterns of emission abatement is driven by two central criteria. First, how efficient is emission reduction undertaken within Annex 2, i.e. how directly the policy instrument targets CO_2 emissions in Annex 2 countries: obviously, the CO_2 pricing policy (*CO2*) is best in this regard while taxes on electricity consumption (*ELE*) and the removal of subsidies in fossil fuel sectors (*SUB*) work only indirectly as a measure to curb emissions. Second, global emission impacts depend on the direction and magnitude to which policy instruments affect emission levels in Non-Annex 2 countries. Since only global emission levels matter for the problem of climate change, a major drawback of sub-global policies to reduce CO_2 emissions is carbon leakage, i.e. the relocation of emissions from regions undertaking action to unregulated regions. Typically, the major driver of leakage is price changes on international fossil fuel markets: if individual countries or groups of countries decide to reduce their carbon emissions, demand for fossil fuels declines and the international price drops. This in turn stimulates unregulated regions to use more fossil fuels and thus to produce with a higher carbon intensity. If the actual policy goal is raising revenues for climate finance, the problem of leakage is particularly relevant. The idea of climate finance is to use raised funds for investments in order to incentivize lower carbon intensities in developing countries that do not regulate their CO_2 emissions directly. Implementing a revenue raising instrument that leads to higher emissions in regions that are envisaged to receive climate finance is thus counterproductive in the most direct way.

Figure 4: Global CO_2 emissions reduction (in Mt) under scenario *CO2*



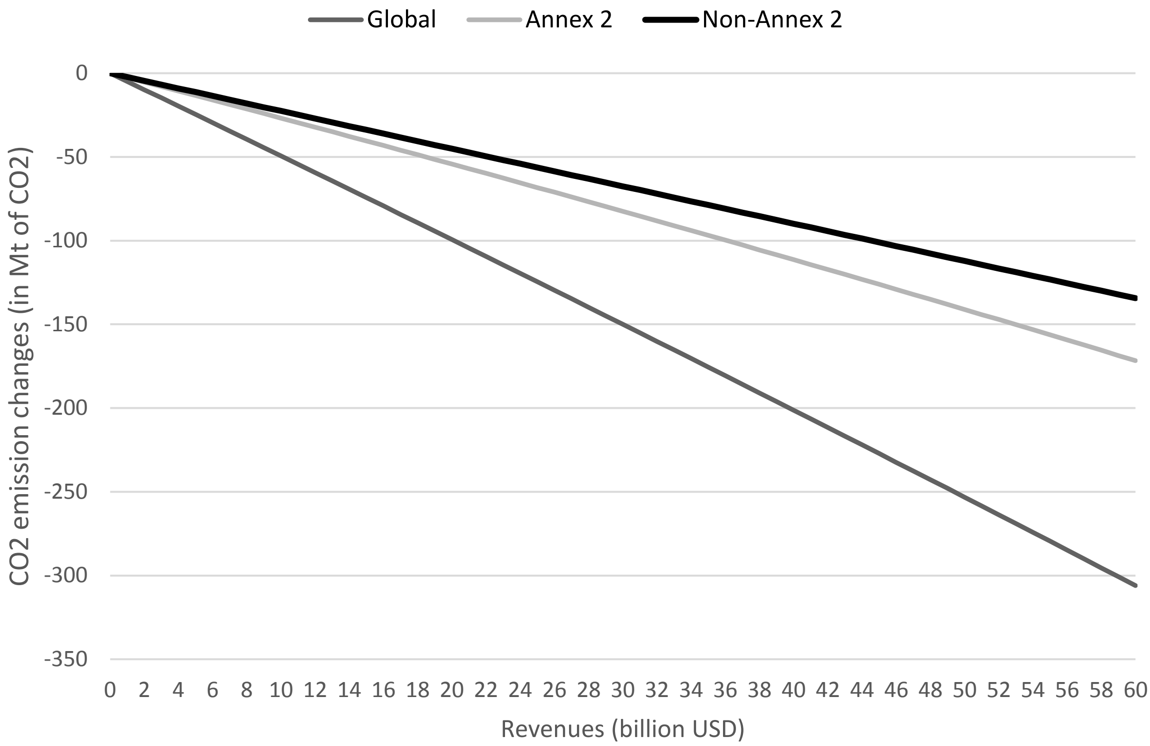
Key: Results are reported for scenarios without compensating transfers (*w/o comp*).

Figure 5: Global CO_2 emissions reduction (in Mt) under scenarios *ELE*



Key: Results are reported for scenarios without compensating transfers (*w/o comp*).

Figure 6: Global CO_2 emissions reduction (in Mt) under scenarios *SUB*



Key: Results are reported for scenarios without compensating transfers (*w/o comp*).

Table 3 reports a summary of our central case simulations regarding adjustment cost and emission impacts for a raised revenue of 10 billion USD, including the leakage rate.[6] The leakage rate is defined as the emission increase in unregulated regions over the emission reduction in regulating regions in percentage terms. A leakage rate of 100%, e.g., means that all the emissions abated in regulating regions are compensated by increased emissions in unregulated regions. We find major differences, which in particular explain the differential impact on global CO_2 emission levels across the different policy regimes. Leakage rates for the electricity consumption tax (*ELE*) amount to 9.9% and are comparable to those in the *CO2* policy, meaning that almost 10% of the emissions abated within Annex 2 countries are offset by increased emissions in Non-Annex 2 countries. With a removal of fossil fuel production subsidies (*SUB*), leakage rates are negative at a level of -84.3%, meaning that Non-Annex 2 countries even reduce emissions as a reaction to the *SUB* policy in Annex 2 compared to the business-as-usual situation. The reasoning behind is similar to the one for the regional cost incidence under *SUB*: Annex 2 countries substitute domestic fossil fuel demand with imports from Non-Annex 2 countries as substitution elasticities in international trade of fossil fuels (particularly oil and coal) are quite high; it then becomes more profitable for Non-Annex 2 to export fossil fuels instead of consuming them and

6 The variation of the leakage rate for varying targeted revenues under the individual scenarios is rather small, so it is sufficient and serves clarity to compare them at one point.

thus in fact shift their economy towards a lower carbon intensity compared to business-as-usual. The decrease in carbon intensity ranges from 0.03% in the gas sector to 0.08% for refined oil. Only the coal sector shows a slight increase of 0.04% in its carbon intensity.

Table 3: Leakage rates in *CO2*, *ELE*, and *SUB* without compensating transfers

Policy	Leakage rate (in %)
CO2	10.5
ELE	9.9
SUB	-84.3

4.3 Sensitivity analysis

We test the robustness of our findings when we alter central parameters in our analysis. Crucial parameters in our analysis are in particular: (i) trade elasticities, which govern the responsiveness of trade patterns to relative price changes; and (ii) fossil fuel supply elasticities, which are important determinants for abatement costs. As laid out below, we find that our main results regarding global and regional costs as well as emission impacts vary in their magnitude, but are qualitatively robust throughout the sensitivity analysis.

Note that different assumptions about central elasticity parameters changes the business-as-usual scenario, i.e., comparison of the scenarios in the sensitivity analysis to the core setting is not straightforward. Nonetheless, we can draw some important conclusions.

For the sake of a clearer representation, we focus on the case of 10 billion USD revenues for all three policy instruments and report only results for scenarios without compensating income transfers. Table 4 provides a summary of the central case simulations discussed above at a revenue of 10 billion USD.

With respect to (i), Table 5 reports global and regional costs with either doubled (*ARM-HI*) or halved (*ARM-LO*) trade elasticities. Under the scenarios *CO2* and *ELE* we find a similar pattern. With higher trade elasticities, Annex 2 is to a lesser extent able to pass through their cost and thus bears a larger share of the global cost of raising revenues. The global cost is slightly increased in this case as the CO_2 price (for *CO2*) and electricity consumption tax (for *ELE*) required to collect 10 billion USD is higher due to better substitution possibilities. The leakage rate increases with trade elasticities. Scenario *SUB* works similar except that global cost are slightly lower than in the core setting. In this case, global effectiveness is increased with the trade elasticities as substitution of fossil fuels in Annex 2 for imports is facilitated. Lowering the Armington elasticities works the other way around.

Table 4: Summary of results on adjustment costs and emission changes for *CO2*, *ELE*, and *SUB* in the central case simulations at a revenue of 10 billion USD

	CO2	*ELE*	*SUB*
Adjustment costs*			
Global	2.7	1.5	1.9
Annex 2	1.4	1.1	2.2
Non-Annex 2	1.2	0.4	-0.3
Emission changes**			
Global	-29.8	-9.4	-49.4
Annex 2	-33.3	-10.4	-26.8
Non-Annex 2	3.5	1.0	-22.6
Leakage (in %)	10.5	9.9	-84.3

* In billion USD; ** In Mt of CO_2

Table 5: Results on adjustment costs and emissions under doubled (*ARM-HI*) and halved (*ARM-LO*) trade elasticities at a revenue of 10 billion USD

		CO2	*ELE*	*SUB*
ARM-HI	Adjustment costs*			
	Global	2.9	1.6	1.7
	Annex 2	1.9	1.3	2.3
	Non-Annex 2	1.0	0.3	-0.6
	Emission changes**			
	Global	-29.0	-9.1	-49.3
	Annex 2	-34.6	-11.0	-24.9
	Non-Annex 2	5.6	1.8	-24.3
	Leakage (in %)	16.2	16.8	-97.7
ARM-LO	Adjustment costs*			
	Global	2.5	1.4	2.1
	Annex 2	0.9	0.9	2.0
	Non-Annex 2	1.6	0.5	0.1
	Emission changes**			
	Global	-30.4	-9.4	-50.0
	Annex 2	-32.4	-9.9	-28.0
	Non-Annex 2	2.1	0.5	-22.0
	Leakage (in %)	6.4	4.9	-78.5

* In billion USD; ** In Mt of CO_2

In (ii), we double (*FFS-HI*) and halve (*FFS-LO*) fossil fuel supply elasticities compared to the core setting (Table 6). We find that under all of our policy scenarios, higher fossil fuel supply elasticities entail slightly larger global cost, which is borne by Annex 2. For *CO2* and *ELE* the reason is that the tax burden of either the CO_2 price or the electricity consumption tax shifts more towards the consumers as suppliers become more elastic. Under *SUB*, the main effect that drives results in the core setting – the substitution of domestic fossil fuel production by imports in Annex 2 – is even reinforced under higher supply elasticities. Under *CO2* and *ELE*, the leakage rate is reduced with higher fossil fuel supply elasticities, as the price drop of fossil fuels that leads to more consumption in Non-Annex 2 is less pronounced. Under *SUB*, leakage is higher than in the core setting because the price increase for fossil fuel is less pronounced. Again, lowering fossil fuel supply elasticities works exactly opposite.

Table 6: Results on adjustment costs and emissions under doubled (*FFS-HI*) and halved (*FFS-LO*) fossil fuel supply elasticities at a revenue of 10 billion USD

		CO2	*ELE*	*SUB*
FFS-HI	Adjustment costs*			
	Global	2.8	1.6	2.1
	Annex 2	1.7	1.2	2.8
	Non-Annex 2	1.1	0.4	-0.7
	Emission changes**			
	Global	-32.3	-10.1	-50.2
	Annex 2	-34.6	-10.8	-32.1
	Non-Annex 2	2.3	0.7	-18.1
	Leakage (in %)	6.7	6.6	-56.5
FFS-LO	Adjustment costs*			
	Global	2.5	1.5	1.6
	Annex 2	1.2	1.1	1.6
	Non-Annex 2	1.3	0.4	0.0
	Emission changes**			
	Global	-26.1	-8.3	-47.2
	Annex 2	-31.8	-10.0	-20.9
	Non-Annex 2	5.7	1.6	-26.3
	Leakage (in %)	17.9	16.6	-125.5

* In billion USD; ** In Mt of CO_2

5. Conclusions

In this paper, we provide an assessment of the macroeconomic adjustment costs that go along with raising climate funds from three alternative public sources in Annex 2 countries: CO_2 emission prices, wires charges on electricity consumption, and the removal of fossil fuel subsidies. We find that these three options do not only induce different global costs to raise given amounts of revenues, but – in the absence of compensating income transfers to Non-Annex 2 countries – have very diverging implications for the cost incidence between developed and developing countries: CO_2 emission prices and a tax on electricity consumption in Annex 2 countries shift significant shares of the burden to Non-Annex 2 countries, while the removal of fossil fuel subsidies within Annex 2 even lead to welfare gains for Non-Annex 2 compared to the business-as-usual situation. The major difference between taxing electricity and removing fossil fuel subsidies that leads to these polar results is the ability to substitute electricity and fossil fuels in the production for imported goods: while electricity is not substitutable on international markets, fossil fuels are rather homogenous goods globally. Thus, the taxation of electricity leads to higher production costs, which are passed through to Non-Annex 2 via trade. The removal of subsidies for fossil fuels, on the other hand, leads to substantial substitution for imported fuels, which Non-Annex 2 countries can benefit from.

Since a central objective of international climate policy is the cost-effective mitigation of climate change, it is important to consider the global CO_2 emission impacts of alternative fund-raising policies. While a CO_2 price is the most targeted and thus effective instrument in terms of CO_2 emission abatement within Annex 2, the global effectiveness of the different instruments hinges critically on the way they affect emissions in Non-Annex 2. While a CO_2 price and a tax on electricity lead to carbon leakage, i.e., increased emissions in Non-Annex 2, the removal of fossil fuel subsidies actually incentivizes decarbonization of Non-Annex 2 economies through higher prices for fossil fuels. This is particularly important as the policy goal of climate finance is to lower emissions in Non-Annex 2 countries.

This paper has focused on the separate assessment of alternative public sources for raising climate funds. In policy practice, these instruments will likely be combined rather than used in isolation in order to provide the target of climate fund revenues of 100 billion USD from 2020 onwards. Subsequent research thus should investigate the interactions across the various climate finance instrument and identify a cost-efficient instrument mix with respect to revenue and CO_2 emission constraints.

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