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A global framework for climate mitigation policies: A technical contribution to the discussion on carbon pricing and equivalent policies in open economies

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World Trade Organization

Economic Research and Statistics Division

A GLOBAL FRAMEWORK FOR CLIMATE MITIGATION POLICIES

**A TECHNICAL CONTRIBUTION TO THE DISCUSSION ON CARBON PRICING
AND EQUIVALENT POLICIES IN OPEN ECONOMIES**

Eddy Bekkers[†], Ayse Nihal Yilmaz[‡], Marc Bacchetta[§], Mateo Ferrero^{**}, Kirti Jhunjhunwala^{††}, Jeanne Métivier^{‡‡}, Bright Okogu^{§§}, Daniel Ramos^{***}, Enxhi Tresa^{†††}, and Ankai Xu^{†††}

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A Global Framework for Climate Mitigation Policies

A Technical Contribution to the Discussion on Carbon Pricing and Equivalent Policies in Open Economies*

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Abstract

We explore a global carbon pricing framework to inform the potential coordination of carbon pricing and equivalent policies. The framework has three main features aligning with the current multilateral system for climate action. First, the carbon price is determined by a global average carbon price to achieve emission reductions required to remain on a 1.5-2 degrees Celsius global warming trajectory. The framework further incorporates a set of economy-level criteria determining variation in carbon prices between economies: historical emissions, the current level of economic development, and the economic costs of climate change. Second, a moderate share of carbon pricing revenues is allocated to support lower-income economies, economies with higher costs of climate change and economies with higher economic costs of carbon pricing. Third, the framework allows economies to achieve equivalent carbon emission reductions through the implementation of alternative policy instruments. Simulations with the Global Trade Model show that, under the framework, the projected economic costs of carbon pricing are in proportion to the economy-level criteria, implying higher costs for economies with higher historical emissions, a higher level of development and lower projected costs of climate change. The projected reduction in output and exports in emission-intensive trade-exposed sectors (EITEs) displays only a weak negative correlation with the carbon price level. The framework is not meant as a policy proposal but as a contribution to the discussion on coordination of carbon pricing policies. Such coordination can help to inform the discussion about policy options to prevent fragmentation of carbon pricing and other climate change mitigation policies. Such fragmentation is costly and could lead to the introduction of complementary policies which could come with trade frictions.

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1 Introduction

Reducing greenhouse gas (GHG) emissions is necessary to mitigate the effects of climate change. Under the Paris Agreement, economies have committed to the objective of reducing carbon emissions to stay on a trajectory of 1.5-2 degrees Celsius global warming. The Paris Agreement requests each economy to outline and communicate its actions to reduce GHG emissions in “Nationally Determined Contributions” (NDCs). A range of policy instruments is employed to realise the emission reductions such as carbon pricing, subsidies and command-and-control measures (e.g., regulations).

One of the policy instruments is a carbon price, a price paid per ton of CO₂ (or equivalent GHG) emitted. The Carbon Pricing Leadership Coalition – composed of a number of economies, civil society representatives and international institutions, such as the World Bank and the IMF – calls carbon pricing “one of the strongest policy instruments available for tackling climate change”.¹¹ This instrument can tackle the externalities generated by GHG emissions. Carbon pricing is generally considered a particularly effective policy tool to reduce GHG emissions, as it provides an economic signal to emitters which incentivises shifts in consumption and investment patterns to reduce emissions (CPLC, 2021).¹² It raises the price of emissions and thus decreases the demand for carbon-intensive goods and services and promotes a shift from production based on fossil fuels to production based on other, renewable sources of energy.

However, there is increasing fragmentation of carbon pricing policies. A patchwork of about 70 different carbon pricing schemes already exist globally, but they cover only 23 per cent of total emissions. Carbon prices vary widely across the globe, from less than US\$ 1 to more than US\$ 130 per tonne of CO₂.¹³ To address carbon leakage and competitiveness concerns as a result of differences in the level of carbon prices, economies consider the introduction of border carbon adjustment (BCA) measures.¹⁴ If this situation worsens or is not effectively managed, it has the potential to escalate trade tensions, which would adversely affect welfare

¹¹<https://www.carbonpricingleadership.org/what>

¹²Carbon pricing can take different forms, the most common of which are carbon taxes or emission trading systems. A carbon tax puts a direct price on GHG emissions and requires economic actors to pay for every ton of carbon pollution emitted. An emission trading system (ETS) following the cap-and-trade system sets a limit on total direct GHG emissions from specific sectors and sets up a market where the rights to emit are traded.

¹³Carbon price data are retrieved from World Bank Carbon Pricing Dashboard: Carbon Pricing Dashboard — Up-to-date overview of carbon pricing initiatives.(worldbank.org)

¹⁴A BCA entails the introduction of a charge on the embodied carbon in products imported from a jurisdiction with a lower level of carbon pricing than in the importing economy or on imported products whose embodied carbon was not otherwise priced. A BCA may also involve rebating the domestic carbon price paid by firms when exporting their goods to compensate for the higher carbon price faced domestically compared with firms in the economy to which they are exporting. Because of the adjustment at the border, final consumers in a jurisdiction would in principle face the same carbon tax rate on domestic and imported goods (Elliott et al., 2013).

and could jeopardize the beneficial role of trade in fighting climate change through a range of channels such as the diffusion of green technologies. Concerns about these risks have already been raised in various World Trade Organization (WTO) Committees, as well as in several other fora, including at meetings of the the United Nations Framework Convention on Climate Change (UNFCCC), G20, G7 and the Organisation for Economic Cooperation and Development (OECD).

More generally, the WTO has been one of the central forums for multilateral discussions on these matters, given the clear intersection between the variable geometry of climate ambitions, trade, and carbon leakage and competitiveness concerns. Indeed, a number of WTO members have started exploring, discussing and presenting their own approaches and perspectives on the topic, including with respect to specific proposed trade-related climate measures (TrCMs), in various WTO bodies and initiatives, such as the WTO Committee on Trade and Environment (CTE), the Committee on Technical Barriers to Trade (TBT) or the Trade and Environmental Sustainability Structured Discussions (TESSD). Discussions vary broadly, from best practices and peer learning to sector-specific issues, to carbon footprint calculation methodologies and equivalency between different TrCMs. Some delegations have raised concerns with regards to the adoption of unilateral TrCMs, including those focused on carbon leakage and competitiveness concerns, such as BCAs.¹⁵

In light of these discussions enhanced coordination of carbon pricing policies could help scale up action against climate change, reduce the costs of unilateral uncoordinated policies, and prevent trade tensions. Against this backdrop, a growing number of economists, governments, international organizations, and non-governmental organizations (NGOs) are calling for, and contributing to, the development of a global carbon pricing approach. For instance, the International Monetary Fund (IMF) proposes an international carbon price floor (i.e., the minimum price to be paid on GHG emissions), equal to US\$ 75 in high-income economies, US\$ 50 in middle-income economies, and US\$ 25 in low-income economies (Parry et al., 2021).

The OECD has also launched its Inclusive Forum on Carbon Mitigation Approaches (IFCMA), an initiative designed to help improve the global impact of emissions reduction efforts around the world through better data and information sharing, evidence-based mutual learning and inclusive multilateral dialogue seeking to take stock of and consider the effectiveness of different carbon mitigation approaches. Recently, the African Heads of State and Government, gathered for the inaugural Africa Climate Summit (ACS) in Nairobi, Kenya, pro-

¹⁵See, *inter alia*, discussions in the Committee on Trade and Environment (WT/CTE/28/Rev.1, paragraph 1.19; WT/CTE/M/71, paragraphs 1.102–122; WT/CTE/M/72, paragraphs 2.95–2.115; WT/CTE/M/73, paragraphs 1.45–1.75), Committee on Market Access (G/MA/M/74, paragraphs 12.3 – 12.43), or Council on Trade in Goods (G/C/M/139, paragraphs 20.3 – 20.59; G/C/M/140, paragraphs 28.3 – 28.60; G/C/M/141, paragraphs 39.3–36.63).

posed “a global tax regime to finance climate action at scale by crowding in and de-risking private capital, including but not limited to financial transactions tax (FTT) and emission levies”.¹⁶

Our paper contributes to this debate by exploring the introduction of a global carbon pricing framework. The objective of a carbon pricing framework is to enhance international coordination on carbon pricing and policies equivalent to carbon pricing, thus helping to reduce trade tensions and increasing the role of trade in combating climate change. The framework consists of three main components, rooted in the current multilateral framework for climate action, including the Paris Agreement, the UNFCCC and related instruments. First, the carbon price is determined by a dynamic formula determined by a global average carbon price to realise emission reductions needed to stay on a trajectory of 1.5 – 2 degrees Celsius global warming and economy-level criteria determining the variation in carbon prices between economies. The economy-level criteria are: historical emissions; the current level of development; and the economic costs of climate change. Second, a moderate share of carbon pricing revenues is allocated to support lower-income economies, economies with higher costs of climate change and economies with higher economic costs of carbon pricing. Third, under the framework economies can realize an equivalent reduction of carbon emissions by employing other policy instruments. The formulas for the carbon price and share of support allocated are dynamic, with historical contributions, current development, and adverse impacts of mitigation updated each period. To tighten the link between the economic costs of mitigation and the economy-level criteria, carbon prices and support are also a function of the adverse impact of climate change mitigation policies.

Simulations are conducted with the WTO Global Trade Model (GTM) to evaluate the ability of the formula to keep climate ambition in line with the Paris Agreement’s overall emission reduction objectives while establishing a tight link between the economic costs of carbon pricing and the economy-level criteria. The simulations generate the following three main insights.

First, under the framework, the economic costs of carbon pricing are distributed in line with the economy-level criteria. In other words, regions with a larger ability to pay, with a larger historical contribution to pollution, and with lower economic costs from climate change are projected to face larger economic costs of carbon pricing. Although without support the relation between economic costs of carbon pricing and the economy-level criteria is weak, a moderate share (20%) of carbon tax revenues allocated to support is sufficient to make this relationship positive. We experimented with different levels of support in the simulations

¹⁶See “The African Leaders Nairobi Declaration on Climate Change and Call to Action”, 6th September 2023, available at https://www.afdb.org/sites/default/files/2023/09/08/the_african_leaders_nairobi_declaration_on_climate_changereveng.pdf .

and found that 20% generates a tight link between the economic costs of carbon pricing and the economy-level criteria. ¹⁷In principle, the framework is flexible with respect to the criteria included and some of the criteria like the adverse impact of climate change mitigation could be omitted. However, the quantitative analysis shows that the benchmark framework performs well in generating a tight link between the criteria and the economic costs of decarbonisation.

Second, interestingly, economies with a larger carbon price would not suffer larger economic declines as measured by real output and real exports in emissions-intensive trade-exposed (EITE) sectors in the benchmark framework that includes support. This result is driven by a Dutch disease type of effect with factor prices rising and competitiveness falling in economies with lower carbon prices because they also tend to receive more support. Without support, there would be a weak negative relationship. Furthermore, the simulations indicate that the introduction of BCA by all economies to correct for differences in carbon prices on top of the global carbon pricing framework would deliver only a marginal contribution to the reduction of global emissions. Moreover, the introduction of BCA would lead to a positive relation between output changes in EITEs and carbon price levels, implying that BCA would reduce competitiveness in economies with a lower carbon price.

Third, in comparison to the proposal for an international carbon price floor as proposed by the IMF, under the global carbon pricing framework, there is a larger dispersion of carbon prices between regions and a more explicit role for support, which allocates a share of carbon pricing revenues to low-income economies and regions facing higher economic costs of climate change.

The main results hold under several robustness checks on the different ingredients of the carbon price formula. Furthermore, in extensions, it is shown that the global carbon price framework can also be implemented employing emissions trading with a unified carbon price. The emission reductions implied by the formula could serve as emission reduction targets for each region in a system of global emissions trading. Hence, the framework is flexible in the way in which carbon pricing is implemented.

Under global emissions trading there is a uniform carbon price and regions pay/receive money if their emissions are above/below their targets. The simulations show that such a system with a uniform price has important advantages in terms of efficiency, because a larger global emission reduction can be realised with the same carbon price as the global average of heterogeneous carbon prices under the framework or alternatively a lower carbon

¹⁷In the literature a range of economic benefits of carbon pricing are identified: the ability to raise additional tax revenues in economies with fragile fiscal institutions and thus limited ability to raise tax revenues; the ability to reduce distortionary income taxes with the revenues from carbon pricing; and the reduction of local pollution (co-benefits of decarbonisation). The first two channels are considered in the simulations, whereas the third channel is not considered due to difficulty in quantifying it.

price is needed to achieve the same level of emissions reductions (see also [Bekkers and Cariola \(2022\)](#)). Still, the economic costs of decarbonisation can be brought in line with the economy-level criteria by including support. However, a uniform carbon price also comes with important disadvantages. Firstly, the combination of a uniform price and support encounters credibility issues if there is uncertainty about the extent to which support will be provided. This situation raises concerns, especially for low-income regions that would need to commit to a uniform price without assurance of support delivery. Secondly, a uniform price may not align with considerations for the unique circumstances of low-income and/or low-emission regions. Third, emissions trading has been shown difficult to negotiate historically ([Cramton et al., 2017](#)). See Section 3.4.4 for further discussion.

To summarize, the paper makes three main contributions to the literature. First, a global carbon pricing framework is introduced with a dynamic formula governing both the relative level of carbon pricing within each economy and the distribution of a portion of carbon tax revenues to support various economies, aligning with the principles of the current multilateral framework for climate action. The formula is concrete, and both the level of carbon pricing and support can be calculated using a limited set of indicators available for a large set of economies. Second, simulations using the WTO Global Trade Model (GTM) show that the global carbon pricing framework generates a strong positive correlation between the economic costs of climate change mitigation and the economy-level criteria if a moderate share (20%) of carbon tax revenues is allocated to support. Third, we discuss how the framework can be considered in a flexible manner in terms of policy instruments used and can thus help inform enhanced cooperation to address the patchwork of carbon pricing instruments across regions and related carbon leakage and adjustment concerns.

The paper is organized as follows. [Section 2](#) introduces the formulas for the levels of the carbon price and support, discusses how these are underpinned by the current multilateral framework for climate action and related literature, describes as background differences in both approaches and interests on carbon pricing, and outlines the implementation of flexibility and data sources. [Section 3](#) presents the results of simulations with the GTM, exploring the relation between the economic costs of carbon pricing and the economy-level criteria, the impact on EITEs, the potential role of emissions trading, the role of dynamics in the model and the potential for convergence in the long run, and a set of robustness checks. [Section 4](#) concludes, also briefly discussing the potential coordinating role of international organisations in the area of carbon pricing.

2 Components of the Global Carbon Pricing Framework

The global carbon pricing framework has three main components: (i) the formula to determine the carbon price within each economy; (ii) the allocation of support; and (iii) flexibility of policy instruments and equivalence. These three components will be discussed in the following subsections. The formula has been crafted to address the challenges associated with varying interests and approaches regarding carbon pricing. Therefore, before delving into the formula in subsection 2.1, we provide an overview of the diverse interests and approaches and a set of guidelines in designing the framework to tackle these differences in Subsection 2.2.

2.1 Differences in interests and approaches

Introducing a global carbon pricing framework is complex, primarily due to the economies' disparities in interests and approaches. These disparities include differences between economies favouring price instruments and economies favouring command-and-control policies, differences between economies at different levels of development, differences between fossil fuel importers and exporters, and differences between different socioeconomic groups within economies.

First, carbon pricing is not the only instrument of climate change mitigation and different economies choose different approaches to achieve the same objective. Instruments such as command-and-control measures (e.g., regulations and efficiency standards), subsidies and public low-carbon infrastructure programs can also help reduce emissions. Some of the reasons why, in some economies, other instruments are preferred to carbon pricing is that the latter tends to affect lower income groups more adversely since they spend a larger share of income on energy and because command-and-control measures tend to be easier to implement since they often focus on a single sector.

Second, although policymakers in most economies agree that the responsibility to tackle global warming should be common but differentiated, they hold different opinions as to how to concretely implement this principle. The CBDR-RC principle – as described, *inter alia*, in Article 3 of the UNFCCC – has been present in several other international environmental policies and laws and can be seen as early as in the 1972 UN conference on Human Environment in Stockholm (Pauw *et al.*, 2014). However, the lack of concrete and universally accepted guidance on how to effectively reflect the principle in climate mitigation policies leads to important differences in approach. In general terms, every economy seeks to recognize and implement the principle of its own accord, making it difficult to reach a consensus

on global approaches for differentiating responsibility (Deleuil, 2012). The bottom-up approach to mitigation pledges adopted by the Paris Agreement can be understood as a partial reflection of the challenge.

Third, fossil fuel exporting economies (FFECs) and economies exporting energy intensive goods are expected to be adversely affected by the introduction of a global carbon price because the demand for fossil fuels will drop and prices will fall leading to the problem of stranded fossil-fuel assets and loss of related income. For example, based on the costs of fossil fuel extraction per economy, it is argued that the Kingdom of Saudi Arabia could maintain its competitive prices in oil and thus continue selling, whereas Canadian and US fossil fuel assets would be stranded much faster (Mercure et al., 2018). Stranded fossil fuels can also have indirect financial impacts, when for example fuel companies are state-owned, leading to a loss of government revenues (Bolton et al., 2020). Given these concerns, many of the FFECs could be reluctant to participate in initiatives for a global carbon price and the potential benefits of a carbon price (e.g., diversification of economies) must be reinforced (Peszko et al., 2020).

Lastly, in addition to differences between economies, there also exist differences in impacts of carbon pricing between socio-economic groups within an economy, based for example on the income of a group or region within a country where the group lives. What matters is the extent to which groups consume fossil fuels and carbon intensive products and the extent to which groups are employed in fossil fuel related sectors. Often these differences have a strong regional component within an economy (Wang et al., 2016). An important finding in the literature is that there is an increased likelihood of progressive distributional outcomes in lower income economies (Ohlendorf et al., 2021). However, even progressive policies can increase consumer prices, which raises the chance of adverse effects for low-income households thus potentially fostering public resistance. Studies focusing on differences between urban and rural households also report ambiguous results, with rural households faring worse in certain economies while better in others. Overall, the conclusion can be drawn that the impacts of a carbon tax vary within economies and within economy differences in impact cannot be tackled solely or directly with a global carbon pricing framework. It requires national governments to design policies such that carbon pricing is introduced in a just way, which requires sufficient resources to compensate the groups most affected by decarbonisation policies.

2.2 Guidelines for designing the framework

The aim of the framework is to retain the advantages of a globally coordinated approach to carbon pricing and equivalent policies and, at the same time, tackle the differences in interests and approaches discussed in the previous subsection to garner acceptance for all

involved parties. Simultaneously, it aims to ensure alignment with the Paris Agreement (and UNFCCC) framework for action. To achieve this aim, the carbon pricing framework should:

1. **Be global** to ensure that it is efficient, addresses carbon leakage and competitiveness concerns and reduces the risk that trade conflicts would be exacerbated as a result of a proliferation of uncoordinated BCAs and other unilateral approaches.
2. **Be equitable** to make sure that it is acceptable by as many economies as possible. The most straightforward source for guidelines on climate actions is the framework provided by the Paris Agreement, the UNFCCC and related discussions, including the importance of enhancing climate adaptation capacity, the effects of response measures, just transition, economic diversification as well as other elements implying, inter alia, that carbon prices could vary by levels of income and a share of the revenues of carbon pricing could be employed to support lower-income economies.
3. **Be limited** in the adverse effects on specific groups particularly affected, e.g., for the FFECs and for low-income groups who spend the largest shares of their income on energy.
4. **Be flexible** in its implementation allowing economies to realize an equivalent reduction of carbon emissions through other policy instruments.

A global carbon pricing framework based on these guidelines will be developed in this section answering the following three main design questions: (*i*) how to set differences in carbon prices as a function of the level of development; (*ii*) how to provide support to lower income economies and economies adversely impacted by climate change; (*iii*) how to assess the effectiveness of alternative mitigation measures, such as command-and-control type of measures, and recognize their equivalence?

2.3 Formula for a global carbon price

The carbon price in region i and period t , P_{it} , is based on the global average carbon price necessary to keep emissions on a path of 1.5 to 2 degrees Celsius global warming by 2100, \bar{P}_t and four economy-level criteria implying variation in the carbon price across economies:

1. The historical contribution to global warming, HC_{it} , calculated based on the cumulative emissions per capita of region i until time t reflecting the understanding that economies with a larger contribution to global warming should take the lead in reduction efforts.
2. The current level of development, CD_{it} , calculated based on the current GDP per capita of region i reflecting the principle that regions with more capacity to undertake decarbonisation measures should also take the lead.

3. The Cost of Climate Change per capita, CCC_i , calculated as the projected GDP per capita loss from climate change, based on estimates in the literature that take into account various macroeconomic costs of climate change.
4. The adverse impact of climate change mitigation per capita, AI_{it} , calculated based on the economic costs of carbon pricing in economy i . The adverse impact of climate change mitigation (AI_{it}) is computed based on three components: the emission intensity of fossil fuel sectors, export shares (revealed comparative advantage) of fossil fuels, and the import share in fossil fuels.¹⁸ Such choice reflects the understanding that economies with a comparative advantage in fossil fuels are economically more adversely affected by the introduction of global carbon pricing.

The four economy-level criteria are normalized relative to the maximum value across all regions such that the value of the criteria are between 0 and 1. When included in the carbon price formula, the variables CCC_i and AI_{it} are transformed such that there is a negative relation between the value of the variable and the level of the carbon price. That is, the carbon price is lower the higher is the cost of climate change and the adverse impact of mitigation for the region. Therefore, in the formula we include a transformation of AI_{it} and CCC_i , namely rAI_{it} and $rCCC_{it}$, which are inversely related to AI_{it} and CCC_i .¹⁹ The carbon price in region i and period t , P_{it} , can thus be written as follows:

$$P_{it} = HC_{it}^{\alpha_{HC}} CD_{it}^{\alpha_{CD}} rAI_{it}^{\alpha_{AI}} rCCC_{it}^{\alpha_{CCC}} \bar{P}_t \quad (1)$$

α_{HC} , α_{CD} , α_{AI} , and α_{CCC} are the weights attributed to the historical level of emissions, the current level of development, the reverse adverse impact of climate change mitigation, and the reverse costs of climate change respectively, all equal to $\frac{1}{4}$. The functional form is multiplicative giving equal weight to the four criteria.

2.4 Allocation of carbon pricing revenues

A share of global carbon tax revenues is allocated to support regions in coping with the costs of climate change and with the adverse effects of climate change mitigation policies. The amount of carbon pricing revenue available for support, $CTREV_t^{glob}$, can be written as follows, with $SUPSH_t$ the share of global carbon tax revenues allocated to support and

¹⁸Fossil fuels sectors include oil, gas, and coal.

¹⁹More specifically, the variables $X_{it} = rCCC_{it}, rAI_{it}$ are transformed by subtracting the value from the sum of the maximum plus minimum value, $rX_{it} = \max(X_{it}) + \min(X_{it}) - X_{it}$. Then, like for the other variables the resulting value is divided by the maximum, $rX_{it} = r\bar{X}_{it}/\max(r\bar{X}_{it})$. This transformation ensures that regions with the largest value for X_{it} get the smallest value of rX_{it} and that values are between 0 and 1. Furthermore, inverting CCC_i and AI_{it} by simply dividing by its value and then normalizing relative to the largest value, would give values flocking either close to 0 or close 1 depending on whether CCC_i and AI_{it} would be respectively very large or very small.

$CO2_{it}$ the quantity of CO2 emissions, identical for all regions:

$$CTREV_t^{glob} = \sum_i SUP_{it} SH_t CO2_{it} P_{it} \quad (2)$$

The support for coping with the effects of climate change for each region can be written as follows:

$$SUP_{it} = SH SUP_{it} CTREV_t^{glob} \quad (3)$$

The share allocated to region i , $SH SUP_{it}$, is determined by the population share of region i in global population multiplied by the costs of climate change per capita and the adverse effects of climate change mitigation:

$$SH SUP_{it} = \frac{POP_{it}^{\beta_{POP}} AI_i t^{\beta_{AI}} CCC_i^{\beta_{CCC}}}{\sum_j POP_{jt}^{\beta_{POP}} AI_{jt}^{\beta_{AI}} CCC_j^{\beta_{CCC}}} \quad (4)$$

POP_{it} is the population size in region i , CCC_i the economic costs of climate change per capita and AI_i the adverse impact of climate change mitigation per capita. These two variables while being similar in content and description as the ones used in carbon price, are not reversed in the formula for support, such that economies with a higher cost of climate change and a larger adverse impact of climate change mitigation receive more support.

Payments into a fund to finance support by region i are proportional to CO_2 emissions in region i and thus by approximation proportional to the level of income. The revenues from the fund are proportional to population. Therefore, this set-up entails net support for regions with a lower level of per capita income or higher net payments by regions with a higher level of per capita income.²⁰

Part of the support could be used to facilitate the low carbon transition of an economy, to cope with the consequences of climate change and cover costs of climate change adaptation. Additionally, the support can also be employed to reduce other taxes and thus reduce the costs of decarbonisation. More generally, low-income economies would be net beneficiaries, enabling them to utilize their carbon pricing revenues for co-financing their project expenditures. However, the allocation of support to different uses is not modelled further in the simulations presented in this paper.

²⁰For some regions, there can be deviations from this principle (e.g., EFTA) as these regions might have higher shares of support received because of adverse impacts and cost of climate change.

2.5 Flexibility and equivalence

As explained in the previous section, economies differ in their preferred decarbonisation policies, with some economies preferring carbon pricing and others opting for command-and-control and/or support measures. Variations also exist in decarbonisation policies within an economy based on the targeted sector of the economy. For instance, many carbon pricing schemes exclusively apply to the energy and select industrial sectors, while other policy tools are directed at different segments like transportation. Therefore, it is important to introduce a degree of flexibility in achieving carbon emission reductions, necessitating the development of a methodology to ascertain the carbon price equivalent of various mitigation policies, including regulations, subsidies, and command-and-control measures.

To date, there is no universally accepted, standardized methodology to map non-pricing policies (such as regulations or support measures) into pricing equivalents. This absence of a standard approach poses challenges when comparing mitigation efforts between economies, given that economies frequently utilize a diverse array of both price-based and non-price-based instruments. There are two potential ways to develop this equivalence: an ex-ante and an ex-post approach. Under the first approach, the equivalence of alternative abatement policies to a specific level of carbon price is determined before they are introduced. Under the second approach, the equivalence of alternative policies is determined based on the realized emission reductions after policies are introduced.

Under the ex-ante approach explicit price equivalents would be determined, by considering the emission reduction potential of alternative measures such as subsidies or regulations and converting these projected emission reductions into the equivalent carbon price generating the same emission reduction. Both the analysis of emissions reduction potential of specific policies and/or NDCs and the work on decarbonisation measures under the OECD's Inclusive Forum on Carbon Mitigation Approaches (IFCMA) can be employed to do such calculations. Calculating such equivalents is complicated and very labour intensive because different regulations and other abatement measures across jurisdictions often have unique characteristics, requiring a unique analysis of the emission reduction potential of each of these measures. The described ex-ante calculation of equivalence is a macro-level approach as it evaluates the impact of policies and their equivalence with carbon prices at the economy-level. A micro-level approach to equivalence would attempt to calculate the reduction of emission-intensity of production at the firm or product-levels induced by regulations and/or support measures.

The ex-post approach would determine the implied emission reduction equivalents of a carbon price level and would allow each economy to choose between different instruments to reach the emission reductions implied by its carbon price. A standardized range for these

emission reductions can be agreed upon based, for instance, on the calculations by a collective initiative and/or a consortium of selected modelling teams. With such an agreement over the implied emission-reductions of carbon pricing at the economy-level, economies would be able to choose among different policies to realize the required emission-reductions. This would enable economies to choose their preferred decarbonisation policies, in line with their domestic interests and political economy concerns. To illustrate with a simple example, assuming that an economy would need to realize the emission reductions (relative to a historical base year), equivalent to a US\$50 carbon price. The economy can achieve the same emission reductions with an explicit carbon price, with an implicit carbon price (e.g., fuel tax, removal of fossil fuel subsidies) or non-price based measures (e.g., efficiency standards, command and control policies, or programs to induce behavioural changes).

The advantage of the ex-ante approach is that the equivalence of policies is determined before they are introduced, which facilitates enforcement. Economies can only be in line with the requirements of a reduction equivalent to a certain carbon price level by introducing policies deemed equivalent. However, this also poses a central challenge: it is difficult to determine the expected emission reduction of various policies.

The advantage of the ex-post approach is that it is more straightforward to determine equivalence. It only requires an agreement over the regional emission reductions implied by regional carbon prices. However, enforcement of the equivalent reduction of emissions is more complicated because equivalence can only be assessed ex-post based on realized emission reductions.

Introducing equivalence would be in line with the Paris Agreement approach to climate change action. Under the ex-ante approach economies would have to introduce policies to reduce emissions whose equivalence with carbon pricing would be evaluated. Under the ex-post approach economies would have to reduce emissions by a certain amount, equivalent to the reduction under an explicit carbon price. Hence, the policy target would become a certain reduction in emissions instead of the introduction of a carbon price with a specific level and as such would bear similarities with the Paris approach. However, the way in which the level of emission reduction for each individual economy is determined would be different: the emission reductions are implied by a carbon price level underpinned by economy-level criteria instead of NDCs announced by individual economies.²¹

We observe that equivalence in terms of emission reductions does not imply equivalence of

²¹In the literature on carbon pricing and climate change mitigation policies, it has been argued that carbon pricing might be easier to negotiate than emission trading. [Cramton et al. \(2017\)](#) argue that negotiations on emission targets are complicated if first a global emission target is set and then economy-level targets. If one economy is more ambitious, other regions would have to do less. Deciding on a global carbon pricing framework with equivalence might circumvent some of these problems of negotiating emission trading, because a carbon price would be negotiated according to set criteria.

carbon prices faced by firms active in different jurisdictions. As discussed further in Section 3.4.3 differences in carbon prices lead to competitiveness concerns and the potential for relocation of production.

2.6 Data sources and implementation

Historical contributions to emissions for the period 1850-2021 are based on the PRIMAP and EDGAR Databases. The current level of development is measured by GDP per capita data from the IMF. For the costs of climate change, estimates by [Dellink et al. \(2019\)](#) are employed who model the demand- and supply-side effects of climate change. The adverse impact of climate change mitigation is based on an analysis of the determinants of the economic costs of carbon pricing according to the simulation model presented in the next section. [Annex B](#) further describes the data sources employed to implement the formulas for the carbon price and support.

The global average carbon price, \bar{P}_t , increases linearly until 2030 to ensure that the global economy stays on a path of emissions corresponding with 2 degrees Celsius global warming according to the simulation model. According to the latest IPCC reports, a reduction in CO₂ emissions of 27% is needed until 2030 relative to 2019 to stay on this path. The average carbon price required for this emission reduction by 2030 is determined based on the simulations and is equal to \$94.

[Table 1](#) shows that the formula assigns the highest total weight for high-income regions characterized by both a high historical contribution to global warming and a high current development status. Nevertheless, the other two variables also play a role. For example, regions with high costs of climate change (and thus a low inverse measure, $rCCC$) have a lower total weight. On the other hand, fossil fuel importing economies often exhibit a high rAI score, as they stand to benefit from global carbon pricing which reduces fossil fuel prices in the world market. The total weights assigned for each economy are multiplied by the global average carbon price, \bar{P}_t to achieve 27% reduction in emissions.²²

3 Simulations of the potential impact of a global carbon pricing framework

To help further inform the debate and shed light on the potential consequences of a global carbon pricing framework, simulations for the global economy are conducted until 2030 with the WTO Global Trade Model (GTM), a recursive dynamic computable general equilibrium

²²If the framework would be applied to a more disaggregated set of regions, the exercise would require a different value of \bar{P}_t to achieve the same level of emission reduction.

Table 1: Values for the components in the formula for the carbon price and support

Region	HC	CD	rCCC	rAI	Total Weight
CEA	0.30	0.13	0.86	0.19	0.28
EAS	0.17	0.18	0.41	0.65	0.30
EUR	0.33	0.45	0.73	0.66	0.52
LAC	0.12	0.11	0.59	0.52	0.25
MIN	0.19	0.10	0.27	0.19	0.18
NAM	0.92	0.61	0.71	0.54	0.68
OAS	0.05	0.04	0.12	0.94	0.12
OCE	0.74	0.70	0.64	0.43	0.61
SEA	0.09	0.07	0.34	0.55	0.18
SSA	0.06	0.03	0.20	0.20	0.09

Source: Own calculations based on PRIMAP, Maddison Project, World Bank, GTAP database.

Notes: The table presents the regional values of the variables determining the carbon price. The first column shows the values for the historical contribution (HC), the second column shows the values for the current development (CD), the third column shows the values for the reversed cost of climate change (rCCC), the fourth column shows the values for the reversed adverse impacts (rAI), the fifth column shows the product of the four variables raised to the power of $\frac{1}{4}$. All four variables are normalized with respect to the maximum value of the final variable. For HC and CD, the value of 1 denotes the largest HC or CD. For rCCC and rAI, the value of 1 denotes the largest rCCC or rAI, hence the smallest CCC or AI. Central Asia (CEA): ROW, RUS; East Asia (EAS): CHN, JPN, KOR; Europe (EUR): E27, EFT, GBR; Latin America and Caribbean (LAC): BRA, LAC; Middle East Northern Africa (MIN): MIN, TUR; Northern America (NAM): CAN, MEX, USA; Other Asia (OAS): Asia least-developed (ASL), IND, OAS; Oceania (OCE): Australia; Southeast Asia (SEA): SEA; Sub-Saharan Africa (SSA): Sub-Saharan Africa least developed (SSL), Sub-Saharan Africa other (SSO).

(CGE) model to analyse the global economic and trade effects of climate change policies. This exercise enables us to generate *(i)* implications of the formula for price dispersion and the allocation of support; *(ii)* simulation results to evaluate the ability of the formula to keep climate ambition in line with the Paris Agreement’s overall emission reduction objectives while establishing a tight link between the economic costs of carbon pricing and the economy-level criteria; *(iii)* additional simulation results such as on the impact of BCA combined with the framework, implementation of the framework under emission trading, variation of the criteria in the formula, and the role of dynamics in the formula. We start by outlining the set-up of the simulations. The simulations also show what level of the global average carbon price is needed to obtain a reduction of global emissions to stay on a trajectory of 1.5-2 degrees Celsius global warming. Simulations are not needed to calculate the other determinants of the formula.

3.1 Set-up of the simulations

As a baseline, we employ a scenario which corresponds to emission reductions based on policies already implemented, or policies converted into legislation, until 2030. This baseline scenario depicts a world in which economies take unilateral action and continue with fragmented policies. Shocks to the electricity and renewable sectors are imposed such that

electrification and renewable shares grow to realise shares in IEA STEPS (Stated Policies Scenario). Finally, the share of coal is reduced for economies who have pledged to phase it out by 2050. Version 10 of the GTAP Data Base (2014), aggregated to 23 regions and 27 sectors, is projected to 2030. [Table A.2](#) displays the aggregation of regions. The simulations are conducted for 23 regions, whereas the results are presented for 10 aggregate regions.

We analyse the impact of carbon pricing with support in a counterfactual policy scenario relative to this baseline. The model employed to conduct the analysis, the WTO Global Trade Model extended with energy, emissions, and electricity modules, is described in detail in [Bekkers and Cariola \(2022\)](#) and [Aguiar et al. \(2019\)](#).

3.2 Implications of the formula for price dispersion and the allocation of support

3.2.1 The framework implies significant dispersion of carbon prices between regions with commensurate variation in emission reductions

[Table 2](#) displays the reductions in emissions implied by the framework according to the simulations in a setting with 27% and 48% reduction in emissions in 2030 relative to 2019, both with and without support. The table shows that the reduction in emissions implied by the framework displays a large degree of variation and is even positive for some regions. The reason is that some regions display high projected GDP growth in the baseline and the relatively low carbon price does not compensate for the increase in emissions because of the high GDP growth.

3.2.2 Support is allocated on net to low-income regions

[Table 3](#) displays the various ingredients for support in equations 2 - 4 to cope with the economic costs of climate change. The first column shows the share of income paid into the fund. For each region, this constitutes 20% of total carbon pricing revenues. Therefore, regions collecting relatively more carbon pricing revenues will pay more for support. Payment to the fund is larger in regions with a higher carbon price and in regions consuming more fossil fuels since these regions have a larger tax base.

The second column shows the support received as a per cent of GDP. The funds received are a function of the support share (in columns 3 and 4 displayed relatively to the population share and the GDP share of each economy in total population and total GDP, respectively). The support share relative to the GDP share is larger in low-income regions and smaller in high-income regions. This implies that the funds received as a per cent of GDP are also larger in low-income regions.

Table 2: The implied emission reductions under different scenarios

Region	27%, support	48%, support	27%, no support	48%, no support
CEA	-27.15	-47.51	-26.99	-46.81
EAS	-39.92	-61.84	-39.67	-61.52
EUR	-32.05	-49.62	-31.93	-49.38
LAC	-14.08	-32.68	-14.26	-32.98
MIN	0.33	-16.87	0.06	-17.12
NAM	-45.83	-64.29	-45.60	-63.95
OAS	16.46	-12.39	15.93	-13.60
OCE	-52.26	-69.94	-52.19	-69.89
SEA	-9.60	-27.23	-10.02	-28.02
SSA	-6.37	-16.69	-8.94	-22.77
GLOB	-27.42	-47.88	-27.42	-47.94

Source: Calculated based on own simulation

Notes: The table shows the regional emission reductions relative to 2019 by 2030 (left panel) and the regional carbon price in USD terms (right panel). In both panels, the first column shows results for the benchmark scenario with support, reaching 27% emission reductions globally by 2030 relative to 2019. The second column shows results for the scenario with support, reaching 48% emission reductions globally by 2030 relative to 2019. The third column shows results in the scenario without support, reaching 27% emission reductions globally by 2030 relative to 2019. The fourth column shows results in the scenario without support, reaching 48% emission reductions globally by 2030 relative to 2019. The world-level carbon price is calculated by taking the emission-weighted average of the regional carbon prices.

Finally, the last column shows the net contribution relative to GDP. Most regions receive support on the net and the support is substantial for the lowest-income regions. The regions paying into the fund on the net are the high-income regions, the regions with a relatively carbon-intensive economy and the regions with a low projected cost of climate change.

Table 3: Support paid and received as a share of GDP

Region	Paid (% GDP)	Received (% GDP)	Received rel. to pop. share	Received rel. to GDP share	Received net (% GDP)
CEA	0.82	1.18	1.42	2.78	0.36
EAS	0.47	0.18	0.59	0.45	-0.28
EUR	0.30	0.13	1.19	0.32	-0.18
LAC	0.30	0.68	1.28	1.62	0.38
MIN	0.44	0.83	1.44	1.94	0.38
NAM	0.48	0.40	1.50	0.94	-0.08
OAS	0.29	1.10	0.59	2.63	0.81
OCE	0.40	0.51	6.40	1.20	0.10
SEA	0.39	1.25	1.41	2.96	0.86
SSA	0.11	4.03	1.20	9.21	3.92

Source: Calculated based on own simulation

Notes: The table shows the amount of money paid for and received from support as a share of GDP. The first column shows the funds paid by the region as a percentage of the region's GDP. The second column shows the funds received as a percentage of the region's GDP. The third column shows the share of funds received by a region relative to the population share of the region in world population. The fourth column shows the funds received by a region relative to the GDP share of the region in world GDP. The fifth column shows the net amount of support received as a percentage of the economy's GDP.

3.3 Four main simulation results

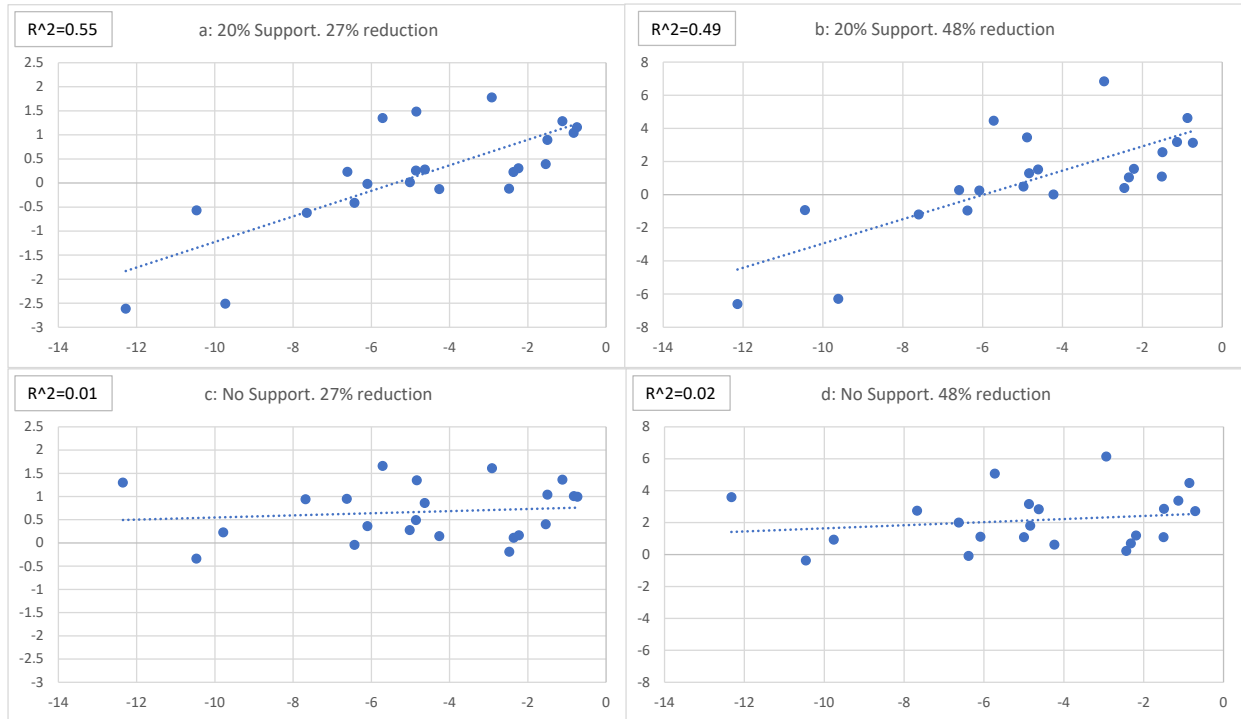
Simulations are conducted with the GTM to evaluate the ability of the formula to keep climate ambition in line with the Paris Agreement while establishing a tight link between the economic costs of carbon pricing and the economy-level criteria. We highlight four main simulation results: (1) on the relation between economic costs and the economy-level criteria; (2) on the effects of including support; (3) on the comparison of the formula based on different criteria; and (4) on the relation between the level of the carbon price and the competitiveness of EITEs.

3.3.1 With support the economic costs of carbon pricing are in proportion to the criteria HC, CD, and CCC

Figure 1 displays the relation between the economic costs of carbon pricing as a function of the economy-level criteria for the costs of climate change mitigation (the historical contribution to emissions, the current level of development, and the costs of climate change). The economic costs are measured by the cumulative negative real income effects in 2030 relative to a baseline without carbon pricing. The figure shows that without support (lower panels) the relation between the economic costs and the economy-level criteria is very weak with the economic costs for the different regions varying randomly between regions. Adding support (upper panels) changes the picture and leads to a positive relation between the economic costs of carbon pricing and the economy-level criteria. The relation is not perfect with some regions paying a higher economic cost than the economy-level criteria would require, in par-

ticular the fossil fuel producing regions.²³ On the other hand, some fossil fuel importers are below the trend line and are paying an economic cost lower than the economy-level criteria would require, whereas also the lowest income regions are below the trend line.

Figure 1: Relationship between $\log(\text{HC.CD.rCCC})$ and the economic costs with different calibrations of benchmark scenario to reach 27% and 48% reduction in emissions by 2030

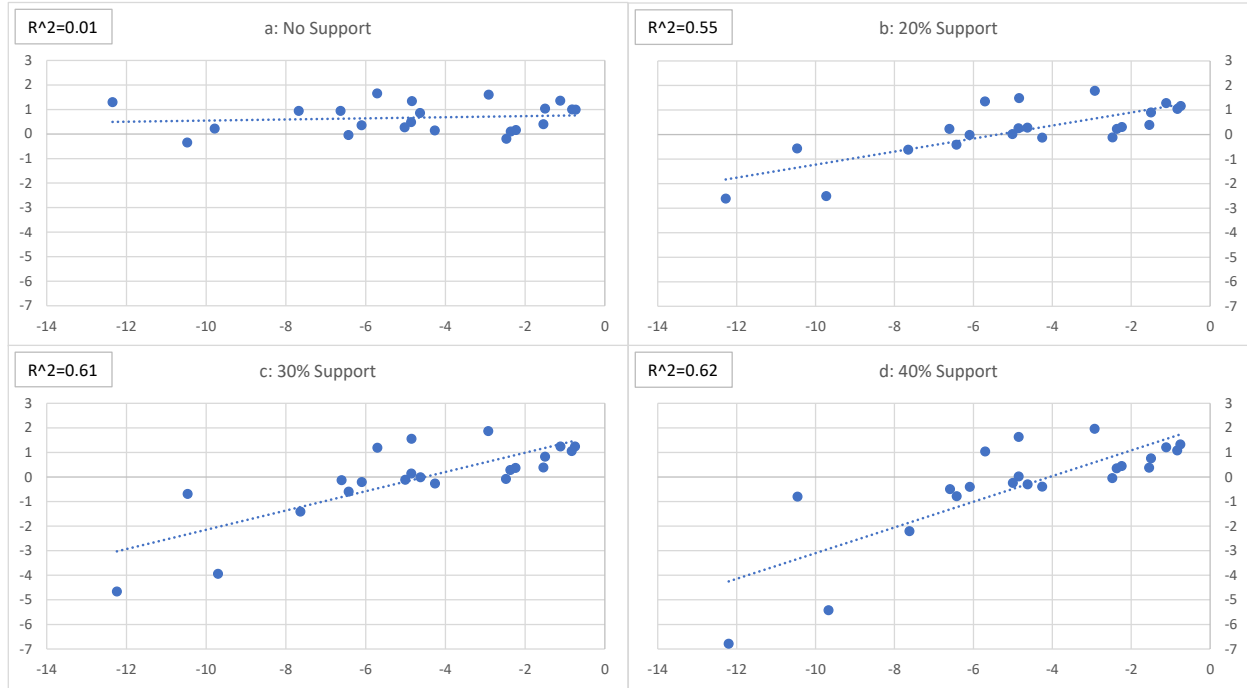


Source: Calculated based on own simulations.

Notes: The figure shows the relationship between $\log(\text{HC.CD.rCCC})$ and the economic costs with different calibrations of benchmark scenario to reach 27% and 48% reduction in emissions by 2030. The horizontal axis (X-axis) denotes $\log(\text{HC.CD.rCCC})$ and the vertical axis (y-axis) reports the economic cost. The benchmark scenario refers to the use of the formulas in equations (1) – (4). Emission reduction is calculated relative to 2019.

The right panel shows that economic costs of a reduction of emissions by 48% relative to 2019, required to stay on a path of 1.5 degrees global warming. The economic costs are much higher, but the positive relationship between the economy-level criteria and the economic costs stays in place, as well as the position of most economies relative to the trend line, once support is provided to regions.

Figure 2: Relationship between $\text{Log}(\text{HC.CD.rCCC})$ and the economic cost with different levels of support, for 23 GTAP regions considered



Source: Calculated based on own simulations.

Notes: The figure shows the relationship between $\text{Log}(\text{HC.CD.rCCC})$ and the economic cost with different levels of support, for 23 GTAP regions considered. The horizontal axis denotes $\text{log}(\text{HC.CD.rCCC})$ and vertical axis reports the economic cost. For panels a,b,c and d, we have: Carbon Price = $(\text{HC.CD.rAI.rCCCP})^\alpha$, with $\alpha = \frac{1}{4}$. If present, support is calculated proportional to Population share, CCC and AI. All scenarios realize 27% reduction in emissions by 2030. R2 is calculated for the regression of the income effects or economic cost on the log of economy-level criteria (HC.CD.CCC). A higher R2 indicates a better fit.

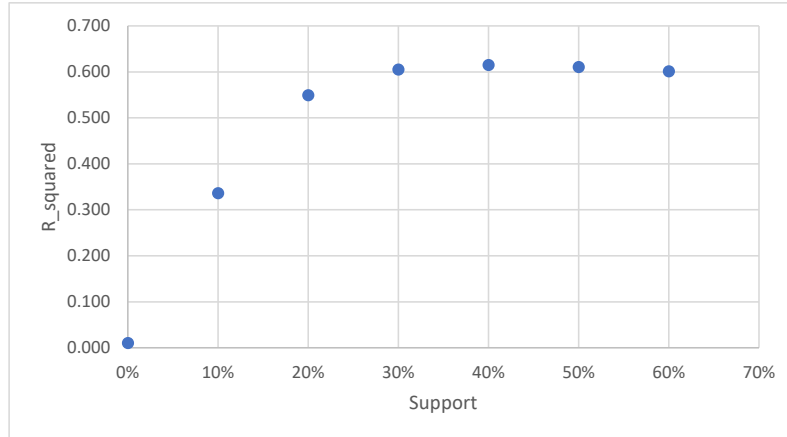
3.3.2 Allocating 20% of carbon revenues to support adversely affected economies is sufficient to align economic costs to the economy-level criteria

Figure 2 displays the relationship between economic costs and the economy-level criteria for various levels of support. To ensure a positive relation between the economy-level criteria and support, it suffices to allocate a moderate share of carbon price revenues to support. The relation between the economic costs and the economy-level criteria is very similar for 20% and 30% support.

Figure 3 shows that a rising share of carbon pricing revenues allocated to support initially improves the fit of the relationship between the economic costs of carbon pricing and the

²³The framework is not designed to generate a perfect fit between the economy-level criteria and the economic costs of carbon pricing. This would require a menu of region specific prices and net support levels instead of a fixed formula for the carbon price and support based on economy-level criteria. The downside of such an approach is that prices would vary depending on the economic model employed whereas under the current framework the formula is determined based on objective criteria.

Figure 3: R^2 values from a regression of the projected economic costs on the log of the economy-level criteria for varying shares of carbon pricing revenues allocated to support



Source: Calculated based on own simulations.

Notes: The figure shows the relationship between the share of carbon pricing revenues allocated to support and the R^2 of a regression of the economic cost (Y axis) on the log of economy-level criteria, $\log(\text{HC.CD.rCCC})$ (X axis). All scenarios achieve 27% reduction in emission

economy-level criteria. However, beyond a threshold, a further increase in support does not raise the fit anymore with the value of R^2 peaking at a share of 40% allocated to support.

The evolution of R^2 in Figure 3 can be explained by the variation in the size of the net contribution into the fund between regions in Table 3. Regions which are net receivers from the fund are also projected to incur economic gains under the framework and have lower economy-level criteria (Figure 2). On the other hand, regions with higher economy-level criteria contribute on net to support. As the share of support is increased, the large net receivers move further down in Figure 3, thus facing lower economic costs whereas the small net contributors move further up, facing higher economic costs. This leads to an immediate improvement in the fit of the line, which continues until a certain threshold. Beyond the threshold, the fit starts to decline because the economic costs faced by the low-income regions have been compensated. Instead, the projected economic gains for these economies would become larger than the trendline determined by the economy-level criteria. Hence, the R^2 stagnates and even starts falling.

Overall, there is a trade-off between providing higher levels of support to get a tighter link between economic costs of carbon pricing and the economy-level criteria and keeping a sufficient share of carbon tax revenues in the economy where they are raised to compensate socioeconomic groups for the adverse income effects of carbon pricing (as discussed in Section 2). Therefore, 20% seems the optimal share of revenues to be used for international support as it strikes a good balance between a strong relation between the economic costs of carbon

pricing and the economy-level criteria on the one hand, and sufficient funds to compensate groups within economies for the adverse effects of carbon pricing on the other hand.

The framework is not designed to generate a perfect fit between the economy-level criteria and the economic costs of carbon pricing. This would require a menu of region specific prices and net support levels instead of a fixed formula for the carbon price and support based on economy-level criteria. The downside of such an approach is that prices would vary depending on the economic model employed whereas under the current framework the formula is determined based on objective criteria. In this light the addition of the adverse impact of climate change as a criterion should be understood. This criterion is instrumental in bringing the costs of carbon pricing more in line with the economy level criteria.

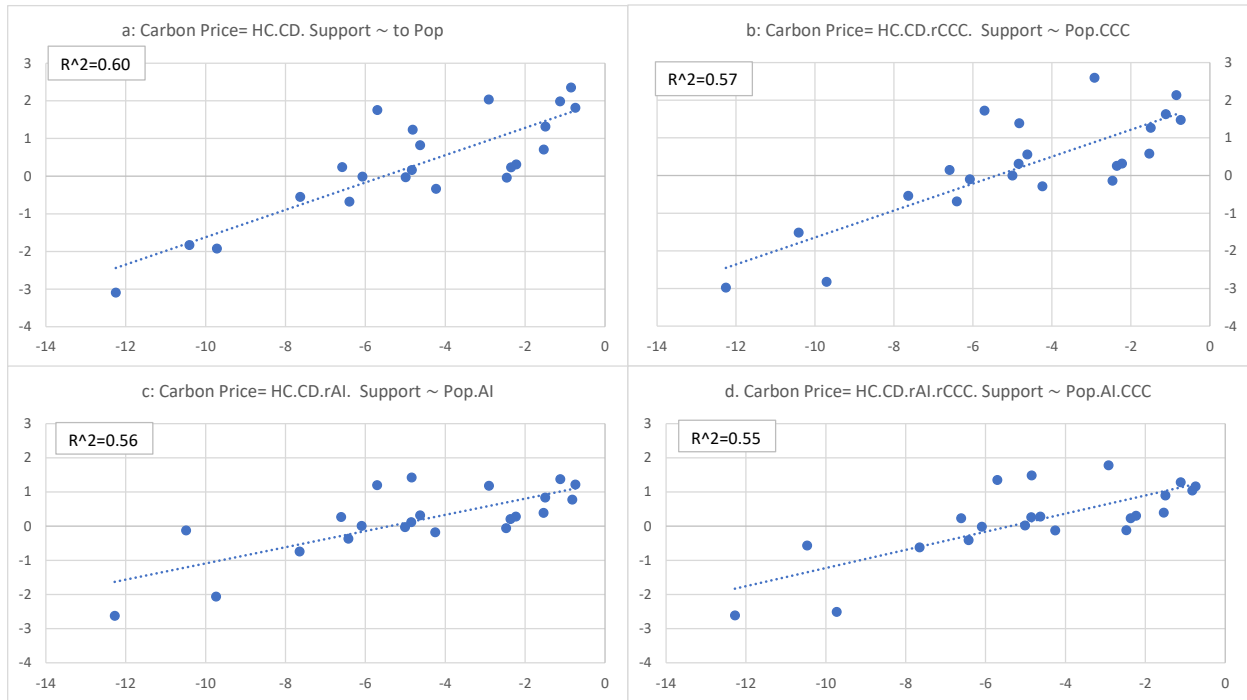
3.3.3 Varying the ingredients of the carbon pricing formula and the level of support shows that the benchmark framework aligns with the economy-level criteria

In this section, we analyse the role of the different economy-level criteria in the formula for the carbon price and for support. [Figure 4](#) shows the impact of varying the criteria in the formula for the carbon price and support. In the upper left figure, the carbon price is only determined by historical contribution (HC) and current level of development (CD), and support is based only on the population share implying equal per capita support. This setting generates a good fit for the relation between the economic costs of carbon pricing and the economy-level criteria with an R^2 of 0.6.

In the upper right figure, the cost of climate change (CCC) is added as a criterion in the formula for the price and support. By doing so, the R^2 is slightly reduced, although it continues to be above 0.5. Comparing the results of this variant with the benchmark (bottom right graph), we see that although the R^2 values are similar, the size of the losses and gains for some economies differ. In particular, fossil fuel exporting economies (FFECs) face larger economic losses when AI is not included. To improve the fit for the FFECs outliers we include the adverse impact, which is calculated as previously described and designed to reduce adverse economic costs for regions with the largest costs. The addition of AI in the bottom left graph doesn't change the R^2 much but does reduce the economic costs for some of the FFECs. Hence, the comparison in [Figure 4](#) shows the importance of including AI to address the special situation of FFEC. These economies have typically a close link between fossil fuel export revenues and economic growth.

In addition to the above, we conduct a thorough sensitivity analysis by generating all possible combinations of these ingredients to isolate and understand the impact of each upon the economic costs of carbon pricing. The complete panel with all these graphs is present in

Figure 4: Relationship between $\log(\text{HC.CD.rCCC})$ and the economic cost with different types of carbon price and support formulas



Source: Own Calculations.

Notes: The figure is showing the relationship between $\log(\text{HC.CD.rCCC})$ (X axis) and the economic cost (Y axis) with different types of carbon price and support formulas. 27% reduction in emissions by 2030 relative to 2019 is ensured in each of these scenarios.

Annex B. The overall conclusion that can be drawn from all the sensitivity tests is similar to the one discussed above. The addition of AI in the carbon price formula helps bring the outliers closer to the line but does not improve the R2. The addition of both ingredients in support only leads to marginal improvements and does not affect the R2 significantly either.

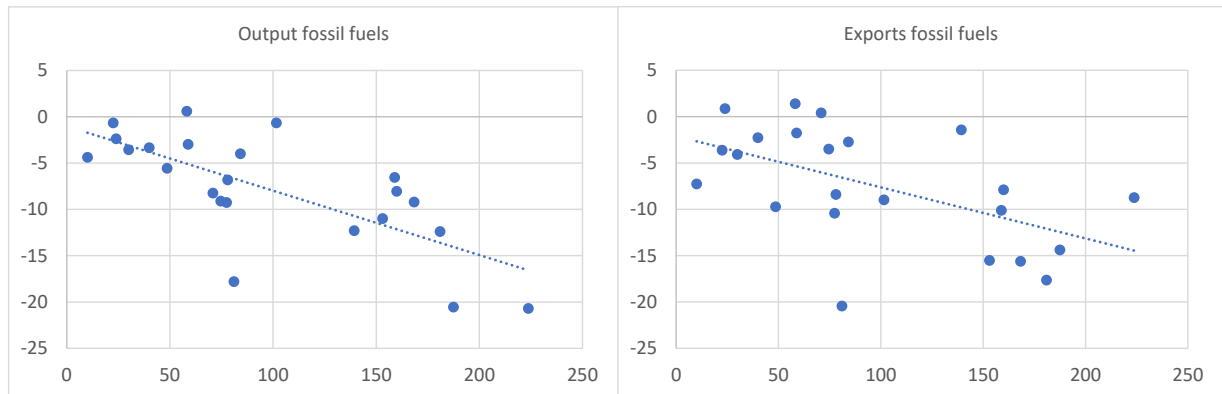
In sum, the simulation results presented in this section show that a more parsimonious formula with only *HC* and *CD* in the formula for the carbon price and support allocated in proportion to population share performs as well in bringing the economic costs of carbon pricing in line with the economy-level criteria. This formulation can be a good alternative in case of concerns about the measurement of other economy-level criteria such as CCC and AI.

3.3.4 Although regions with a higher carbon price face larger reductions in fossil fuel production, emission intensive sectors do not suffer larger losses

Figure 5 shows the projected percentage change in real production and real exports in the fossil fuel sectors (oil, gas and coal) by the year 2030, correlated with the cumulative increase

in fossil fuel prices. The figure clearly demonstrates that regions implementing a higher carbon price experience more substantial reductions in fossil fuel production and exports, as expected. This outcome can be attributed to a shift towards renewable energy sources and a decrease in overall fossil fuel production, both of which are influenced by the higher carbon pricing mechanism.

Figure 5: Relationship between carbon price and changes in output and exports for the fossil fuel sector, comparing benchmark GCPF with baseline (2030)



Source: Own Simulations.

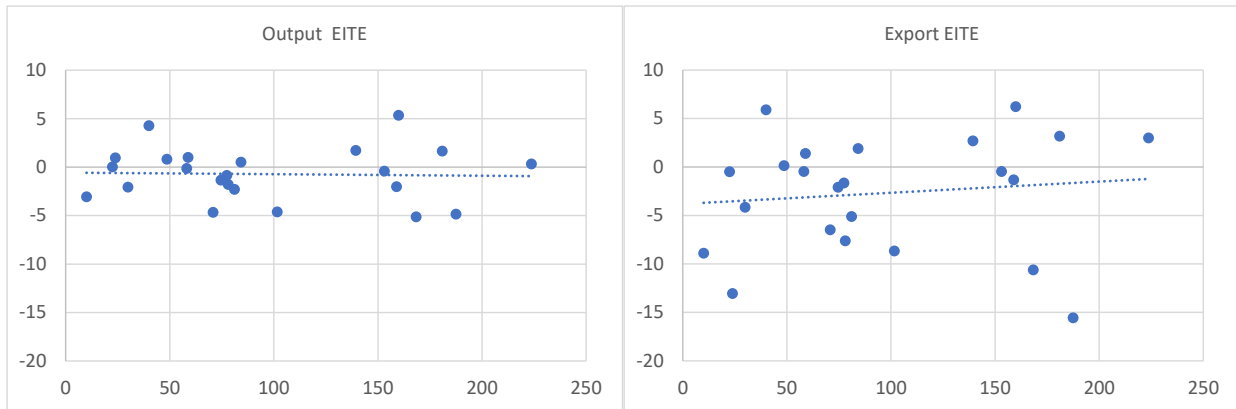
Notes: Left figure shows the relationship between the carbon price (X axis) and the change in the fossil fuel production (Y axis) by 2030, relative to the baseline scenario without carbon pricing. Right figure shows the relationship between the carbon price (X axis) and the change in the fossil fuel exports (Y axis) by 2030, relative to the baseline scenario without carbon pricing.

Figure 6 shows the projected percentage change in real production and real exports in the emission-intensive trade-exposed sectors (EITEs) at an aggregated level. The overall picture in these sectors is different. Notably, there is no clear correlation in the figure between the reduction in output within these sectors and the magnitude of the carbon price. In the case of exports, the relationship is even slightly positive. This would indicate that the concern that regions implementing higher carbon prices would experience a more pronounced decline in EITEs production is not substantiated by the simulations when support is considered. The figures suggest that most regions are expected to witness a decline in both production and exports in EITEs, irrespective of the level of the carbon price introduced.

An important factor contributing to this unexpected finding is the influx of funds into some regions as a result of support. Support increases the demand for the factors of production like labour and capital in recipient regions. Consequently, these regions experience reduced competitiveness in their exports—a phenomenon akin to the Dutch Disease effect. Hence, the existence of support would mitigate the exposure of EITE sectors to competitiveness losses for regions with higher prices.

Indeed, Figure 7 reveals that in the absence of support, there is a negative relationship

Figure 6: Relationship between carbon price and change in output and exports for the EITE sector, comparing benchmark GCPF with baseline (2030).

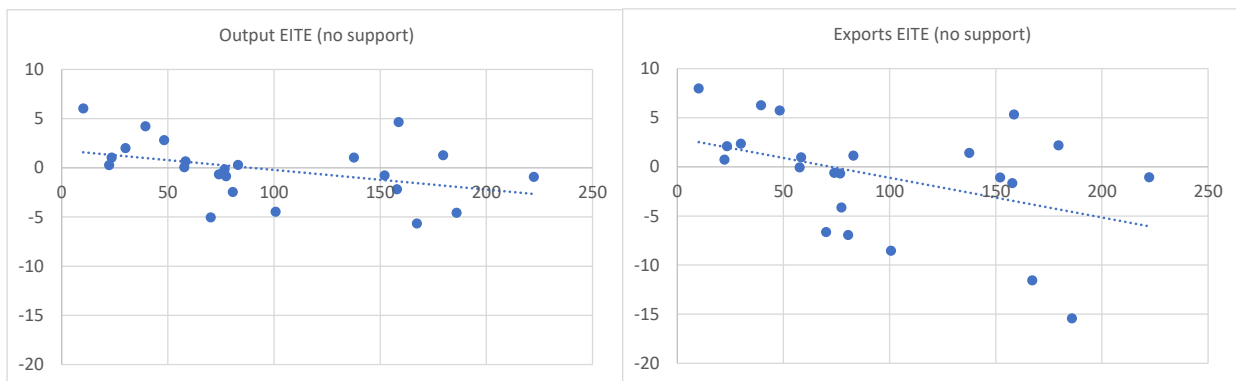


Source: Own Simulations.

Notes: Left figure shows the relationship between the carbon price (X axis) and the change in the EITE production (Y axis) by 2030, relative to the baseline, in the benchmark scenario with support. Right figure shows the relationship between the carbon price (X axis) and the change in the EITE exports (Y axis) by 2030, relative to the baseline, in the benchmark scenario with support.

between the carbon price level and the change in EITE exports or production. However, the negative relationship is still relatively modest. On average (according to the trend line), moving from the region with the lowest to the highest carbon price, the projected modification in exports changes from +2% to -5%.²⁴

Figure 7: Relationship between carbon price and changes in production and exports, for the EITE sector, in the scenario without support.



Source: Own Simulations.

Notes: The left figure shows the relationship between the carbon price (X axis) and the change in the EITE production (Y axis) by 2030, relative to the baseline, in the scenario without support. Right figure is showing the relationship between the carbon price (X axis) and the change in the EITE exports (Y axis) by 2030, relative to the baseline, in the scenario without support.

²⁴Other possible drivers of the link between the carbon price and the change in EITE production and exports are analysed econometrically in Annex A.

A potential concern is that the relation between the carbon price and the projected loss of output/exports may vary among the specific sectors within the EITEs, such as chemicals and iron and steel. [Annex B](#) analyses the relationship for 5 disaggregated EITE sectors in the framework with support. Although EITEs on average do not have a negative relationship between the level of the carbon price and the changes in output/exports, there are specific sectors, such as non-metallic minerals and paper products, where this negative association is observed on the output side. However, for the other sectors, as well as for changes in exports, this negative correlation is not evident.

3.4 Additional simulation results

In this section we first analyse the robustness of the simulation results by considering the introduction of border carbon adjustments (BCAs) in conjunction with the framework. Furthermore, we explore how the global carbon pricing framework could be implemented in combination with emission trading.

3.4.1 Adding multiple BCAs would contribute little to reduce global emissions

The benchmark simulation leading to 27% reductions in emissions incorporates varying levels of carbon prices across regions. Two types of border carbon adjustment mechanisms are simulated to analyse the effect of such policies on regional emission reductions and competitiveness in the emission-intensive trade-exposed industries.

In [Table 4](#), the first column shows the changes in emissions from 2019 to 2030 in the benchmark scenario and the second column shows the changes in emissions in a scenario where economies impose a BCA duty on the imports originating from regions with lower carbon prices. The third column shows the changes in emissions in a scenario where economies impose a BCA duty on imports originating from regions with lower carbon prices, as well as give rebates to domestic exporters, selling to regions with lower carbon prices. The results show that border adjustments make a modest contribution to the reductions in global emissions. Emissions are projected to fall with 27.7% in the two BCA scenarios, compared with a 27.4 per cent reduction in global emissions in the benchmark.

Border adjustments are typically targeted towards preventing “carbon leakage”, i.e., the relocation of emission-intensive industries from regions with high carbon prices to regions with low carbon prices, resulting in global increase in carbon emissions. [Table 4](#) shows that under the two BCA scenarios, emission reductions in some of the high carbon pricing regions are marginally lower in absolute terms relative to the benchmark scenario. Similarly, emission reductions in some of the lower carbon pricing regions are larger in absolute terms

Table 4: Emission Reductions Relative to 2019 comparing the benchmark GCPF with the GCPF with BCA added

Region	Benchmark, 27%	BCA imports	full BCA
CEA	-27.15	-28.25	-28.15
EAS	-39.92	-39.88	-39.86
EUR	-32.05	-31.62	-31.44
LAC	-14.08	-14.13	-14.01
MIN	0.33	-0.58	-0.69
NAM	-45.83	-45.73	-45.70
OAS	16.46	15.21	14.91
OCE	-52.26	-52.11	-51.73
SEA	-9.60	-9.88	-10.02
SSA	-6.37	-8.56	-8.59
GLOB	-27.42	-27.69	-27.68

Source: Based on our own calculations.

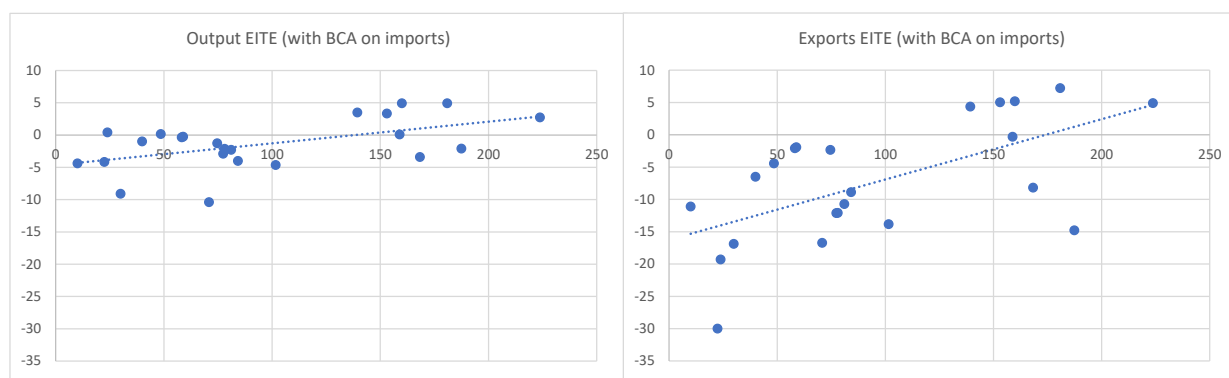
Notes: The table shows the regional emission reductions by 2030 relative to 2019. The first column shows results for the benchmark scenario with support, achieving 27% reductions in global emissions. The second column shows results for the benchmark scenario with border carbon adjustments on imports implemented by all regions against other regions with lower carbon prices. The third column shows results for the benchmark scenario with full border carbon adjustments (i.e., on the import and export side) implemented by all regions against other regions with lower carbon prices.

in the BCA scenarios relative to the benchmark scenario. Moreover, for regions with rising emissions in the benchmark scenario, the increase is limited in the BCA scenarios.

3.4.2 BCAs combined with the framework lead to a shift in competitiveness in the emission-intensive trade-exposed sectors to regions setting a higher carbon price

Figure 8 depicts the relationship between the carbon price and the projected change in production and exports in EITEs in the benchmark scenario extended with import-only BCAs. Compared to similar figures without BCA in Figure 6, the relationship between the carbon pricing level and the projected change in EITE exports turns from flat to positive when adding BCA. This means that adding BCA to the framework would lead to a loss of competitiveness in the EITE sectors for regions with lower carbon prices, i.e., regions with a lower level of historical emissions, level of development, and higher costs of climate change. Hence, whereas Figure 6 showed that BCA does not seem to be necessary to insulate EITE sectors in regions with high carbon prices from competitiveness losses, Figure 8 shows that adding BCA reverses the pattern and generates competitiveness losses for regions with lower carbon prices.

Figure 8: Relationship between the carbon price and change in EITE exports



Source: Calculated based on own simulations.

Notes: The left panel shows the relationship between the carbon price (X axis) and the change in EITE exports (Y axis) by 2030, relative to the baseline in a scenario with import only BCA. The right panel shows the relationship between the carbon price (X axis) and the change in EITE exports (Y axis) by 2030, relative to the baseline in a scenario with full BCA.

3.4.3 BCAs could be combined with the framework in different ways

There are three reasons for differences in carbon prices under the framework. First, economies set different prices depending on the criteria in the formula. For example, economies with a lower current development and historical contribution, and higher costs of climate change set higher prices. Second, economies can employ instruments equivalent to pricing to reduce emissions, which would lead to lower or no levels of explicit carbon prices. Third, if some economies do not follow the framework, they could have lower or no carbon prices.

Such (explicit) price differences could lead to competitiveness concerns and relocation of production from high to low carbon pricing regions in particular in EITEs. Even though the dynamic nature of the framework and the presence of support limit such production relocation to some extent, there is still a question of how to deal with differences in (explicit) carbon prices and whether to introduce some form of BCA.

In determining how to deal with differences in carbon prices and whether to introduce BCA, a decision hinges on the importance of two guiding policy elements: concerns of level playing field and those related to the situation of low-income regions. The first underscores the importance that firms face comparable costs and/or requirements imposed by governments in terms of level of the carbon mitigation costs. The second emphasizes that different jurisdictions introduce different carbon mitigation requirements depending on their responsibility to address a global problem.

3.4.4 The framework can also be implemented with global emissions trading

The benchmark scenarios, with and without support, are extended to include two supplementary scenarios aimed at simulating a global emission trading system. In a global emission trading system, all regions are allowed to buy and sell emission permits resulting in a unified global carbon price. Consequently, there is no longer a variation in carbon prices between regions. However, the magnitude of emission reductions is equivalent to those specified in the benchmark framework. Within this global emission trading system, regions buy and sell emission permits such that the global emission reduction of 27% by 2030 relative to 2019 is realized.

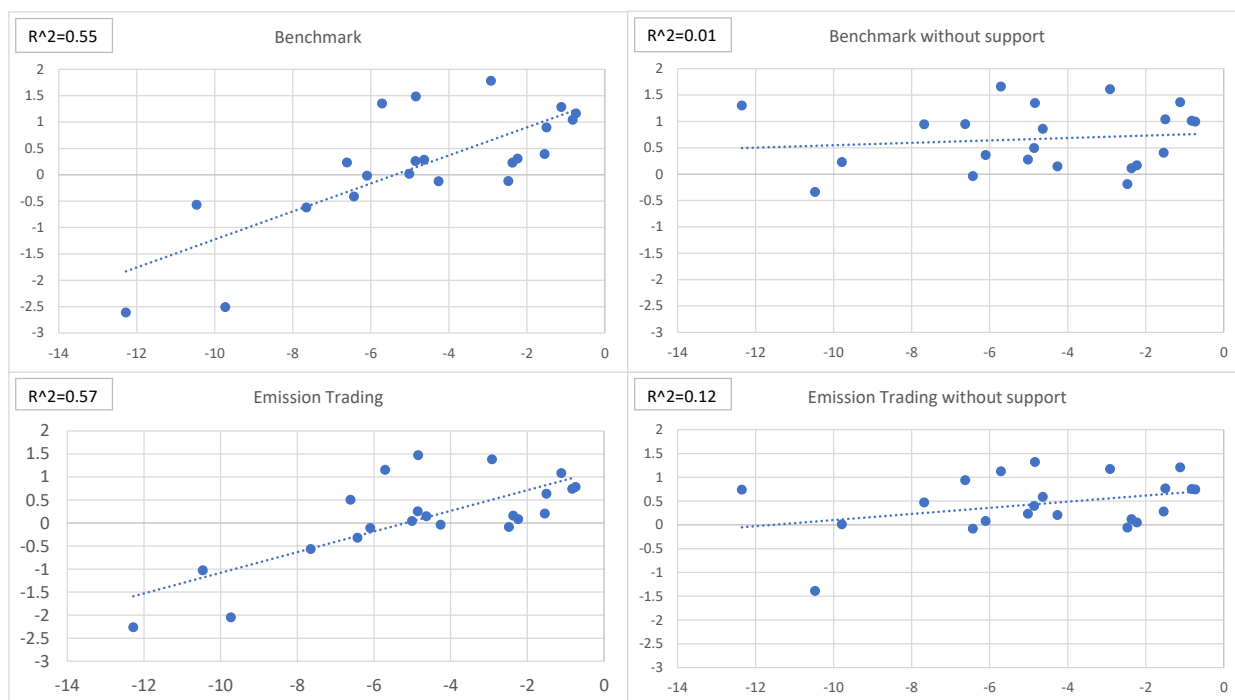
In the first emission trading scenario, no additional support is allocated. In the second scenario, support is introduced to the global emission trading system in line with benchmark scenario: 20% of the carbon pricing revenues are distributed based on population share, CCC and AI. Crucial is that in both scenarios, regions would have the same emission reduction targets as in the benchmark model. In this setting the economy-level criteria play the same role as in the benchmark model: regions with higher historical emissions, for example, would be required to reduce emissions by a more substantial amount, necessitating either a higher reduction in emissions than other regions or the purchase of more emission permits from other regions.

Figure 9 displays the relationship between economic costs and the economy-level criteria in the benchmark scenarios (upper panels) and in the emission trading scenarios (lower panels), both with 20% support and without support. Comparing the benchmark scenario with support and the emission trading scenario with support (left panel in Figure 9) shows that in both simulations, there is a significant relation between the economic costs and the economy-level criteria. The R2 of a linear regression of the economic costs on the log of economy-level criteria $\log(\text{HC.CD.rCCC})$ are similar.

Comparing the benchmark scenario without support and the emission trading scenario without support (lower right panel in Figure 9) shows that without support, a global emission trading system gives a better fit between the economic costs and the economy-level criteria.²⁵ However, the relationship is still weak. Hence, also under global emission trading, additional support seems necessary to bring the economic costs of carbon pricing in line with the economy-level criteria.

²⁵This finding is in line with Bekkers and Cariola (2022) who find that between different options to design global carbon pricing, emissions trading with a progressive distribution of emission rights performs best in model simulations to achieve the dual objective of an equitable outcome and incentivizing regions to participate in global carbon pricing. However, as discussed below emissions trading comes with other downsides related to practical implementation.

Figure 9: Relationship between economic costs and the economy-level criteria in the benchmark framework and under emission trading, with and without support



Source: Calculated based on own simulations.

Notes: The figure shows the relationship between the economic costs (Y axis) and $\log(\text{HC.CD.rCCC})$ (X axis). The top panel presents the benchmark scenario with and without support. In the benchmark scenario, the carbon price is determined based on HC, CD, rCCC and rAI. When support is present, it is calculated proportional to population share, CCC and AI. The bottom panel presents scenarios in which global emission trading occurs between regions, which determines a single carbon price as a market outcome. All scenarios achieve 27% global emission reductions in 2030 by 2019.

Table 5 displays the regional emission reductions in the benchmark scenario with 20% support (first column), with no support (second column), global emission trading without support (third column) and global emission trading with support (fourth column). By construction, all these scenarios lead to a 27% global reduction in emissions by 2030 relative to 2019. However, as can be seen from the table, the distribution of realized regional emission reductions is different. Under global emission trading, certain developing regions with high abatement potential (e.g., SSA) would realize higher emission reductions than in the benchmark scenario. In a similar vein, most of the high-income regions would realize lower emission reductions as they buy emission permits from other regions and emit more domestically.

Comparing carbon pricing levels at the global level, emissions trading yields a lower price level (US\$ 77) than the benchmark scenario (US\$ 94) to reach a global emission reduction of 27% (last row of Table 5). Under global emissions trading, more emissions would be reduced in developing economies with more abatement potential.

Table 5: Regional Emission Reductions Across Scenarios

	Benchmark, sup- port	Benchmark, no support	Emission trad- ing, no support	Emission trad- ing, support
CEA	-27.15	-26.99	-27.17	-27.17
EAS	-39.92	-39.67	-37.64	-37.77
EUR	-32.05	-31.93	-23.68	-23.66
LAC	-14.08	-14.26	-15.51	-15.31
MIN	0.33	0.06	-8.54	-8.53
NAM	-45.83	-45.6	-31.09	-31.09
OAS	16.46	15.93	-13.5	-13.68
OCE	-52.26	-52.19	-38.13	-38.03
SEA	-9.60	-10.02	-17.04	-16.72
SSA	-6.37	-8.94	-30.36	-28.6
GLOB	-27.42	-27.42	-27.42	-27.42
Global price	93.90	93.40	77.06	77.04

Source: Own calculations.

Notes: The table shows the regional emission reductions by 2030 relative to 2019. The first column shows results for the benchmark scenario with support, achieving 27% reductions in global emissions and carbon prices are determined based on the formula. The second column shows results for the benchmark scenario without support, achieving 27% reductions in global emissions by 2030 relative to 2019. The third column shows results for the global emission trading scenario without support, achieving 27% reductions in global emissions by 2030 relative to 2019. The fourth column shows results for the global emission trading scenario with support, achieving 27% reductions in global emissions by 2030 relative to 2019.

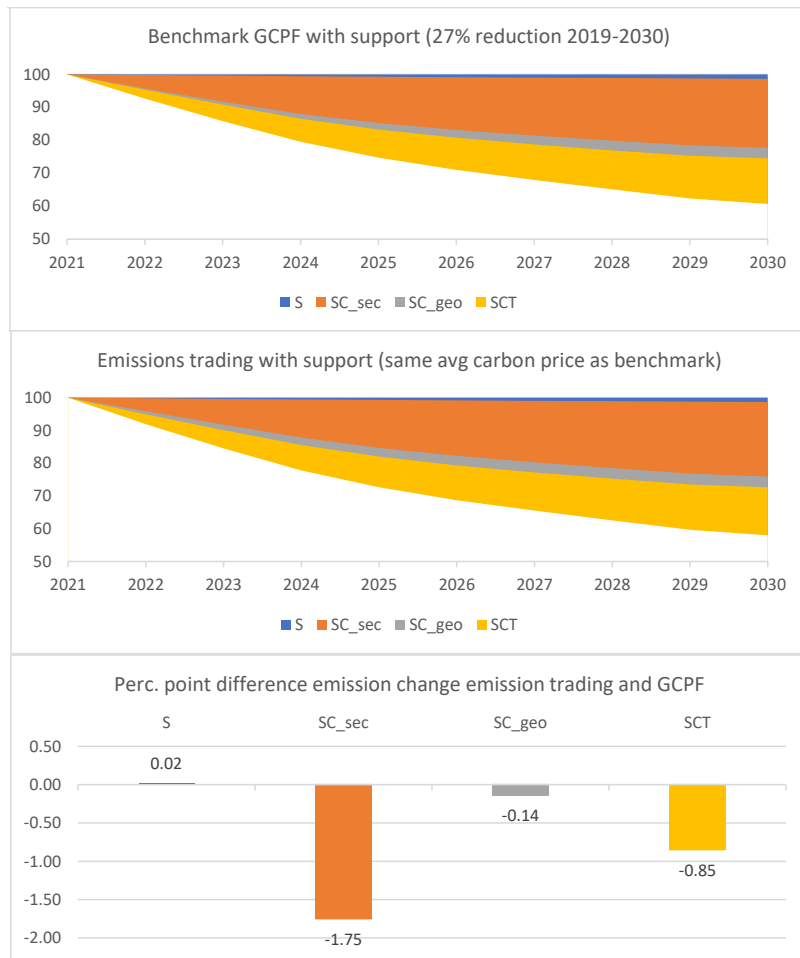
Comparing the emission reductions induced by the benchmark carbon pricing framework with the emission reductions under emissions trading, emissions trading is more efficient since a smaller average carbon price is needed to realise the same reduction in emissions. Alternatively, simulations with the GTM show that imposing the same (carbon-weighted) average carbon price under emissions trading would result in a larger emissions reduction of about 31%.

To explore what is driving the additional efficiency, the emission reductions are decomposed into a scale, composition, and technique effect as in [Copeland \(2021\)](#). The scale effect refers to emission changes due to changes in the level of production. The composition effect refers to emission changes because of changes in the sectoral composition of production. The technique effect refers to the changes in the emission intensity of production within sectors, either via changes in the amount of emissions for the same mix of intermediate and energy inputs or via changes in the mix of intermediate and energy inputs (for example from using oil, gas and coal as energy input towards using electricity generated from renewable energy as input). Following [Copeland \(2021\)](#) the three effects are added cumulatively in the decomposition calculations.

Furthermore, as in [Le Moigne et al. \(2023\)](#) we decompose the composition effect into sectoral (SC-sec) and geographic (SC-geo) composition effects. The sectoral composition effect

(SC-sec) is calculated as the change in emissions because of a global average change in the sectoral composition of production, whereas the geographic composition effect (SC-geo) includes the change in emissions due to changes in the sectoral composition of production in all regions. Since the effects are added cumulatively, the second composition effect calculates the contribution to emission changes because of changes in specialization between regions. In other words, while the scale, sectoral composition and technique effect can occur without international trade, the effect of the geographic composition effect is mainly due to international trade.

Figure 10: Decomposition of emission reductions into scale, composition (sectoral and geographic), and technique effects in benchmark GCPF and under emissions trading



Source: Own Calculations.

Notes: the upper and middle panels display the cumulative decomposition of the projected emissions reduction into a scale effect, sectoral composition, geographic composition, and technique effect for the benchmark GCPF (upper panel) and for emissions trading with the same average (carbon emissions weighted) carbon price as in the benchmark (middle panel). The lower panel shows the percentage point difference of the four effects between the emissions trading scenario with the same average carbon price and the benchmark GCPF.

Figure 10 presents the decomposition of emissions into the scale, sectoral composition, geo-

graphic composition, and technique effects. The upper left panel shows the decomposition for the benchmark carbon pricing framework and the middle panel for emissions trading realising the same average carbon price (94 USD) as the benchmark and thus generating a larger reduction in emissions (about 31%). The lower panel shows the percentage point difference of the four effects comparing the emissions trading scenario realising the same average carbon price and the benchmark GCPF.

The figure makes clear that a uniform carbon price generates additional emission reductions mainly through a larger reallocation towards less emission-intensive sectors (sectoral composition effect) and because production is organised using less emissions in production (technique effect), whereas the geographic composition effect plays a less important role. This seems to indicate that better exploiting economies' green comparative advantage as in [Le Moigne et al. \(2023\)](#) does not seem to play a big role in the additional emission reduction under a uniform price and that this channel is present both under a uniform and a heterogeneous price.

[Le Moigne et al. \(2023\)](#) proxy green comparative advantage, the allocation of emissions generating production according to economies' relative competitiveness in producing clean/green goods, with the geographic composition effect. Part of the sectoral composition and technique effect could reflect a reallocation of production since the reduced global demand for and use of coal for example are part of the sectoral composition and technique effect. Nevertheless, the additional emissions reductions from uniform pricing are relatively modest.

Although the simulations indicate that emission trading with a uniform carbon price is more efficient than a framework with heterogeneous prices, the literature has extensively discussed the downsides of emission trading ([Cramton et al., 2017](#)) presenting three arguments. (See also [Bekkers and Cariola \(2022\)](#)). First, quantity based approaches (cap-and-trade) generate large uncertainty for participating economies making them reluctant to agree in negotiations. Second, negotiations on emission targets might be complicated if first a global target is negotiated and then economy-level emission targets. If one economy does more in such a setting, i.e., sets more ambitious emission targets, other economies will do less. Therefore, each economy has an incentive to free-ride on the efforts of other regions. Third, the introduction of emissions trading is complicated in economies with a weak institutional environment. The fact that emission rights constitute a potentially large value implies a risk of rent-seeking and unfair distribution of the emission rights ([Cooper, 2015](#)).

Table 6: Static vs dynamic prices by 2030, \$ per ton of CO₂

Region	Static carbon price	Dynamic carbon price
CEA	82.11	79.59
EAS	91.47	92.25
EUR	169.89	156.65
LAC	80.81	75.74
MIN	45.55	46.19
NAM	216.14	200.14
OAS	27.04	27.7
OCE	198.25	187.45
SEA	53.82	54.88
SSA	25.62	24.40

Source: own calculations with the WTO Global Trade Model

Notes: the table shows the carbon price by 2030 under a static and dynamic carbon price.

3.4.5 The dynamic nature of the framework allows carbon prices to come closer in the long run

The framework is dynamic, implying that the ingredients of the carbon price are updated each period. In other words, historical contributions (HC), current development (CD), and adverse impacts (AI) change every period incorporating the changes in emissions and level of development in that period. For example, historical contribution computed in period t considers historical emissions from 1850 to the year t , whereas historical contribution computed at time $t+1$ considers historical emissions from 1850 to the year $t+1$.

[Table 6](#) compares the dynamic carbon prices with the static carbon prices, which would arise without dynamic adjustment (reporting regional averages). In the static experiment, the ingredients of the carbon price equation remain constant at their 2022 levels. The table shows that, moving from a static approach towards a dynamic approach, carbon prices for most high-pricing regions fall whereas carbon prices for many low-middle-pricing regions rise. The reason is that under the dynamic framework, the initially high levels of carbon prices lead to an adjustment of historical contribution and current development over time, accounting for the impact of carbon pricing on the economy. In contrast, in a static framework, the weights which multiply remain constant, leaving no room to adjust the determinants of the price with the changing levels of emissions and development.

Moreover, the dynamic nature of the framework would imply that, in the long run, the carbon price levels in economies of different income levels would come closer to each other, addressing partially the competitiveness and production relocation concerns. Economies that initially set lower prices due to their low historical contribution and low levels of development, will catch up in terms of emissions due to increased production and growth.

This can be seen in [Figure 11](#) and [Figure 12](#). [Figure 11](#) presents the per capita emission path-

ways in the benchmark scenario against a hypothetical scenario without carbon pricing.²⁶ The figure shows that per capita emissions will fall more for economies with higher prices (called economies with high weight according to the criteria) by 2030 under the benchmark scenario compared to a hypothetical scenario than for low-and-middle-weight economies. Moreover, given that the benchmark scenario uses historical emissions to determine the weight for the carbon price, the impact of the current period’s per capita emissions on the historical emissions is limited. Replacing historical emissions with current emissions could pace up the dynamic adjustment. In a similar vein, [Figure 12](#) shows that, under the benchmark scenario, the median value for the dynamic weights for high-weight economies falls over time, whereas the weights for low-and middle-weight economies increase. Therefore, the high-weight economies’ competitiveness and production relocation concerns for initially setting higher carbon prices will be alleviated in the long run.

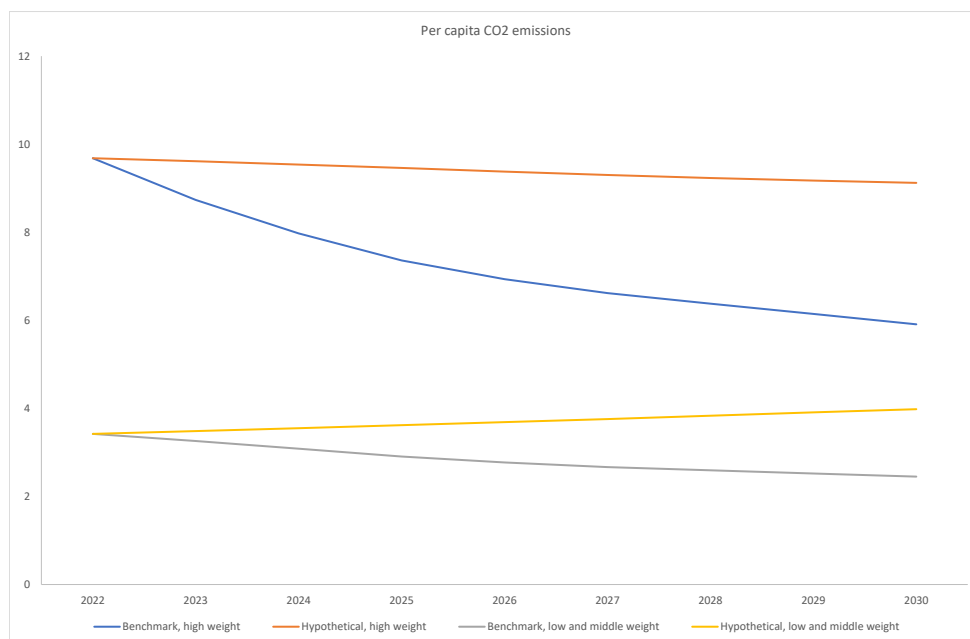
It must be noted that carbon prices will converge to a single price only if economies reach similar levels of development and historical contributions. Nonetheless, a potential middle-ground solution could involve initially setting differentiated prices and adjusting the prices based on levels of economic development and historical contribution. This approach strikes a balance between those advocating for a uniform price and those arguing in favour of heterogeneous prices.

In summary, there are three ways in which the framework could help inform discussions over competitiveness and production relocation concerns. First, carbon prices are computed dynamically and adjust over time. As low-pricing economies grow economically, there is a tendency for carbon prices in different regions to come closer to each other, although they do not converge by 2030 in our model. Second, if production relocates to regions with lower carbon prices, this increases production-related emissions in the host economy and thus drives up its carbon price. Third, the presence of support creates an inflow of funds towards the regions with lower carbon prices and drives up the factor prices, as explained in [Section 3.3.4](#)

The periodic update of the carbon prices in the dynamic scenario could also be timed to coincide with or be aligned to the periodic review process established by the Paris Agreement to take stock of the achievement of its objectives. Under this Agreement, parties are expected to periodically update their NDCs, demonstrating increasing levels of ambition to align their long-term development strategies with the Agreement’s aim of limiting warming to 1.5 – 2 degree Celsius. The “Global Stocktake” (Art. 14 of the Paris Agreement), mandated to take place for the first time in 2023 and every 5 years thereafter is meant to provide parties with

²⁶In the hypothetical scenario, ingredients of the carbon price follow their baseline pathways, isolated from the impact of carbon pricing on the economy. In addition, values for the follow the same levels as the benchmark simulation. Therefore, the hypothetical scenario serves as a no-carbon pricing baseline which is comparable to our benchmark simulation.

Figure 11: Per capita emissions under the benchmark and hypothetical simulations



Source: Calculated based on own simulations.

Notes: The figure shows the per capita emissions under the benchmark scenario for high and middle and low-weight regions and the hypothetical scenario with weights determined by a world without carbon pricing, also for high and middle and low weight regions.

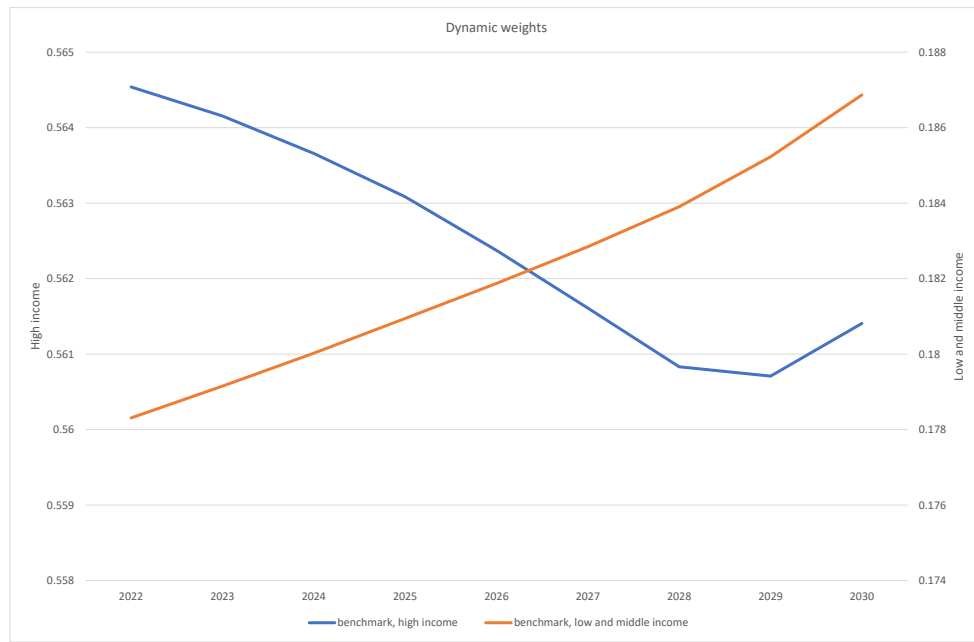
the opportunity to periodically take stock of their advancements and facilitate compliance with its long-term objectives.

4 Concluding remarks

In this paper a global carbon pricing framework is discussed, and its potential economic effects are explored: a global carbon price varying by economy as a function of a set of economy-level criteria rooted in with the principles of the Paris Agreement. These criteria include the historical contribution to GHG emissions, the current level of development, the adverse impact of climate change mitigation, and the economic costs of climate change. A concrete formula for the level of a carbon price is introduced, accompanied by the allocation of a share (20%) of carbon pricing revenues to support low-income regions, regions facing particularly adverse effects from climate change mitigation policies, and regions facing economic costs of climate change. The framework is flexible in its implementation, allowing economies to realize carbon emission reductions through alternative policy instruments achieving emission reductions equivalent to those attainable through the introduction of a carbon price based on the proposed formula.

Simulations are conducted with the WTO Global Trade Model to illustrate how the global

Figure 12: Evolution of per capita emissions in high-emissions and low-emissions economies



Source: Calculated based on own simulations.

Notes: The figure shows the per capita emissions under the benchmark scenario for high and middle and low weight regions and the hypothetical scenario with weights determined by a world without carbon pricing.

carbon pricing framework would result in changes of emissions, output and trade patterns. In an exercise with 23 regions, the level of the carbon price, the implied reduction in emissions, the amount of support and the economic costs of each region are calculated.

The analysis generates several insights: (i) in the framework with support, the economic costs of a global carbon price are distributed in line with the economy-level criteria.²⁷ Hence, regions with a larger ability to pay, with a larger historical contribution to pollution, and with lower economic costs from climate change will incur larger economic costs for decarbonisation. Furthermore, although without support the relation between investments in decarbonisation and the economy-level criteria is weak, a share (20%) of carbon tax revenues allocated to support is sufficient to make this relationship positive; (ii) the regions with a larger carbon price would not suffer larger economic declines as measured by real output and real exports in emissions-intensive trade-exposed sectors when support is allocated.

The framework is flexible in both the use of policy instruments and the inclusion of criteria in the carbon price and support. First, the framework is flexible in the instruments applied

²⁷The simulations do not consider co-benefits of climate change mitigation such as reductions in local pollution. Taking such benefits into account would lower the economic costs of climate change mitigation for individual economies. Furthermore, the long run benefits of climate change mitigation are not considered in the simulation. Rather, the simulations focus the short-run costs of taking action for economies individually, whereas the benefits occur in the long run and are global.

by regions to decarbonize the economy. Instead of introducing an explicit carbon price, the emission reduction implied by the carbon price of each region according to the formula and the simulations can be used as a target. Calculating the implied emission reductions of the carbon price in each of the regions implied by the formula with a suite of models and using the median emission reduction would solidify the approach to equivalence. Second, the framework is flexible in the choice of determinants to be included in the carbon price and the support function and the weights given to each of the determinants. Third, the framework is also flexible in the type of carbon pricing introduced since global emissions trading can be introduced instead of a carbon tax. Under such an approach each region would have an identical emission reduction target as under a carbon price according to the formula and regions would trade emission rights with each other. The global carbon price would be lower with emissions trading (77 USD vs 94 USD per ton of CO_2).²⁸ Comparing the decomposition of emission reductions under the benchmark framework and emissions trading shows that emissions fall more under the latter mainly because of a sectoral composition effect reflecting a global shift in production between sectors and a technique effect reflecting a shift in the employed sources of energy in production.

The framework differs from the IMF proposal for an international carbon price floor (ICPF) in three important ways. First, the level of the carbon price is underpinned by the objective to reach Paris Agreement temperature goals and economy-level criteria established in the international climate change cooperation framework, whereas the ICPF varies only by level of income with three different carbon price levels. Second, the proposed average carbon price is higher than under the ICPF (to stay on a path of 2 degrees global warming), but the economy-level criteria included imply more variation of carbon prices with low-income regions with smaller historical emissions displaying lower carbon prices and higher-income regions higher carbon prices. Third, under the global carbon pricing framework there is a more prominent role for support, allocating a share of carbon pricing revenues to low-income regions and regions with higher economic costs of climate change.

The results on emissions trading indicate that a uniform price together with emissions trading with emission reduction targets based on the emissions reductions implied by the heterogeneous prices under the framework is more efficient. It helps countries to better exploit their green comparative advantage, a process in which international trade plays an important

²⁸An important detail is that the framework implies targets for carbon prices from which emission reductions follow. In principle, an alternative framework could be designed by first setting regional emission reduction targets and then calculating the implied carbon prices. However, carbon price targets bring the economic costs more in line with the economy-level criteria because of the different abatement potentials across regions. In the case of emission targets, two regions with similar values of economy-level criteria would have the same emission targets. But these emission targets would lead to a lower carbon price level in the region with a higher abatement potential. Consequently, the economic costs in two regions with the same economy-level criteria would be different, because of differences in abatement potential.

role. Furthermore, the simulations comparing the economic costs of economies under the framework with and without support show that support is needed to bring the economic costs in line with the economy-level criteria, whereas the heterogeneity of the carbon prices contributes little to bring the economic costs in line with the economy-level criteria. Hence, the emissions trading version of the framework with a uniform price combined with support performs better both from an efficiency and a equity perspective. However, as discussed in the introduction a uniform price combined with emissions trading comes with a set of disadvantages. A uniform price combined with support suffers from a credibility problem if there is uncertainty about the extent to which support will be provided, because of political feasibility problems. Low-income regions would have to commit to a uniform price with support not being delivered yet. Furthermore, a system of emissions trading is difficult to negotiate ([Cramton et al., 2017](#)).

We conduct additional simulations to show the impact of possible BCA mechanisms. We find that the introduction of BCAs compensating for differences in carbon prices on top of the global carbon pricing framework would lead to a positive correlation between the level of the carbon price and projected output changes in EITE sectors, thus shifting competitiveness of EITE sectors from economies with a low carbon price to regions with a high carbon price. Furthermore, introducing BCA in addition to the global pricing framework would contribute only marginally to the reduction of emissions. The framework could constitute an alternative for a world with fragmented carbon pricing regimes accompanied by BCAs, although the framework can also go together with BCAs.

Introducing carbon pricing at a global scale also requires coordination in several important areas, including: (1) the measurement of effective carbon prices, reconciling implicit forms of carbon pricing (e.g., energy taxes and subsidies) and explicit forms of carbon pricing (e.g., carbon taxes and emission trading schemes); (2) the equivalence of carbon prices and alternative policies (e.g., regulation, subsidies, command-and-control); (3) more coherent approaches on the measurement and verification of the carbon content of trade; and (4) the comparison of spill-over effects of decarbonisation policies such as subsidies and regulations. Several international organisations, including the WTO, could play a pivotal role in coordinating efforts in these areas.

Future work could extend the analysis in this paper in the following ways. First, the costs of climate change adaptation can be included as a variable. Currently, the formula does not take into account the economic costs of “proactive” adaptation efforts such as those facilitating ecosystem shifts. Higher costs for these measures could also be a motivation to set lower carbon prices/provide more support for these areas. Second, the incentives to participate in the framework could be analysed, by calculating the payoffs in the case of participation and non-participation thus analysing the existence of a cooperative Nash equilibrium where

all economies would participate. Third, the model can be extended with innovation and technology spillovers between regions to compare different policies to realise a net zero world by 2050, i.e., introducing a uniform price focused on reducing emissions in regions with the largest emissions potential or a heterogeneous price with a larger price in more developed economies focused on the development and dissemination of emissions reducing technologies from technological leaders to other regions.

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Appendix A Additional background material

Appendix A.1 Data sources

Historical Contributions to emissions are obtained for the period 1850 – 2021, using two databases. Emissions until 2018 are obtained from the PRIMAP database, which has collected data on greenhouse gas emissions using economy specific reports (CRF, BUR, UNFCCC) as well as third party resources such as EDGAR, FAO, BP and CDIAC. We have used the January 2021 version as it uses the IPCC categorization for reporting of emissions which

helps us remove LULUCF²⁹ emissions. We have restricted our focus to data relating to CO₂ emissions only.³⁰ Uncertainty in carbon emission calculations has always been prevalent as also described by [Janssens-Maenhout et al. \(2019\)](#) who cite both the EDGAR and PRIMAP database in their paper on the trend of carbon emissions. Emissions for the years 2018 – 2021 are obtained from the EDGAR dataset, version 7 ([Crippa et al., 2022](#)). To ensure that these uncertainties are considered, we normalize the values before using them in the price formula, by dividing the per capita historical contribution of each region with the maximum value among all regions.

Population data from 1850 – 2019 are sourced from two databases. For the period 1850 – 2009 we use the Project Maddison data, and we append to it population data for 2009 – 2019 from the World Bank. Additionally, to fill in missing values, widely prevalent from 1850 – 1900, we use the inverse difference weights (idw) methodology of interpolating from future recorded values. This complete dataset is then used to convert all values of historical contribution as well as other ingredients into per capita terms.

Data on GDP in per capita terms starting from 2022 are projected using the WTO Global Trade Model, targeting IMF projections and OECD SSP projections.

The static economic costs of climate change (CCC) are calculated based on [Dellink et al. \(2019\)](#). They estimate a production function determining economic output and estimate a climate change function which is a function of the tonnes of carbon in the atmosphere. Then they model different effects of climate change and relate them to different variables in the production function representing the activity of a specific industry or group of industries in the basic structure of the model. The analysis is based on an assessment of a wide range of impacts gathered in two broad categories. The first includes impacts that affect the supply-side of the economic system, namely the quantity or productivity of primary factors. Land and capital destruction from sea level rise, crop productivity impacts in agriculture, and labour productivity impacts on human health belong to this category. And the second category includes demand side impacts (e.g., changes in tourism flows, changes in energy demand for cooling and heating, etc.). Then, the GDP losses projected by [Dellink et al. \(2019\)](#), for the different regions by 2060 are used as our basis to compute the per capita CCC.

In a robustness check CCC is calculated based on [Roson and Sartori \(2016\)](#), who compile various effects of climate change based on non-economic literature. Different categories of climate change effects – sea level rise, variation in crop yields, heat stress and labour

²⁹Land Use, Land use change and forestry related emissions

³⁰To this end, the source variable is HISTTP. Emissions from fossil fuels come from the related categories – IPC1, IPC2, IPC3, IPC4, IPC5. Data for the agricultural categories IPCM0EL, IPCMAG, IPCMAGELV are removed.

Table A.1: Export share, import share and emission intensity in fossil fuels' effect on economic costs.

Dependent Variables	(1)	(2)	(3)
RCA_FFL	1.991*** (0.400)	1.636*** (0.359)	1.476*** (0.320)
NIS_FFL		-1.428*** (0.470)	-1.308*** (0.414)
EL_FFL			0.823** (0.310)
Constant	0.768*** (0.169)	1.473*** (0.272)	1.141*** (0.269)
Observations	23	23	23
R-squared	0.541	0.686	0.771

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: Own calculations.

Notes: Regression results to determine the value of the AI variable based on the fitted values. Variables are constructed based on simulations using GTAP 10 database.

productivity, human health, tourism and domestic energy consumption – are translated into economic effects and aggregated to estimate the net change in GDP (Roson and Sartori, 2016).

The adverse impact of carbon pricing (AI) is calculated based on three variables – the normalized export share in fossil fuels (revealed comparative advantage in fossil fuels, RCA_FFL), the normalized emission intensity of production of fossil fuels (EI_FFL), and the normalized import share of fossil fuels (NIS_FFL). The data for these variables are acquired from the GTAP Data Base, Version 10. To determine AI, we employ the economic costs of carbon pricing, measured as income losses by 2030 (i.e., the negative of the real income effects) in a simulation that includes the economy-level criteria in the formula of the carbon price: the historical contribution, current level of development and the costs of climate change. These values for the economic costs are regressed on three determinants of AI, as specified below.

$$EC_{it} = \beta_1 RCA_FFL_{it} + \beta_2 EI_FFL_{it} + \beta_3 NIS_FFL_{it} + \epsilon_i \quad (A.1)$$

Table A.1 displays the regression results of this estimation (column 3), showing that about 80% of the variation in economic costs can be explained with the three variables. The fitted values from this regression are then normalized to vary between 0 and 1.

Both the variables CCC_i and AI_{it} are transformed such that the carbon price is negatively related to both variables, using the following steps. First, these variables are transformed

Table A.2: Aggregation of economies and regions in the simulations

Region	Description	Region used in analysis	GTAP region
CEA	Central Asia	Russian Federation; Rest of World	Russian Federation; Georgia; Belarus; Ukraine; Armenia; Rest of Europe; Kazakhstan; Rest of the World; Azerbaijan; Rest of Eastern Europe; Albania; Tajikistan; Rest of Former Soviet Union; Kyrgyz Republic
EAS	Eastern Asia	Korea, Republic of; Japan; China	Korea, Republic of; Japan; China
EUR	Europe	United Kingdom; EFTA; European Union	United Kingdom; Rest of EFTA; Switzerland; Norway; Belgium; Malta; France; Netherlands; Cyprus; Spain; Hungary; Germany; Poland; Czech Republic; Sweden; Slovak Republic; Bulgaria; Portugal; Austria; Denmark; Slovenia; Ireland; Luxembourg; Croatia; Latvia; Estonia; Italy; Finland; Lithuania; Romania; Greece
LAC	Latin America and the Caribbean	Latin America; Brazil;	Rest of Central America; Bolivia, Plurinational State of; Rest of South America; Puerto Rico; Honduras; Colombia; Costa Rica; Uruguay; Dominican Republic; Panama; Caribbean; Nicaragua; Chile; Venezuela, Bolivarian Republic of; Guatemala; Trinidad and Tobago; Argentina; Rest of North America; Ecuador; Paraguay; Peru; Jamaica; El Salvador; Brazil;
MIN	Middle East and Northern Africa	Türkiye; Middle East and Northern Africa	Türkiye; Jordan; Saudi Arabia, Kingdom of; Morocco; Israel; Egypt; Rest of Western Asia; Rest of North Africa; Kuwait, the State of; Iran, Islamic Republic of; United Arab Emirates; Bahrain, Kingdom of; Tunisia; Oman; Qatar
NAM	Northern America	United States of America; Mexico; Canada	United States of America; Mexico; Canada;
OAS	Other Asia	Other Asian economies; India; Asia LDC	Rest of Oceania; Hong Kong, China; Rest of South Asia; Sri Lanka; Chinese Taipei; New Zealand; Pakistan; Mongolia; Rest of East Asia; India; Nepal; Lao People's Democratic Republic; Rest of Southeast Asia; Cambodia; Bangladesh
OCE	Oceania	Australia	Australia;
SEA	Southeast Asia	Southeast Asia; Indonesia	Singapore; Brunei Darussalam; Malaysia; Viet Nam; Thailand; Philippines; Indonesia;
SSA	Sub-Saharan Africa	Sub-Saharan Africa LDC; Sub-Saharan Africa other	Ghana; Kenya; South Africa; Central Africa; Nigeria; Côte d'Ivoire; Rest of South African Customs; Cameroon; Namibia; Botswana; Senegal; Mauritius; Togo; South Central Africa; Madagascar; Mozambique; Zimbabwe; Burkina Faso; Ethiopia; Uganda; Benin; Rest of Eastern Africa; Tanzania; Rest of Western Africa; Guinea; Malawi; Zambia; Rwanda

into non-negative values by respecting the order of magnitude across regions.³¹ This step ensures that all values can be normalized at a later stage between 0 and 1. Note that negative values of CCC for regions like Canada and the Russian Federation signify that these regions are projected to benefit economically from increasing temperatures, due to factors like crop productivity increases according to the employed studies by [Dellink et al. \(2017\)](#) and [Roson and Sartori \(2016\)](#). Second, the sum of the maximum and minimum values of the non-negative variables is calculated. Third, the value of the non-negative variable is subtracted from this sum. Lastly, the resulting variable is normalized with respect to its maximum value. The final normalized variables are denoted as $rCCC_i$ and rAI_{it} . This procedure ensures that a negative relationship is established between the variable $rCCC_i$ and the cost of climate change; and similarly, between the variable rAI_{it} and the adverse impact from climate change mitigation.

[Table A.2](#) displays the aggregation of regions in two steps. The simulations are conducted for 23 regions, thus aggregating 141 economies and regions in the GTAP database, whereas the results are presented for 10 regional aggregates.

³¹In order to make the values non-negative by respecting the order of magnitude across regions, the following homothetic transformation is applied to the initial values of CCC_i and AI_{it} :

$$\begin{aligned}
 CCC_{nonnegative_i} &= CCC_i - \min(CCC_i) + \min(abs(CCC_i)) \\
 AI_{nonnegative_i} &= AI_i - \min(AI_i) + \min(abs(AI_i))
 \end{aligned}$$

Appendix B Additional Simulation Results

Appendix B.1 Comparison IMF international carbon price floor

In this subsection the global carbon pricing framework (GCPF) is compared with the IMF proposal for an international carbon price floor (ICPF). [Table B.1](#) displays the level of the carbon price and the implied emission reductions according to simulations with the GTM. This comparison generates two main insights. First, compared to the IMF international carbon price floor, the carbon price is higher in the benchmark presented above. The reason is that the average emission reduction in the IMF proposal is only 19%, whereas the emission reduction is 27% in the benchmark framework. For reasons of comparison, the emission reduction realized in the carbon pricing framework is also set at 19% in the simulations reported in [Table B.1](#).³² Second, the carbon price varies more in the benchmark than in the IMF proposal. Hence, a carbon price determined by economy-level criteria, as well as the objective to reach the Paris Agreement temperature targets, displays more dispersion between historically large emitters and economies with a high level of development and historically low emitters and economies with a low level of development.

[Figure B.1](#) compares the relationship between the economic costs of carbon pricing and the economy-level criteria in the GCPF and ICPF. The upper panels show the scatter plots for the GCPF with support (on the right) and without support (on the left). The bottom panels show a similar setup but considering the IMF's ICPF. This figure suggests that the IMF's ICPF without support (the bottom right panel) implies a very weak relation between the economy-level criteria and the economic costs of decarbonisation. However, when support is included in the IMF scenario (bottom left panel) the correlation between economic costs and the economy-level criteria becomes positive, but with a higher dispersion between economies and a lower R2 than under the GCPF.

Appendix B.2 Varying the measurement of the criteria

[Figure B.2](#) shows the impact of measuring the different ingredients of the carbon pricing formula using slightly different metrics of the variables, as a robustness check by plotting the relationship between $\log(\text{HC.CD.rCCC})$ with the income effects of imposing a carbon price.

In more details, on the upper-right panel, historical contributions are computed for a latter period which is 1970 – 2019.³³ In the upper-left panel, for the current development meas-

³²In an analysis by IMF Staff employing a model similar to the WTO Global Trade Model, a similar reduction around 19% of emissions under the ICPF is found comparing 2030 with 2019 [Chateau et al. \(2022\)](#). This shows that the effect of carbon pricing on emissions in our model is similar to the effects in the model employed by IMF Staff.

³³As a variant, the projected emissions in the future could also be included to make sure that regions with

Table B.1: The carbon price and implied emissions reduction under the GCPF and ICPF reaching 19% emission reduction

Region	Emission reductions relative to 2019				Carbon price 2030			
	WTO support	IMF support	WTO no support	IMF no support	WTO support	IMF support	WTO no support	IMF no support
CEA	-20.17	-21.39	-20.10	-21.39	48.10	50.00	47.65	50.00
EAS	-27.86	-27.87	-27.64	-27.74	56.05	53.30	55.81	53.30
EUR	-26.96	-24.60	-26.88	-24.58	94.81	75.00	94.37	75.00
LAC	-9.58	-10.76	-9.73	-10.93	46.08	50.00	45.80	50.00
MIN	4.71	-2.34	4.47	-2.43	29.14	50.00	28.90	50.00
NAM	-38.50	-30.60	-38.33	-30.55	123.40	73.03	122.82	73.03
OAS	24.53	13.00	24.12	12.68	17.98	30.01	17.87	30.01
OCE	-44.79	-38.17	-44.74	-38.22	113.81	75.00	113.15	75.00
SEA	-2.68	1.89	-3.03	1.46	33.27	25.00	33.08	25.00
SSA	-1.70	-8.39	-3.53	-10.02	15.93	25.00	15.94	25.00
GLOB	-19.02	-18.97	-19.02	-19.02	57.56	52.41	57.33	52.43

Source: Calculated based on own simulations.

Notes: The table shows regional emission reductions relative to 2019 by 2030 (left panel) and the regional carbon price in USD terms (right panel). In both panels, the first column shows results for the benchmark scenario with support, reaching 16% emission reductions globally by 2030 relative to 2019. The second column shows results for the IMF ICPF scenario with support, reaching 16% emission reductions globally by 2030 relative to 2019. The third column shows results in the benchmark scenario without support, reaching 16% emission reductions globally by 2030 relative to 2019. The fourth column shows results for the IMF ICPF scenario without support, reaching 16% emission reductions globally by 2030. World-level carbon price is calculated by taking the emission-weighted average of the regional carbon prices.

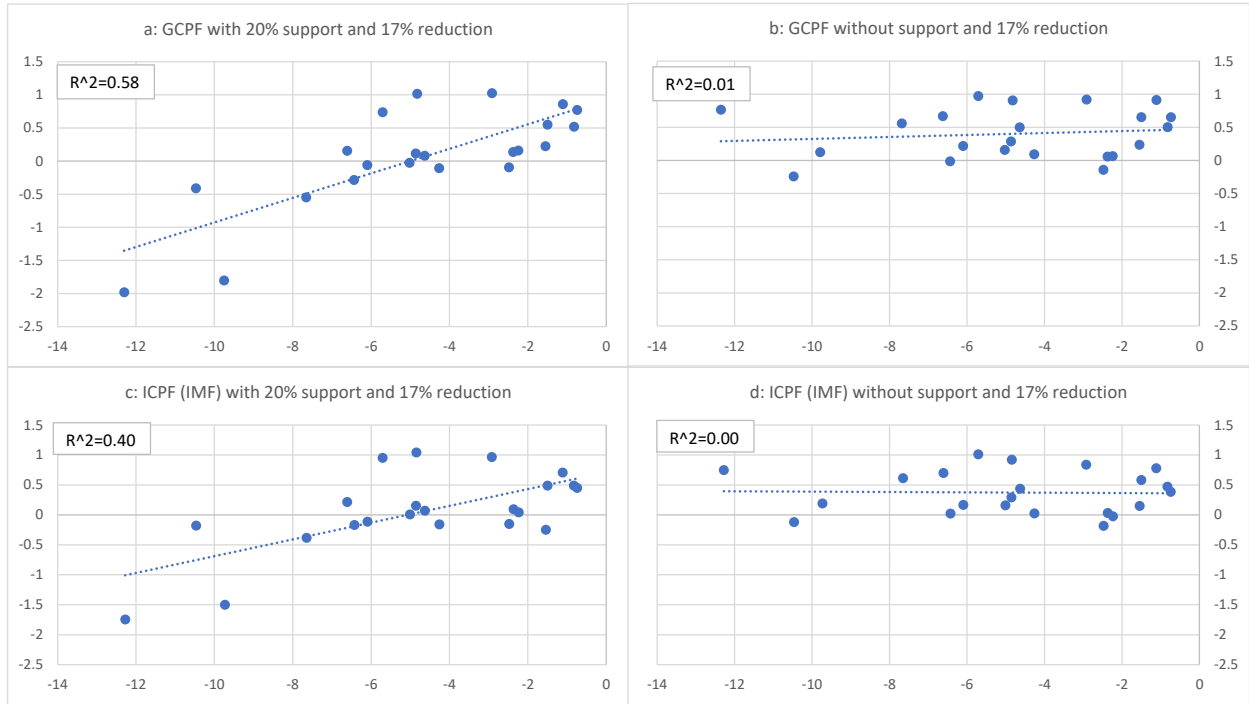
ure, GDP PPP is used, instead of GNI PPP.³⁴ Then, in the bottom right panel, CCC is computed based on estimates of [Roson and Sartori \(2016\)](#). The results are similar to the benchmark, with FFECs remaining in the upper part of the line. The lower-left panel shows the robustness simulation for AI where the adverse impact is constructed as equal to the fitted values of an estimation where on top of the fossil fuels export share, import share and emission intensity, also import shares, export shares and emission intensity of EITEs are regressed on the economic costs. In this way, the adverse effects for producers of EITEs are also controlled for. The figure shows that this has only a minor impact on the results.³⁵ Finally, the lower-right panel shows results when the costs of climate change are measured differently, based on [Roson and Sartori \(2016\)](#). Again, the scatter plot remains similar to the benchmark, although there are changes for individual economies.

low current levels of income decarbonize sufficiently to enable a trajectory of 2 degrees of global warming.

³⁴As a variant, simulations with GDP in dollar terms are also run and the results remain similar.

³⁵The R-squared of such estimation is 76.61 per cent, similar to the benchmark which is of 75.93 per cent.

Figure B.1: Relationship between $\log(\text{HC.CD.rCCC})$ and economic costs for carbon price calculations under the GCPF and ICPF



Source: Own Calculations.

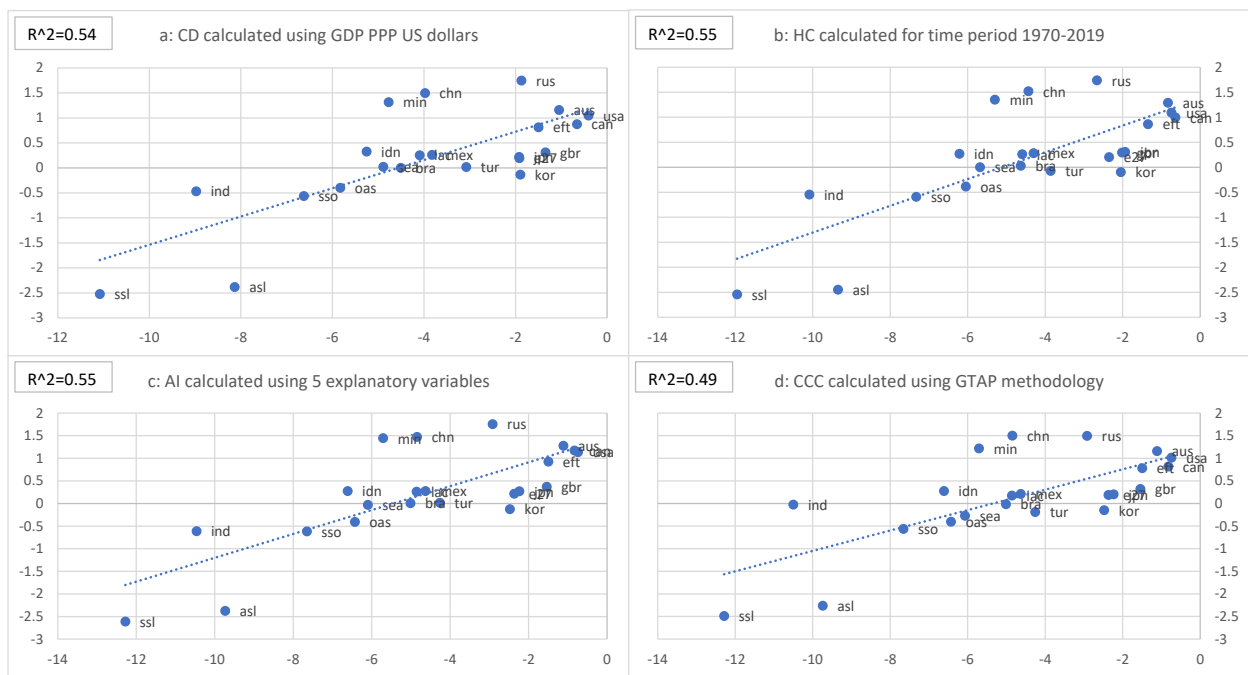
Note: The figure is showing the relationship between the $\log(\text{HC.CD.rCCC})$ in the X axis and economic cost in the Y axis, for carbon price calculations using the formula presented in the current paper and the IMF International Carbon Price Floor. All four scenarios record a 19% reduction in emissions. Support, if present, is calculated in proportion to population, CCC and AI.

Appendix B.3 Further support to improve relationship

In this section we analyse various options to improve the relationship between the economic costs and the economy-level criteria. In the upper-right panel in Figure B.3, simulation results are displayed based on a setting in which carbon tax revenues allocated to global support are not equal to 20% in all regions but are proportional to GDP. This implies that emission intensive regions which collect a relatively large share of carbon tax revenues in the benchmark would pay less for international support. The figure shows that indeed some economies above the trendline move down in terms of economic costs compared to the benchmark (upper-left panel). However, the impact is small.

The two bottom panels display the results of simulations under which another variable is added to support to tighten the relationship between the economic costs and the economy-level criteria. It consists of the residual of an estimation where the income changes from the benchmark simulation (see upper left panel) are regressed on the economy-level criteria. In other words, economies that suffer more in terms of income changes would get more support based on the residual that explains income changes. The bottom panels of the figure show

Figure B.2: Robustness checks using different variants of carbon price ingredients

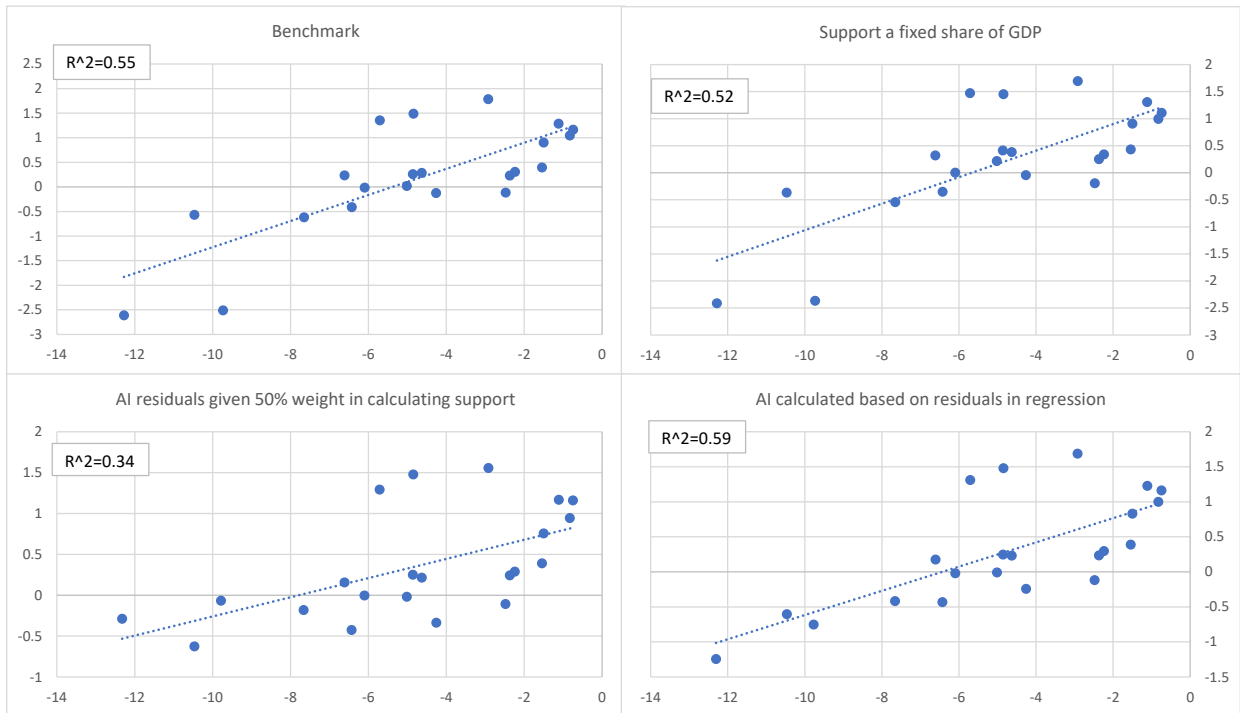


Source: Own Calculations.

Notes: The figure shows the relationship between the economic costs (Y axis) and log(HC,CD,rCCC) (X axis). All figures represent a scenario where the carbon price is determined based on HC, CD, rCCC and rAI; and 20% of revenues given as support which is calculated proportional to population, CCC and AI. In all scenarios 27% reduction in emission by 2030 is achieved, relative to 2019.

that although the regions on the left move closer to the regression line, overall the fit of the regression is not improved. This reinforces the finding in the sensitivity analysis that the fit of the relation between economic costs and economy-level criteria in the benchmark model cannot be further improved by modifying the determinants of the carbon price and support or adding additional variables.

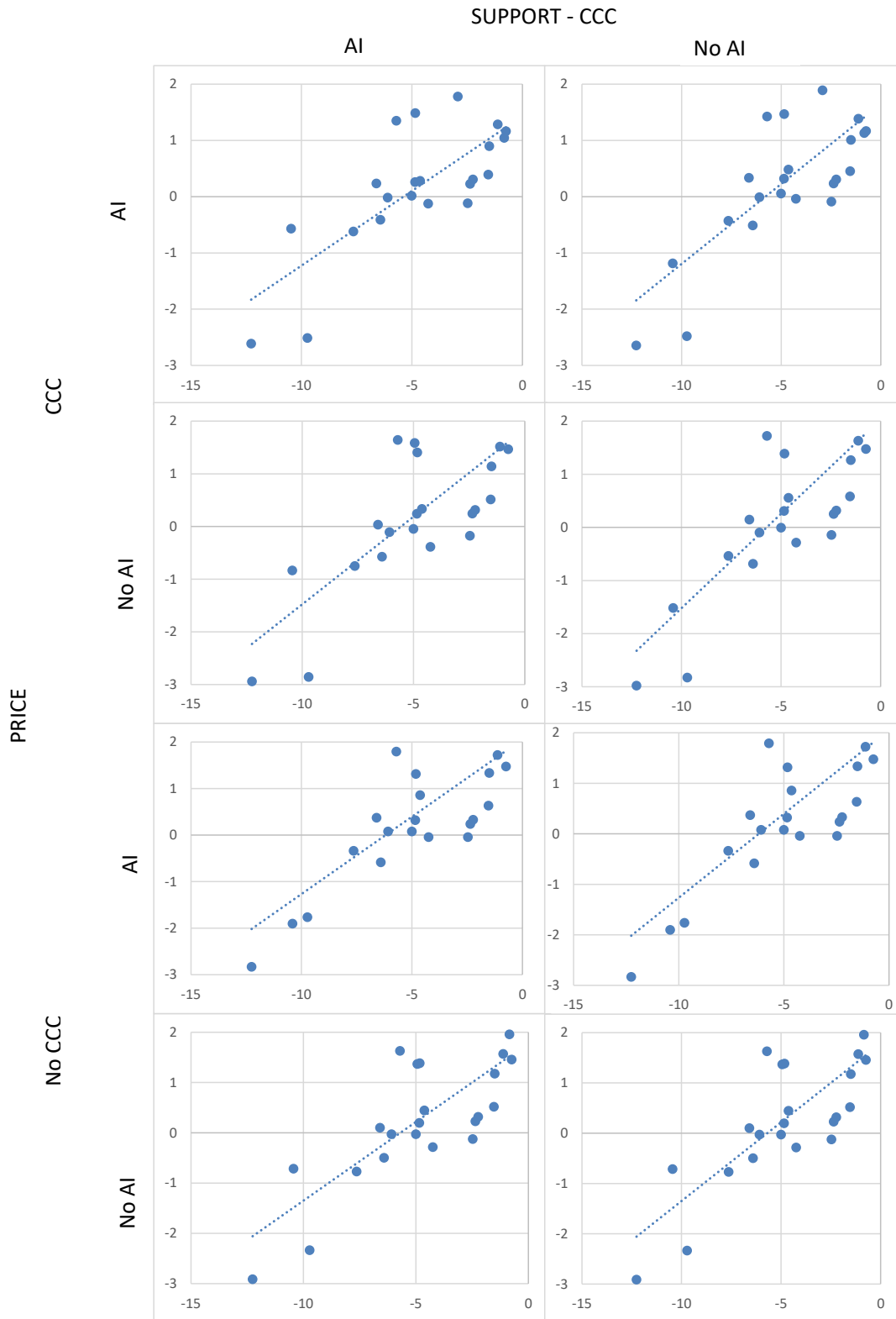
Figure B.3: Additional variables in support to account for outliers



Source: Own Calculations.

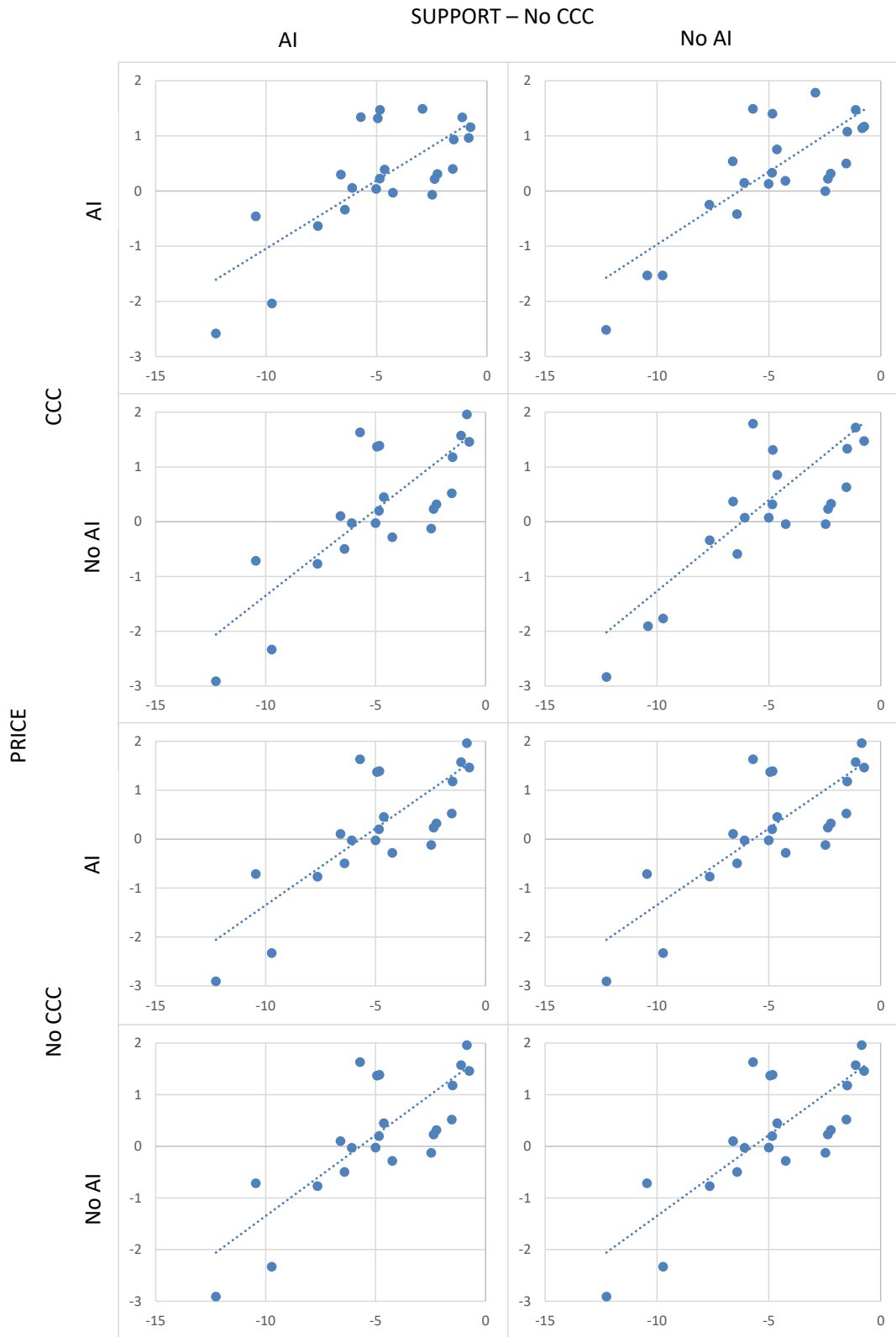
Notes: The figure is showing the relationship between the economic costs (Y axis) and $\log(\text{HC.CD.rCCC})$ (X axis). All figures represent a scenario where the carbon price is determined based on HC, CD, rCCC and rAI; and 20% of revenues given as support which is calculated proportional to population, CCC and AI. In all scenarios 27% reduction in emission by 2030 is achieved, relative to 2019.

Figure B.4: Relationship between $\log(\text{HC.CD.rCCC})$ (horizontal axis) and the economic costs (vertical axis) for various combinations of calculating the carbon price and support.



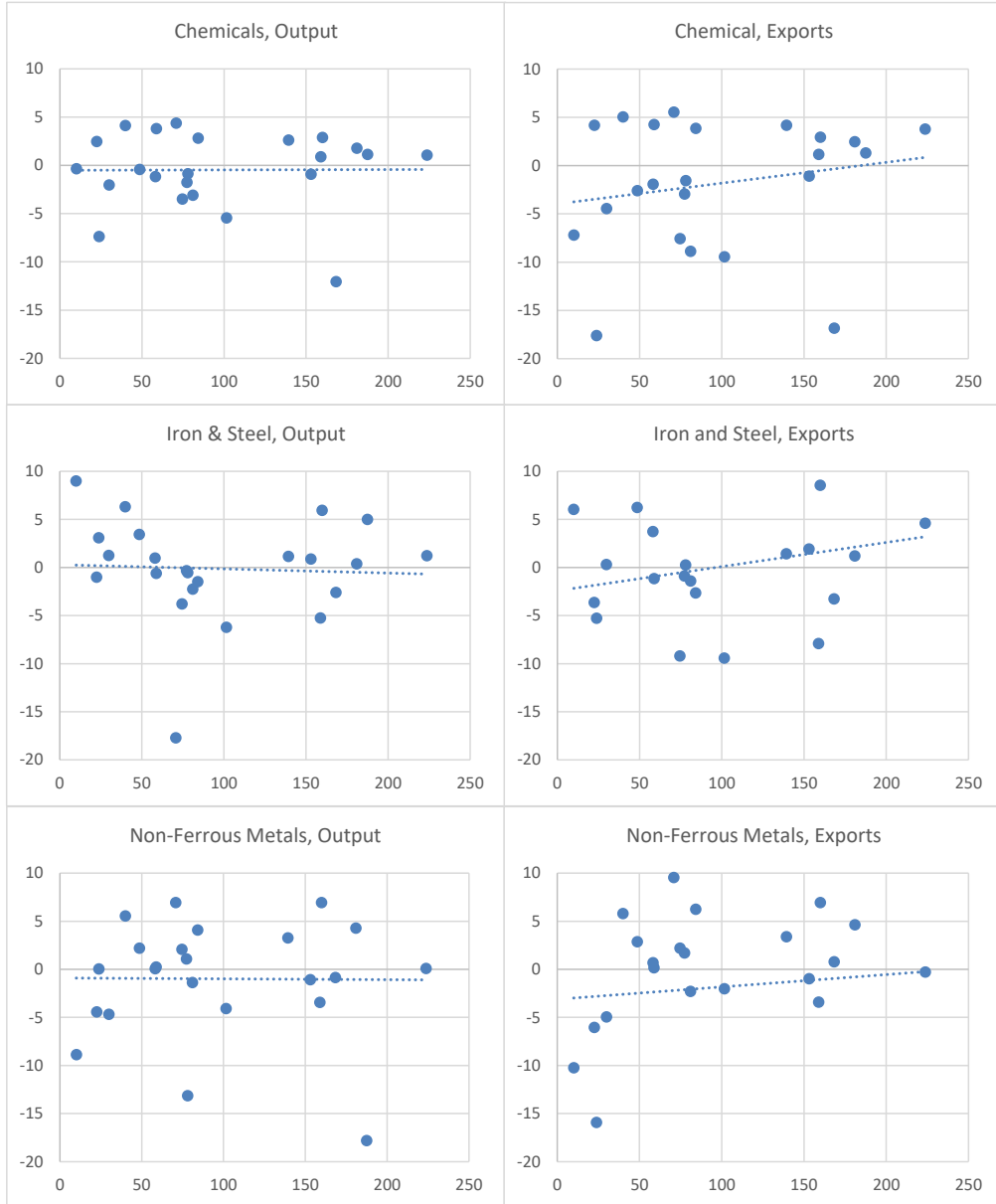
Source: Calculated based on own simulations.

Figure B.5: Relationship between $\log(\text{HC.CD.rCCC})$ and the economic costs for various methods of calculating carbon price and support (panel B).



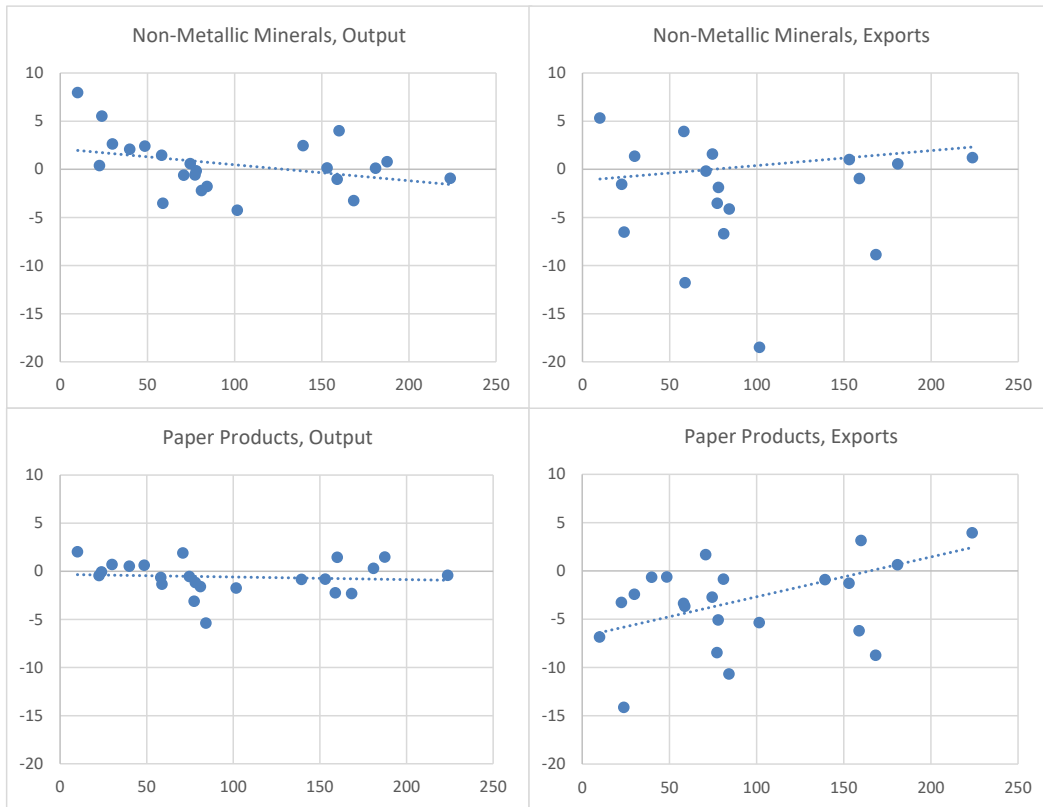
Source: Calculated based on own simulations.

Figure B.6: Relationship between the level of the carbon price and the projected change in production and exports in disaggregated EITE sectors, relative to baseline (2030).



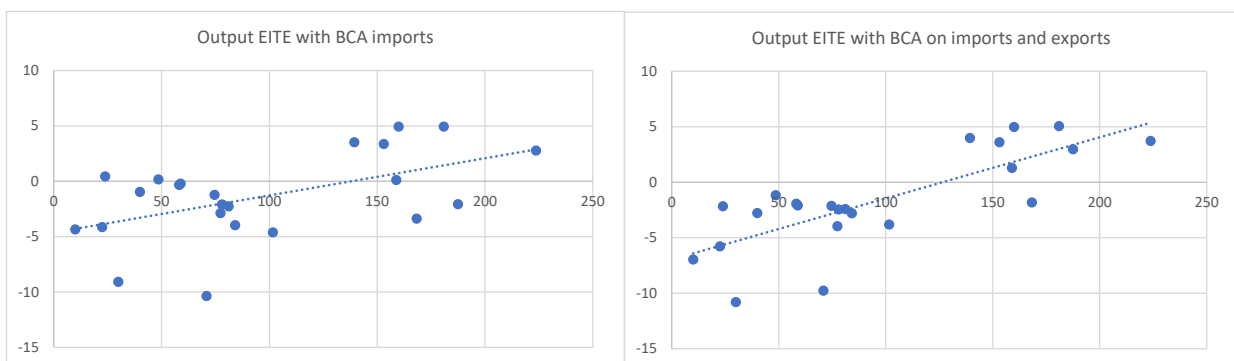
Source: Calculated based on own simulations.

Figure B.7: Relationship between the level of the carbon price and the projected change in production and exports in disaggregated EITE sectors, relative to baseline (2030).



Source: Calculated based on own simulations.

Figure B.8: Relationship between carbon price and change in production in EITE sectors, relative to baseline (2030) with import only BCA (left panel) and full BCA (right panel)



Source: Own Calculations.

Notes: The left panel shows the relationship between the carbon price (X axis) and the change in EITE production (Y axis) by 2030 relative to the baseline, in a scenario with import-only BCA. The right figure shows the relationship between the carbon price (X axis) and the change in EITE production (Y axis) by 2030, relative to the baseline, in a scenario with full BCA.