Climate Policies after Paris: Pledge, Trade, and Recycle

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Abstract: This article summarizes the insights of an Energy Modeling Forum study on the magnitude and distribution of economic adjustment costs to greenhouse gas emission constraints in the aftermath of the Paris Agreement where countries voluntarily committed themselves to Nationally Determined Contributions (NDCs). The model cross-comparison suggests that tightening of NDCs in line with the commonly agreed 2°C temperature target will induce global economic costs of roughly 1% in 2030 – yet, these cost are unevenly spread across regions with fossil fuel exporting countries being most adversely affected from the transition towards a low-carbon economy. In order to reduce adjustment costs at the global and regional level, comprehensive emissions trading which exploits least-cost abatement options is strongly desirable as it can relax contentious normative debates on equitable burden sharing. Lump-sum recycling of revenues from GHG pricing in equal amounts to every household appeals as an attractive strategy to mitigate regressive effects of emission pricing and thereby make stringent climate policy more acceptable on societal fairness grounds.

Keywords: Paris Agreement; emissions pricing and trading; revenue recycling
JEL-Classification: D58, H23, Q54, Q58

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1 Introduction

Anthropogenic climate change risks irreparable harm to the ecosystems on which mankind depends. The international community has recognized the threat of man-made climate change since nearly three decades calling for rigorous abatement of greenhouse gas emissions to prevent "dangerous human interference with the climate system" (UNFCCC, 1994). However, attempts to halt global warming have been short on progress so far. One reason is that climate protection constitutes a global public good. Each single country has a strong incentive to benefit from emission abatement of other countries while scaling back on its own emission reduction to save abatement costs. International agreements have little bite in coercing common action since they lack a supranational authority. Another fundamental impediment to climate protection is the asymmetric timing of costs and benefits from emission abatement. While decarbonization of production and consumption patterns induces economic adjustment costs in the short- and mid-run, most of the benefits of avoided climate damages will not materialize before decades from now given the physical inertia of the climate system.

The discrepancy in the time scale of costs and benefits explains why climate policy has been dominated all along by the issue of how large emission abatement costs are and how these costs are distributed. With respect to international burden sharing the United Nations Framework Convention on Climate Change (UNFCC) devised the postulate of Common but Differentiated Responsibilities (CBDR): That is, all countries share the obligation to address the threat of climate change but responsibilities differ due to different historical contributions to global emissions and different capabilities. The CBDR principle got reflected in the Kyoto Protocol which put the onus of greenhouse gas emission reduction on industrialized countries while developing countries did not commit themselves to climate targets. While celebrated as the first international climate treaty to become effective in 2005, it fell short of providing a blueprint for effective climate policy based on common burden sharing. First of all, the US – responsible for a large part of historical greenhouse gas emissions – withdrew from the Kyoto Protocol in 2001. The US government was concerned about the domestic compliance costs while it feared that other big emitters such as China or India without emission reduction commitments would take (comparative) advantage of the Kyoto deal. For similar reasons Canada ceased to be a Party to the Kyoto Protocol in 2012 and other major industrialized regions such as Japan and Russia indicated that they will not accept new Kyoto-type commitments after the initial five year commitment period (2008-2012).

Mindful of the difficulties in pushing mandatory agreements for industrialized countries only, the Paris Agreement in 2015 marked a major change in emphasis. The Paris Agreement sets out a global framework to avoid dangerous climate change by its goal to limit global warming to well below 2°C, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. The change in emphasis is twofold. First, the Paris Agreement requests contributions by *all* countries to mitigate global warming – not only by industrialized countries as has been the case with the Kyoto Protocol. As of December 2020, all 196 members of the UNFCCC have signed the agreement and 189 have become party to it.[1] It is hence the first-ever universal, legally binding global climate change agreement. Second, the Paris Agreement marks a shift of top-down mandated reduction targets as has been the case for Kyoto towards a bottom-up strategy where individual countries voluntarily commit themselves to Nationally Determined Contributions (NDCs) (UNFCCC, 2020).

The Paris Agreement has been celebrated as an international breakthrough to deal with the challenge of global warming in a comprehensive manner. However, the individual NDCs submitted so far fall short of being in line with the target to limit global warming to well below 2°C.[2] Recognizing that the set of voluntary pledges are inadequate to achieve the long-term temperature goal of the Paris Agreement, countries are asked to review and revise their NDCs every five years until the collective pledges are deemed sufficient to achieve the objective – where the effectiveness of the voluntary NDC approach might be promoted through naming and shaming. At the same time, it is obvious that more stringent climate policy actions up to 2030 which are in line with the Paris temperature goal will cause substantially higher economic adjustment costs (Vandyck et al., 2016; Hof et al., 2017).

On critical inspection, the Paris Agreement may not be seen as a game changer but rather as an admission that international climate policy critically hinges on voluntary bottom-up consensus decision making. This insight not only echoes the experience of the preceding Kyoto Protocol but reflects the limitations of international negotiators when it comes to feasibility within the domestic political environment: Emission reduction pledges submitted abroad must build on sufficient political support at home. Although societal awareness on the risks of climate change has grown sufficiently over the last decade in many countries – not at least because of grassroot movements such as Fridays for Future – decision makers are concerned about the adverse economic effects of more stringent climate policies not only on the national

[1] The only significant emitters which still are not parties are Iran and Turkey. The United States formally withdrew from the agreement the day after the 2020 presidential election, but the nation rejoined the agreement immediately after the inauguration of President Joe Biden (Viser et al., 2020; United Nations, 2021).

[2] Several studies including Vrontisi et al. (2018), Fujimori et al. (2016) and van Soest et al. (2017) find that the NDCs are not in line with even the 2°C target.

economy as a whole or the competitiveness of exposed industries but in particular on lower-income households. Concerns on the regressive impacts of climate policies are well justified. Putting a price tag on energy or energy-related pollutants such as CO_2 will raise consumer prices for energy goods such as electricity, natural gas, heating oil or gasoline. Since these goods constitute a larger share of the budget for poorer households than for richer households, higher energy or emission prices tend to be regressive. Even in countries which are seemingly rich on average populist protests for (more) economic justice have been initially sparked by rising fuel prices – the yellow vests movement in France that started in October 2018 is a case in point.

Against this background the Energy Modeling Forum Study on "Carbon Pricing after Paris" (EMF36) is designed to help policymakers chart sensible climate policies which balance the unequivocal need for drastic greenhouse gas emission abatement with normative considerations on fair burden sharing both at the international level but also within domestic boundaries. Our starting point is to take stock of the economic impacts associated with the implementation of the actual NDCs under the Paris Agreement in the target year by 2030, focusing thereby on CO_2 emissions from fossil fuel combustion as the major source of anthropogenic greenhouse gas emissions. We assume that individual countries have a vested interest to meet their domestic emission reduction pledges at minimum compliance costs and therefore exploit the cheapest abatement options domestically. Cost-effective emission reduction will be achieved by uniform emission pricing which can be implemented in terms of an economy-wide emission tax or emissions cap-and-trade system. We next investigate the question how the magnitude and regional distribution of adjustment costs changes as we transit towards more ambitious emission reduction targets which would ultimately align the current NDCs by 2030 with the long-run 2°C temperature goal. Starting from this reference situation, our primary objective is to sketch climate policy designs which lower the economic costs of emission reduction at the international and domestic level and thereby help to increase the likelihood that individual countries together can achieve the ambitious Paris temperature targets. This is where economic theory provides fundamental guidelines which can be translated into tangible numbers by means of applied economic analysis such as the EMF36 study. The first fundamental guideline is on exploiting efficiency gains from where-flexibility at the international level. Since greenhouse gas emissions are a global externality it does not matter where emissions are reduced, as long as they are removed from the atmosphere. Cost-effective global climate policy then implies to abate greenhouse gases where it is cheapest, i.e., to equate the costs of abatement at the margin across all abatement options. In this vein, basic economic theory suggests that NDC parties should strive for uniform global emission pricing through international trade in emission pledges. The EU emissions trading system which started 2005 provides a landmark for cost-efficient where-flexibility in abatement across multiple countries. There is wide-spread evidence on substantial cost savings from emissions trading both at the level of subnational as well as multilateral jurisdictions (Weyant and Hill, 1999; Metcalf, 2009; Böhringer et al., 2009). The second guideline is that emission pricing creates revenues whose recycling can drastically affect the overall incidence of emission reduction policies (for a review see Fullerton and Muehlegger, 2019). More specifically, economic theory suggests that lump-sum recycling of revenues from emission pricing to households can more than compensate the regressive effects of emission pricing (Chiroleu-Assouline and Fodha, 2014; Klenert and Mattauch, 2016). The basic intuition behind is straightforward. Since each household receives an equal share of revenues, the the lump-sum transfer constitutes a larger share of additional disposable income for lower-income households; if sufficiently high, the transfers can mitigate or even overcompensate initially regressive effects of emission pricing.

Our model cross-comparison study provides quantitative insights into the magnitude and distribution of Post-Paris climate policy designs up to 2030 where we pay special attention to the role of where-flexibility and revenue recycling for making stringent emission reduction politically (more) feasible. Based on simulations with several established energy-economy models our key findings are as follows. First, tightening of the NDCs towards 2030 in line with the 2°C temperature target will induce global economic adjustment costs of roughly 1% by 2030 relative to a business-as-usual case; across regions, fossil fuel exporting countries are most adversely affected from the transition towards a low-carbon economy. Second, international emissions trading can substantially reduce adjustment costs at the global and regional level, thereby attenuating contentious normative debates on equitable burden sharing; global cost savings from comprehensive global emissions trading as compared to only domestic action range from 50-90% depending on the stringency of the NDC pledges. Third, lump-sum revenue recyclig in equal shares to households offsets the regressive effects of emission pricing which might be crucial to make more ambitious climate policies acceptable on societal fairness grounds.

Our main findings can be summarized in a climate policy triad of 'Pledge, Trade, and Recycle': To achieve the Paris temperature target, more ambitious reduction pledges are necessary in the short-term whose political feasibility will hinge on cost reductions through international emissions trading and progressive revenue recycling at the domestic level.

The remainder of this article is organized as follows. Section 2 lays out the study design with respect to key research questions and specific policy scenarios to be shared across all modeling groups. Section 3 discusses the simulation results of the model-based cross-comparison. Section 4 concludes.

2 Study design

Our study on 'Carbon Pricing after Paris' shares the main features as previous studies under the umbrella of the Energy Modeling Forum (EMF).[3] The mission of EMF is to develop a better understanding of important energy and associated environmental problems. To achieve this goal EMF studies build on the collective capabilities of experts who apply and compare numerical models to the policy issues at stake in a systematic manner. The ex-ante assessment of economic, environmental, and social impacts triggered by public policies is meanwhile a central requirement for the policy design in various countries. The three dimensions of sustainable development are inherently intertwined and subject to trade-offs: Accomplishing one objective often means backpedaling on another. Numerical simulation models facilitate a quantitative trade-off analysis while accounting for the complex interaction of multiple forces that affect economic performance, environmental quality, and social conditions. In the end, the decisions how to resolve potential trade-offs will be based on normative values but scientific analysis can help to put decision making on an informed basis rather than leaving it on fuzzy or contradictory hunches.

Our analysis is based on a systematic cross-comparison of simulation results from 17 internationally established energy-economy models simulating pre-defined policy scenarios with harmonized assumptions. The joint assessment is complemented with additional specific insights on the incidence of emission pricing at the country or household level emerging from individual simulations of the expert groups. Table 1 provides a summary of the groups involved in the model-comparison study, their models, and their specific research contribution.

[3]See https://emf.stanford.edu.

Table 1: Expert teams participating in the EMF36 model comparison study

Model	Institution	People	Title of specific contribution
DART Kiel	Kiel Institute for the World Economy (IfW)	Sonja Peterson, Malte Winkler, Sneha Thube	Gains from linking the EU and Chinese ETS under different assumptions on restrictions, transfer payments, and international trade
UOL	University of Oldenburg	Christoph Böhringer, Jan Schneider	The Incidence of CO_2 Pricing Under Alternative International Market Responses – A Computable General Equilibrium Analysis for Germany
SNoW	Statistics Norway	Taran Fæhn, Hidemichi Yonezawa	Emission targets and coalition options for a small, ambitious country: An analysis of welfare costs and distributional impacts for Norway
JRC-GEM-E3	Joint Research Center (JRC), Sevilla - EU Commission	Toon Vandyck, Matthias Weitzel, Krzysztof Wojtowicz, Luis Rey Los Santos, Anamaria Maftei, Sara Riscado	Climate policy design, competitiveness and income distribution
C-GEM	Tsinghua University	Duan Maosheng, Li Mengyu	Exploring Linking Opportunities for China's Emissions Trading System under the Paris Targets – EU-China and Japan-Korea-China cases
CEPE	ETH Zürich	Florian Landis, Gustav Fredriksson, Sebastian Rausch	Between- and Within-Country Distributional Impacts from Harmonizing Carbon Pricing in the EU
WEGDYN	Wegener Center for Climate and Global Change - University of Graz	Jakob Mayer, Anna Dugan, Gabriel Bachner, Karl Steininger	Is carbon pricing always regressive? Insights from a recursive-dynamic CGE analysis with heterogeneous households for Austria
EC-MSMR	Environment and Climate Change Canada	Nick Macaluso, Peter Johnston, Madanmohan Ghosh, Elisabeth Gilmore	A model intercomparison of the welfare effects of regional cooperation for ambitious climate mitigation targets (joint with EDF)
EDF-GEPA	Environmental Defense Fund (EDF)	Gökçe Akin-Olçum, Ruben Lubowski, Margaret McCallister	A model intercomparison of the welfare effects of regional cooperation for ambitious climate mitigation targets (joint with EC Canda)
TEA	COPPE - Universidade Federal do Rio de Janeiro (UFRJ)	Rafael Garaffa, Bruno Cunha, Talita Cruz, Paula Bezerra, André Lucena, Angelo Gurgel	Distributional effects of carbon pricing on households: a case study for Brazil under the Paris Agreement goals
TUB	TU Berlin	Mohammad M. Khabbazan, Christian von Hirschhausen	Implications of the Paris targets for the Middle East through different cooperation options
Fudan	Fudan University	Wu Libo, Shuaishuai Zhang, Haoqi Qian	Distributional Effects of China's National Emission trading Scheme: Labor and Capital Share Changes in the Household Sector
ENVISAGE	Purdue University	Maksym Chepeliev, Israel Osario-Rodarte, Dominique van der Mensbrugghe	Distributional impacts of carbon pricing policies under Paris agreements: inter and intra-regional perspective
ICES	Euro-Mediterranean Center on Climate Change (CMCC)	Ramiro Parrado	—
ZEW	Zentrum für Europäische Wirtschaftsforschung (ZEW)	Sebastian Rausch	—
IEG	Institute of Economic Growth (IEG, India)	Basanta Pradhan, Joydeep Ghosh	The implications of income distribution of achieving climate targets for India in the context of COVID-19
BC3	BC3 and Massachusetts Institute of Technology (MIT)	Xaquín Garcia Muros, Jennifer Morris, Sergey Paltsev	Distributional impacts of low-carbon policies in USA and Spain: Does one size fit all?

In what follows we briefly discuss model characteristics and data inputs. We then motivate the policy scenarios that are investigated in the model-cross comparison.

2.1 Models and data

All models that participate in the cross-comparison are computable general equilibrium (CGE) models. CGE models constitute a powerful numerical simulation method to perform economy-wide impact assessment of policy reforms based on microeconomic theory and empirical data. More specifically, CGE models are rooted in general equilibrium theory that combines assumptions regarding the optimizing behavior of economic agents with the analysis of equilibrium conditions (Shoven and Whalley, 1992). Producers employ primary factors and intermediate inputs at a least cost subject to technological constraints; consumers maximize their well-being subject to budget constraints and preferences. Substitution and transformation possibilities in production and consumption are typically described by means of continuous functional forms where economic responses are driven by empirical estimates of elasticities and initial value shares derived from empirical economic accounts.

A key strength of CGE models is their comprehensive coverage of market interactions through price- and income-responsive supply and demand reactions by economic agents. The disaggregation of macroeconomic production, consumption, and trade activities at the sector level based on regional input–output matrices permits to track structural change. Policy reforms such as CO_2 pricing do not only affect the prices of consumer goods, but also sources of income, such as wages and returns to capital. Compared to partial equilibrium approaches such as bottom-up energy system models or microsimulation models, CGE models do not only capture the incidence of changes in relative prices on the expenditure side but also on the income side. With an explicit representation of different economic agents such as firms, households, and governments CGE models can quantify the distributional impacts of policy measures.

To summarize: CGE models incorporate key dimensions of impact assessment in a micro-consistent framework, thereby accommodating the systematic quantitative trade-off analysis between environmental quality, economic performance, and income distribution.

As is customary in applied general equilibrium analysis base-year data together with exogenous elasticities determine the free parameters of the functional forms. For base-year calibration all models share input data of the Global Trade Analysis Project (GTAP) database which includes detailed balanced accounts of production, consumption, bilateral trade, as well as data on physical energy flows and CO_2

emissions for up to 141 regions and 65 sectors (Aguiar et al., 2019, 2016; Chepeliev, 2020; Peters, 2016). As discussed below, the business-as-usual projection of the models towards 2030 is based on common data inputs from the International Energy Outlook (IEO) 2017 (EIA, 2017) and the World Energy Outlook (WEO) 2018 (IEA, 2018), respectively.

The regions and sectors of the GTAP dataset are aggregated towards the specific requirements of the EMF study. With respect to regional coverage, the composite dataset includes major industrialized and developing regions which play a key role in the international climate policy negotiations. With respect to sectoral coverage, the composite dataset maintains all primary and secondary energy carriers in GTAP: coal, crude oil, natural gas, refined oil products, and electricity. The explicit treatment of these primary and secondary energy carriers is essential in order to distinguish energy goods by CO_2 intensity and the degree of substitutability (fuel switching). In addition, we incorporate a composite sector for energy-intensive and trade-exposed industries (EITE) which are most vulnerable to emission pricing. The remaining sectors of the GTAP dataset are categorized in four additional composite sectors: transport, agriculture, other manufacturing, and services.

Table 2 lists the set of regions and sectors (commodities) that are covered by all models to warrant a systematic cross-comparison of results.

Table 2: EMF36 sectors and regions

Countries and regions	**Sectors**
Countries	*Energy*
United States	Coal
Canada	Petroleum and coal products
Japan	Crude oil
South Korea	Natural gas
Russia	Electricity
China	*Other sectors/aggregates*
India	Energy-intensive and trade-exposed (EITE)**
Brazil	Transport
Aggregated regions	Agriculture
Australia and New Zealand	Other manufacturing
Europe*	Services
Middle East	
Africa	
Other Americas	
Other Asia	

* Includes EU28 + EFTA members.
** Includes chemical products; basic pharmaceutical products; rubber and plastic products; non-metallic minerals; mining of metal ores; iron and steel; non-ferrous metals; paper, pulp, and print.

2.2 Scenarios

The primary objective of our analysis is to quantify the medium-term economic impacts of CO_2 emission pricing in the aftermath of the Paris Agreement for alternative NDC ambition levels and for different degrees of international cooperation through emissions trading. As the policy-relevant target year for the impact assessment we take 2030 which constitutes the milestone to which most Paris parties have submitted their first-round NDCs.

Against this background, we devise the EMF36 core scenarios along two dimensions which are critical for the magnitude and distribution of economic adjustment costs to Post-Paris climate policies: (i) the stringency of future NDCs (ambition), and (ii) the scope of international emissions trading across sectors and regions (cooperation). Table 5 presents an overview of the fifteen core scenarios that emerge as the cross-product of the two scenario dimensions for three NDC variants and five emissions trading variants.

The default policy instrument to effect emission reduction is emission pricing which can be equally implemented via an emission tax or an emissions cap-and-trade system. Adressing public concerns on the regressive impacts of emission pricing, revenues are recycled lump-sum to the consumers. A subgroup of models (see Table 3) which distinguishes consumers by income deciles investigates to what extent the progressive effect of an equal-per-household rebate offsets the regressive effect of higher energy prices.[4] CO_2 revenues are recycled lump-sump in equal shares to households. As CO_2 pricing typically depresses other government tax revenues, we adopt the convention that the government recycles the remaining CO_2 revenues after balancing its budget in order to keep government expenditures constant.

The impacts of a policy reform (in our case: the implemetation of NDCs) are usually quantified with respect to a reference situation where the reform is not in place — the so-called business-as-usual or benchmark equilibrium. Comparative static analysis then provides a comparison of two different economic situations, before and after a change in specific exogenous parameters such as the imposition of emission reduction pledges. If policy targets and measures refer to the future there is the need to establish a future business-as-usual which captures the evolution of the economy in the absence of these targets and measures. In the following we describe our business-as-usual assumptions and subsequently lay out the two core scenario dimensions.

[4] The single-country model BC3 uses BaU projections and CO_2 emission reduction targets for Spain which are in line with our specifications in Sections 2.2.1 and 2.2.2.

Table 3: Models with household impact analysis

Model	Specification	Specific country
BC3	Single-country	Spain
TEA	Multi-region	Brazil
CEPE	Multi-region	Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Latvia, Lithuania, Poland, Portugal, Slovakia, Slovenia, Spain, United Kingdom, Bulgaria, Croatia, Romania
JRC-GEM-E3	Multi-region + soft-link*	Austria, Belgium, Czech Republic, Germany, Estonia, Greece, Spain, Finland, France, Italy, Romania
SNoW	Multi-region	Norway
Fudan	Multi-region	China
UOL	Multi-region	Germany

* JRC-GEM-E3 feeds its macroeconomic results for 11 European countries into the EUROMOD-ITT (Indirect Tax Tool) in order to perform the household impact assessment.

2.2.1 Business-as-usual

The costs of complying with future emission constraints are directly linked to the structural characteristics of an economy exhibited in a hypothetical business-as-usual (BaU) situation without such emission constraints (Dellink et al., 2020). The BaU projections do not only determine the magnitude of the effective abatement requirement (the difference between the future business-as-usual emissions and the exogenous emission ceiling) but also the ease of emission abatement (the curvature of marginal abatement costs).

Due to the importance of BaU projections for the economic impact assessment of future climate policy constraints, we perform sensitivity analysis with respect to assumptions on future GDP growth and CO_2 emissions in 2030 from two official, widely-used sources: the International Energy Outlook (IEO) 2017 (EIA, 2017) and the World Energy Outlook (WEO) 2018 (IEA, 2018).

Table 4 shows the CO_2 emissions and GDP values for 2011 which serves as the historical base-year for the model study together with the respective growth indices up to 2030 that are derived from the IEO and WEO projections.

Table 4: BaU projections on CO_2 and GDP in 2030

Region	**CO_2**			**GDP**		
	2011	2030		2011	2030	
		IEO	WEO		IEO	WEO
	Mt of CO_2	2011=1	2011=1	billion USD	2011=1	2011=1
United States	5107	0.89	0.90	15533	1.51	1.46
Canada	523	1.08	1.02	1778	1.38	1.45
Japan	1028	0.90	0.80	5905	1.13	1.18
South Korea	501	1.20	1.44	1202	1.57	2.14
Russia	1503	0.95	1.05	1904	1.26	1.33
China	7098	1.14	1.28	7567	2.72	2.92
India	1771	1.86	2.47	1880	3.01	3.80
Brazil	372	1.25	1.19	2476	1.32	1.39
Australia and New Zealand	411	1.10	1.32	1550	1.64	2.14
Europe	4211	0.89	0.80	19182	1.29	1.34
Middle East	1808	1.28	1.29	3372	1.74	1.77
Africa	952	1.33	1.40	2076	1.98	2.00
Other Americas	1167	1.15	1.12	3471	1.60	1.55
Other Asia	2128	1.48	1.70	3569	2.07	2.31

2.2.2 NDC targets

We use the NDCs submitted by the Paris parties to the UNFCCC (UNFCCC, 2020) to derive three different ambition levels for emission reductions – referred to as *NDC*, *NDC+*, *NDC-2C*.

Our starting point are the NDCs under the Paris Agreement as listed in Kitous et al. (2016). Various countries have provided two different pledges – unconditional pledges which we label as *NDC* and more ambitious pledges that are conditional on reduction efforts of other regions which we label as *NDC+*. We translate these NDCs into region-specific reduction requirements for CO_2 emission from fossil fuel combustion in percent from the 2030 business-as-usual emission levels projected by IEO and WEO.[5] Given that total emission reduction pledges even for the more ambitious *NDC+* fall substantially short of what is deemed to be necessary in 2030

[5] Note that we assume a minimum reduction target of 5% for countries that state their NDCs as an emission intensity target reflecting the assumption that such a target will lead to some degree of effective carbon pricing, even if BaU projections suggest that targets are reached without carbon pricing. These minimum targets are binding for China and India against both BaUs, such that they have the same reduction targets of 5% under *NDC* despite different CO_2 emission projections in IEO and WEO. For countries that state their target vis-à-vis BaU emissions in 2030 and provide an own BaU we interpret the targets as actual emission targets. A detailed description along with supplemental materials of how the region-specific reduction targets for *NDC*, *NDC+*, and *NDC-2C* ambition levels are derived from official data sources is available from the authors upon request.

for meeting the long-run Paris temperature goal, we construct a third ambition level – called *NDC-2C*. For the *NDC-2C* targets we scale emission levels in *NDC+* uniformly across regions in order to comply with an emission reduction for 2030 which is on the 2°C emission trajectory suggested by integrated assessment analysis.[6]

Figure 1 visualizes the reduction targets for the composite regions incorporated in our model study across the three ambition levels with respect to the BaU emission levels projected by IEO and WEO. The blue bars show reduction targets under *NDC*, and the orange and green incremental bars show the additional reduction requirements under *NDC+* and *NDC-2C*, respectively. For regions without an orange incremental bar, *NDC* and *NDC+* are identical.

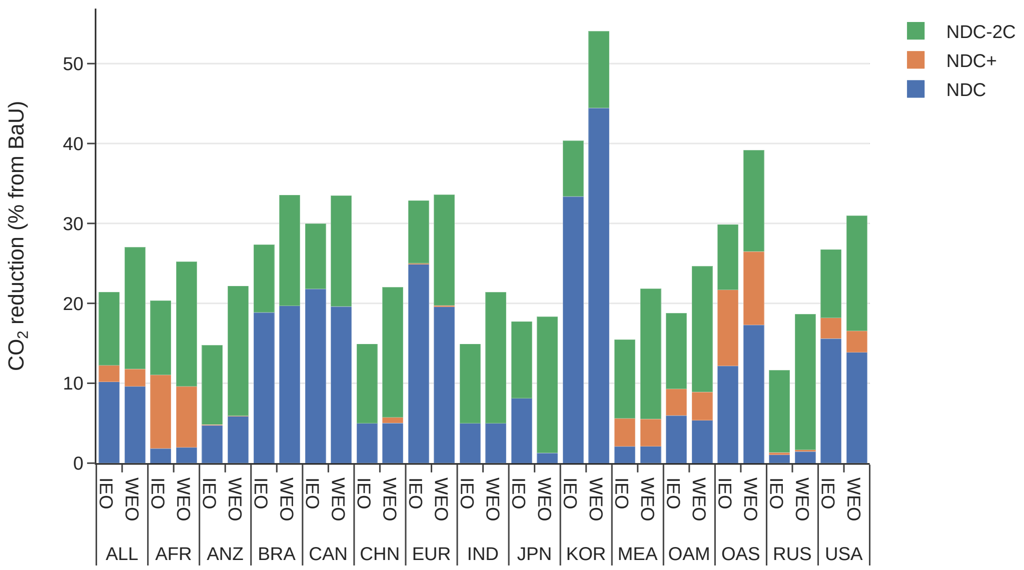
Global reduction requirements are roughly 10% for *NDC* and 12% for *NDC+* compared to the BaU projections. For a 2°C emission trajectory (*NDC-2C*), the global reduction requirement is 27% for the BaU based on WEO and 21% for the BaU based on IEO. This is primarily due to higher projected CO_2 emissions growth in China and India in WEO. Our budget approach for *NDC-2C* where we scale to a given level of global emissions then implies a higher reduction requirement against WEO projections compared to IEO projections.

Compared to global average reduction requirements we see that Africa, Middle East, and Russia have rather low reduction targets under *NDC*, while Brazil, Canada, Europe, and South Korea have substantially stricter targets. The consideration of conditional targets (*NDC+*) primarily plays a role in Africa, Middle East, as well as Other Americas and Other Asia.

Regions generally face a higher reduction target against the BaU that projects higher CO_2 emissions in 2030. For example, Europe has an effective target of 25% against IEO projections and of 20% against WEO projections, whereas South Korea faces a higher reduction target against WEO projections.

[6]We use an average value for reductions in global CO_2 emissions from energy use in 2030 compared to 2011 in 2°C scenarios derived from data provided by the IAMC 1.5°C Scenario Explorer and Data hosted by IIASA (Huppmann et al., 2019).

Figure 1: Reduction targets for CO_2 emissions from fossil fuels for different amibition levels (in % from 2030 BaU projections based on IEO or WEO)



Note—. ALL - Global average; AFR - Africa; ANZ - Australia and New Zealand; BRA - Brazil; CAN - Canada; CHN - China; EUR - Europe; IND - India; JPN - Japan; KOR - South Korea; MEA - Middle East; OAM - Other Americas; OAS - Other Asia; RUS - Russia; USA - United States.

2.2.3 International where-flexibility

The second scenario dimension reflects five alternative degrees of international cooperation via emissions trading across sectors and regions. On the one extreme (*ref*), we assume that there is no international emissions trading at all, i.e., regions meet their reduction targets by strictly domestic emission pricing.[7] On the other extreme (*global*), we assume full where-flexibility such that there is only one global emission price applying to all sectors and regions. In between the two extremes, we specify three cases that sketch more likely variants of cross-country cooperation in coordinating abatement efforts via joint emission markets. The variant *partial* prescribes emissions trading only in energy-intensive and trade-exposed (EITE) sectors (as well as the power sector) where stakeholders are most concerned on adverse impacts of stringent emission constraints.[8] In this case, regional CO_2 emissions in other sectors are kept at *ref* levels. Furthermore, we set up two "Club-Trading" cases which might occur within the next few years: Variant *eur-chn* considers emissions trading between Europe and China while variant *asia* considers emission trading between China, Japan and South Korea. For both "Club-Trading" cases, we assume again partial trading across sectors, i.e. there is a joint emission market for EITE and power sectors, while all other sectors face a domestic emission constraint set at the *ref* emission level. Note that across all where-flexibility specifications, global emissions keep constant at the same level.

[7] Note that composite regions reach their reduction targets through one constraint, that is, implicitly the assumption that there is emissions trading within composite regions.

[8] These sectors are also covered in existing national and supranational emission trading schemes such as the EU emission trading scheme.

Table 5: EMF36 core scenarios

Acronyms	Description
Ambition	
NDC	Translation of unconditional nationally determined contributions
NDC+	Translation of conditional nationally determined contributions
NDC-2C	Scaling of *NDC+* emission levels to reach 2°C temperature goal
Cooperation	
ref	Reference case where each region reaches its reduction target without further international emissions trading
global	Emissions trading across all regions and sectors
partial	Emissions trading across all regions in EITE and power sectors
eur-chn	Emissions trading between Europe and China in EITE and power sectors
asia	Emissions trading between China, Japan and South Korea in EITE and power sectors

We denote specific scenarios composed of one ambition level and one international cooperation variant with their respective acronyms separated by a slash ("/"). For example, the scenario where regions implement their unconditional nationally determined contributions domestically without international emissions trading is labelled *NDC/ref*. We also refer to scenario *NDC/ref* as the central case, since it describes the status quo of the Paris Agreement.

3 Results

We begin our presentation of results for the year 2030 with global (average) CO_2 prices and global welfare impacts. Subsequently, we discuss regional effects, before we summarize findings on welfare implications of equal-per-household revenue-recycling across income deciles.

Welfare changes are measured in terms of Hicksian equivalent variation (HEV) in income denoting the amount of money that is necessary to add to or deduct from the BaU income of households so that they enjoy a utility level equal to the one in the counterfactual policy scenario on the basis of BaU prices. A negative HEV hence indicates a welfare loss as compared to the BaU welfare (utility level). We aggregate welfare results from a utilitarian welfare perspective, that is, in the exposition of global welfare results we are agnostic on the cost distribution across regions, and in the exposition of regional welfare results we are agnostic on the cost distribution across households. Across all scenarios, we abstain from accounting for benefits from avoided climate damages. Negative welfare impacts can thus be interpreted as gross economic adjustment costs to emission reductions from BaU. Global emission levels are constant across the different emissions trading variants such that we can perform meaningful global cost-effectiveness analysis at each respective ambition level *NDC*, *NDC+*, and *NDC-2C*. Note that our reduction targets relate to CO_2 emissions from fossil fuel combustion only, which is by far the most important source for GHG emissions.

Since important parameterizations are streamlined in common assumptions on the business-as-usual and the counterfactual climate policy scenarios, variations across models can be explained to a large extent by structural differences across models that capture the price-responsiveness of production, consumption, and trade to CO_2 emission constraints. These differences drive the marginal and inframarginal costs of the represented economies to substitute away from carbon-intensive inputs. The abatement options include fuel switching, substitution of energy with non-energy inputs (energy efficiency), as well as output and demand reductions (energy savings). The costs of different abatement options are governed by cross-price elasticities and cost shares between various energy goods with different CO_2 intensities, as well as between energy and non-energy goods. Another important driver of economic impacts to emission constraints is the representation of existing or anticipated climate policies as well as assumptions about future energy prices or technological change with respect to carbon- and energy efficiency that are employed to meet the streamlined regional GDP values and CO_2 emissions in the 2030 BaUs. All these choices translate into model-specific implied marginal abatement cost (MAC) curves that provide a first-round approximation on the direct costs of emission abatement as the area under the MAC curve. The MAC curves are in general convex, indicating that it gets increasingly more expensive to abate the next unit of CO_2 as we decarbonize the economy. With the option for emissions trading the direct adjustment costs to domestic emission constraints will be adjusted by cost savings through exports or imports of emission allowances. Furthermore – in a general equilibrium framework – there are important income effects, most notably via policy-driven changes in international prices (the so-called terms of trade) that will increase or decrease the initial direct costs of emission restrictions depending on the structural characteristics of a specific economy in international trade.

For the exposition of results we focus on the BaU based on IEO projections, and point to differences to results based on WEO projections where they are relevant.

3.1 Global impacts

We focus on global impacts in *ref* and *global* for the three different ambition levels on emission reduction *NDC*, *NDC+*, and *NDC-2C*. These six scenarios comprise the full range on stringency in emission reductions and where-flexibility in emissions trading. At the low-cost end we have the combination of least ambitious emission reduction targets (*NDC*) and full where-flexibility (*global*). At the high-cost end we have the most ambitious emission reduction targets (*NDC-2C*) and a purely domestic implementation (*ref*) which does not exploit cost savings from international emissions trading.

Figure 2 shows the global average CO_2 prices in *ref* and *global* for the different ambition levels. In *ref* this is the emission-weighted average across regional CO_2 prices, whereas in *global* it is the globally uniform (tradable) CO_2 price.

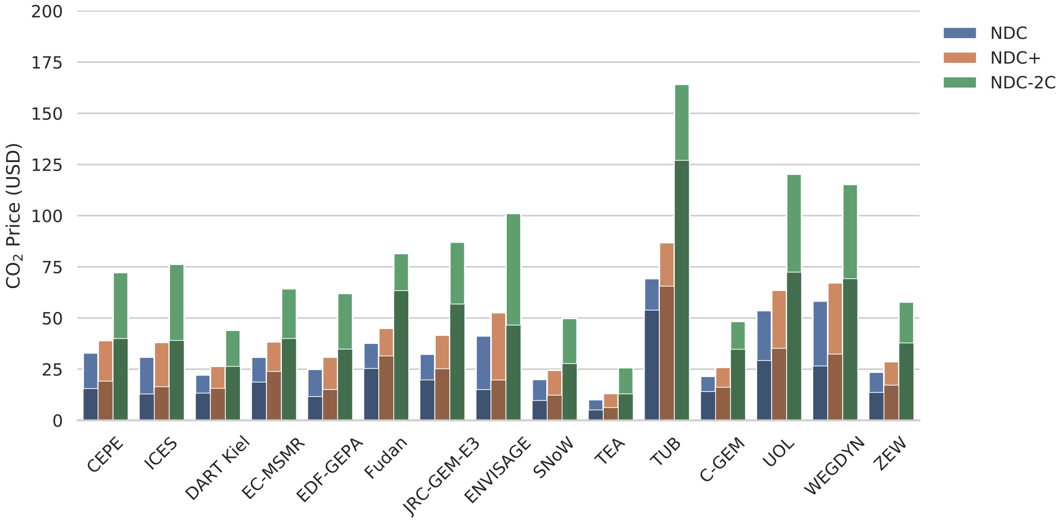
We first focus on *ref*, where regions implement their reduction targets domestically without international emissions trading. As expected, the global average CO_2 price increases with the ambition level reflecting the monotonicity of regional MAC curves. In the central case (*NDC/ref*), we find a range between 10 USD per tCO_2 to 69 USD, with a mean of 33 USD. For the most ambitious reduction targets in *NDC-2C/ref*, global average prices range from 26 USD per tCO_2 to 164 USD with a mean across models of 78 USD. This is within the range of findings of the High Level Commission on carbon pricing which "concludes that the explicit carbon-price level consistent with achieving the Paris temperature target is at least [..] USD 50–100/tCO_2 by 2030" (Stiglitz et al., 2017).

Considering comprehensive global emissions trading note that for each ambition level the global average CO_2 price is necessarily lower in *global* compared to *ref* and the wedge between the two prices indicates cost-saving potentials.[9] We find that moving to *global* roughly halves the required (then globally uniform) CO_2 price in most models. For two individual models, namely TUB and Fudan, the decline in CO_2 prices through trading is less pronounced.

Figure 3 shows the global welfare impacts in *ref* and *global* for the three different ambition levels on emission reduction *NDC*, *NDC+*, and *NDC-2C*. We find that at the global level welfare effects roughly mirror the results for CO_2 prices, where higher

[9]This is the case because for each ambition level the global emission reduction is the same in *ref* and *global*, but in *ref* marginal abatement costs (CO_2 prices) differ across regions. Given convex MAC curves, the emission-weighted average in *ref* must be higher than in *global*.

Figure 2: Global average CO_2 prices in *ref* and *global* under different ambition levels (*NDC*, *NDC+*, *NDC-2C*)



Note—. The lighter shaded bars represent CO_2 prices in *ref*. The darker shaded bars represent CO_2 prices in *global*.

CO_2 prices correspond to higher economic adjustment costs. Under *NDC/ref*, we find a range from 0.07% up to 0.8%, and a mean of 0.43% for the global economic adjustment costs compared to the BaU. Under more restrictive emission caps that are in line with a 2°C path in 2030 (*NDC-2C*) global adjustment costs in most models more than double and range from 0.16% to 1.84%, with a mean of 0.94%.[10] From a global perspective, *NDC+* leads to very similar adjustment costs as *NDC*, reflecting that conditional Paris pledges by individual regions only lead to roughly 2% additional global emission reduction compared to unconditional pledges.

Comprehensive international emissions trading (*global*) provides substantial global cost savings by 50%-90% in most models. The mean global welfare loss is 0.15% in in *NDC/global* and 0.47% in *NDC-2C/global*.[11] Welfare gains through global emissions trading thereby increase with the stringency of the reduction targets. Under the actual Paris pledges (*NDC*) moving from *ref* to *global* increases global welfare on average by 0.28%. For the most stringent reduction targets under *NDC-2C* this

[10] This amounts to a additional global costs in *NDC-2C/ref* of 0.5% percentage points compared to the central case (*NDC/ref*). For the alternative BaU based on WEO projections we find average global economic adjustment costs of 0.36% (*NDC/ref*) and 1.2% (*NDC-2C/ref*), which corresponds to slightly lower global reduction requirements under *NDC*, and to higher reduction requirements under *NDC-2C* (see Figure 1). The additional global adjustment costs thus amount to 0.84% percentage points.

[11] Note that we implicitly assume emissions trading in composite regions even in *ref*, compare footnote 7, meaning that our results provide lower bound estimates for the cost-saving potential of where-flexibility.

figure is 0.47%.[12] TUB and Fudan find considerably lower cost savings from trading as the rather small CO_2 price wedges between *ref* and *global* indicated, while JRC-GEM-E3 finds almost no differences between the reference case and full trading from a global perspective.[13]

A policy-relevant message arises from the comparison between *NDC/ref*, which depicts the status quo of the Paris Agreement, and (*NDC-2C/global*). In most models, the global adjustment costs for *NDC-2C/global* are quite similar to the costs of *NDC/ref*. This gets reflected in the mean global adjustment costs, which are 0.43% in scenario *NDC/ref*, and 0.47% in *NDC-2C/global*. The key message here is that – from a global welfare perspective – the actual reduction pledges under the Paris Agreement can be ratcheted up roughly cost-neutrally towards much more stringent pledges in line with the 2°C temperature goal if at the same time the where-flexibility through international cooperation towards globally uniform CO_2 emission pricing is fostered.[14] Cost savings through where-flexibility hence pay the bill for a more ambitious international climate policy.

For the intermediate cases of where-flexibility *eur-chn*, *asia*, and *partial* (omitted in Figure 3 for the sake of clarity) most models find a ranking in terms of global welfare impacts that roughly mirrors the share of global CO_2 emissions eligible for international trading. In *global* the share by definition amounts to 100%, in *partial* to around 55%, in *eur-chn* to 25%, and in *asia* to around 20%.

3.2 Regional incidence

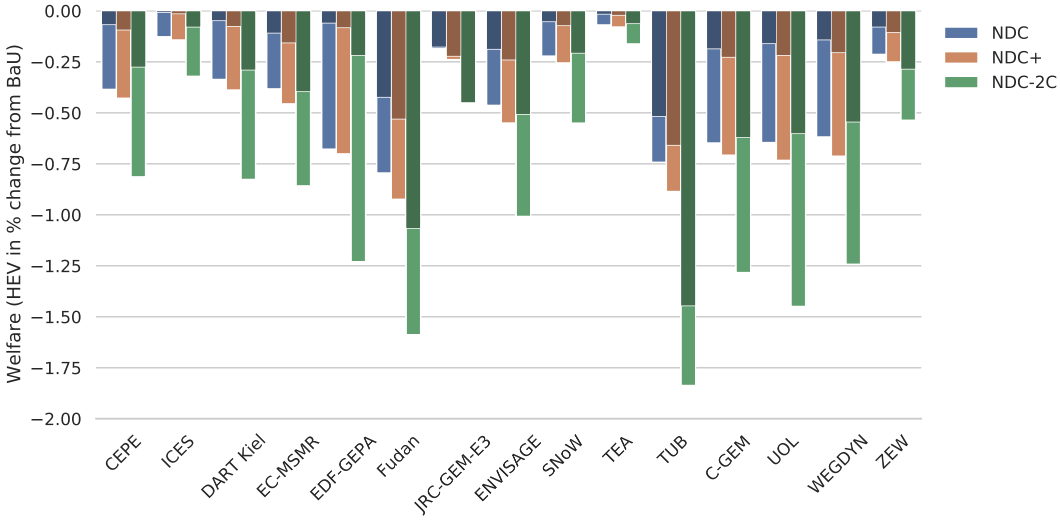
Welfare effects at the regional level are driven by two effects. First, regions face abatement costs in line with their emission reduction targets and abatement options that are reflected in the regions' CO_2 prices (marginal abatement cost); Second, regions are subject to indirect spillover effects due to price adjustments on international markets (the so called terms-of-trade effect), both for energy and non-energy goods. Fossil fuel demand and thus prices decline under emission pricing, which benefits fuel importers and hurts fuel exporters. Production costs for energy- and trade-exposed (EITE) goods increase due to emission pricing. This does not only

[12] As a subtlety it should be noted that cost savings from comprehensive international emissions trading tend to decrease in relative terms, i.e. as a fraction of *ref* adjustment costs with higher ambition levels. The logic behind is that it becomes increasingly expensive to substitute away from carbon when production and consumption patterns are getting less carbon intensive.

[13] JRC-GEM-E3 model captures lock-in effects in power generation technologies that lead to second-best emission abatement choices.

[14] This finding becomes weaker in the BaU based on projections from WEO. Here, global adjustment costs are on average 1.8 times higher in *NDC-2C/global* compared to *NDC/ref*, see also footnote 10.

Figure 3: Global welfare effects in *ref* and *global* under different ambition levels (*NDC*, *NDC+*, *NDC-2C*)



Note—. The lighter shaded bars represent welfare changes in *ref*. The darker shaded bars represent welfare changes in *global*.

affect changes in comparative advantage, but the heterogeneous nature (imperfect substitutability) of traded commodities makes it possible for EITE exporters to pass through domestic abatement costs to some extent via higher prices to the respective importers.

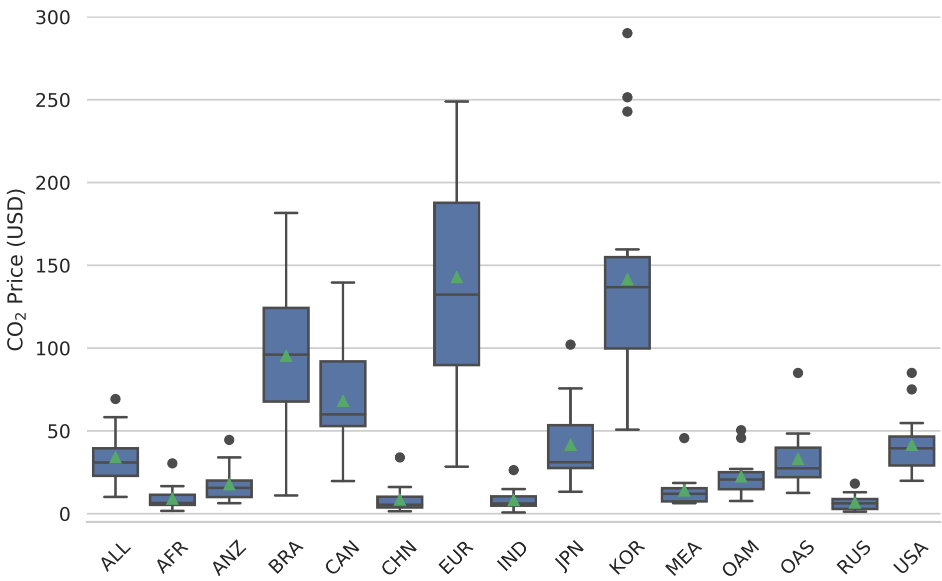
Variations across models can be traced back to modeling choices that govern the magnitude of these effects. Direct abatement costs are driven by the shape of the MAC curves that are in turn determined by cost and expenditure shares in production and consumption and the cross-price elasticities of substitution across production inputs and consumption goods. International spillovers and feedbacks are driven by cost shares and elasticities in international trade, which determine the ease of substitution away from more expensive imported goods in domestic production and consumption.

We begin our exposition of regional effects with the status quo of the Paris Agreement where regions implement their Paris emission reduction pledges without further international emissions trading (scenario *NDC/ref*). We then explore implications of increasing the ambition level and the degree of international cooperation.

3.2.1 Regional compliance with Paris pledges

Figure 4 shows a summary on regional CO_2 prices (marginal abatement costs), which depend on the effective reduction targets shown in Figure 1 and the regions' abatement abilities. As expected, regions with higher reduction targets face higher

Figure 4: Regional CO_2 prices in *NDC/ref*



Note.—Box-Whisker plot shows the median (line), mean (green triangle), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Dots indicate outliers. Region keys: ALL - Global average; AFR - Africa; ANZ - Australia and New Zealand; BRA - Brazil; CAN - Canada; CHN - China; EUR - Europe; IND - India; JPN - Japan; KOR - South Korea; MEA - Middle East; OAM - Other Americas; OAS - Other Asia; RUS - Russia; USA - United States.

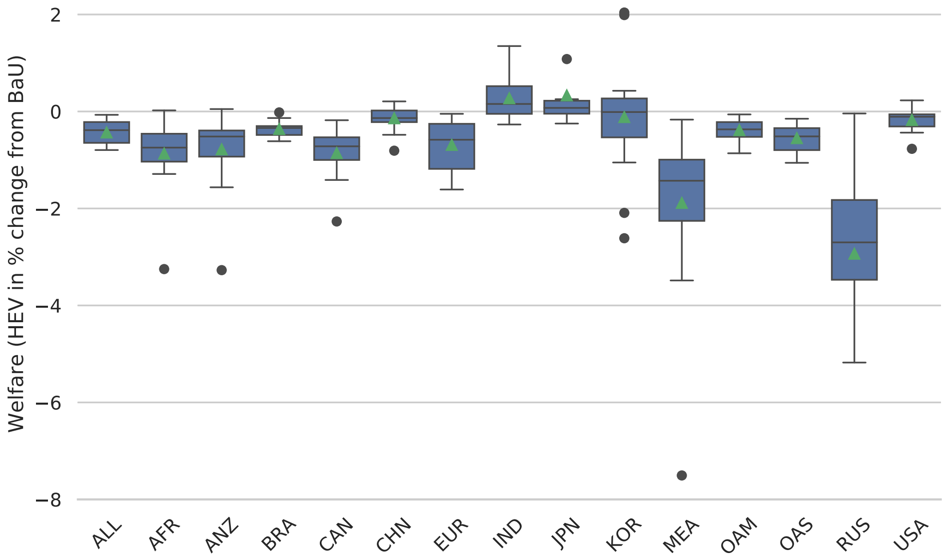
CO_2 prices. More specifically, the regions with the highest reduction targets Brazil, Canada, Europe, and South Korea also face the highest CO_2 prices, while regions with lower targets like Africa, China, India, the Middle East, and Russia exhibit low CO_2 prices.

Figure 5 shows a summary of regional welfare impacts across models. We find that the direct abatement costs from compliance with the reduction target as inferred from the regional CO_2 prices (Figure 4) are strongly overlaid by terms-of-trade effects largely transmitted via changes in international fuel prices.[15] Individual regions may even benefit from emission reduction constraints. This is the case for India and Japan as large importers of fuels, where terms-of-trade gains more than offset the direct costs of emission abatement. The major share of the burden of global emission reductions falls on the fuel exporting regions Middle East and Russia, although both regions have relatively low reduction targets and associated CO_2 prices.

An interesting example showcasing the two effects driving regional adjustment costs is South Korea, where outcomes range from more than 2% gain in welfare to a loss of 2.6%. South Korea has the highest effective reduction target among all

[15]Note that all participating models implement international trade based on the usual assumption of product heterogeneity (Armington, 1969), which gives rise to substantial terms-of-trade effects based on empirical estimates of trade elasticities (Balistreri et al., 2018).

Figure 5: Regional welfare across all models in *NDC/ref*



Note.—Box-Whisker plot shows the median (line), mean (green triangle), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Dots indicate outliers. Region keys: ALL - Global average; AFR - Africa; ANZ - Australia and New Zealand; BRA - Brazil; CAN - Canada; CHN - China; EUR - Europe; IND - India; JPN - Japan; KOR - South Korea; MEA - Middle East; OAM - Other Americas; OAS - Other Asia; RUS - Russia; USA - United States.

regions (33%, see Figure 1), leading to relatively high direct abatement costs. At the same time, South Korea is a fossil fuel importer, profiting from declining fuel prices, and an exporter of EITE goods. Which of these effects is dominating differs across models due to differences in the structure of the BaU economies and the choice of elasticities.

Generally we see more heterogeneity across models on the regional level than on the global level. The cross-model variation in welfare is especially large for regions which have the most ambitious climate targets and regions where international feedback effects play an important role. The largest divergence is found for Russia and Middle East as large exporters of fossil fuels. But also South Korea and Europe with strict targets which at the same time are significant importers of fossil fuels show a huge variation.[16]

[16]For most regions the alternative BaU based on WEO projections entails rather similar welfare impacts. Europe is better off under the WEO projections due to the lower effective emission reduction requirement (see Figure 1). That in turn slightly benefits Russia, as European oil and gas imports drop less. Only for South Korea the incidence substantially greater as their effective reduction requirement is higher, and at the same time international oil and gas prices decline slightly less.

3.2.2 Ambition level and international cooperation

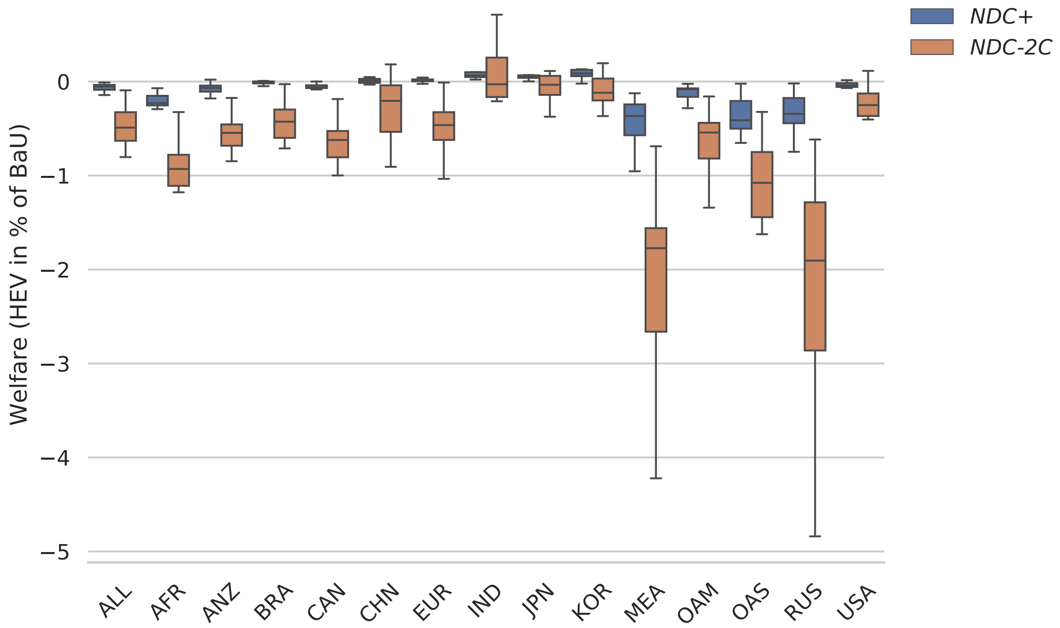
Figure 6 summarizes how regional welfare is affected as we move towards higher ambition levels *NDC+* and *NDC-2C*. Welfare effects are stated in percentage points from the respective values in *NDC/ref*.[17] Note that we still assume compliance via strictly domestic action, i.e., no international emissions trading. We observe that the difference between *NDC* and *NDC+* is rather small for most regions. For regions that step up their emission reduction pledges markedly in *NDC+* – Africa, Middle East, Other Americas and Other Asia – welfare declines; also fossil fuel exporters suffer slightly more under the additional negative demand shock. The highest emission reduction ambition level (*NDC-2C*) leads to additional global adjustment costs of 0.5% compared to *NDC*.[18] We find that the additional global adjustment costs for scaling up emission reduction targets towards a 2°C trajectory is rather unevenly distributed.[19] India, Japan, and South Korea do not face higher adjustment costs compared to the lowest ambition level (*NDC*). The gains from indirect international spillovers for these regions increase with the level of emission abatement, as direct abatement costs clearly increase as well. The fuel exporters Middle East and Russia lose overproportionally. All other regions lose roughly up to an additional 1% of BaU welfare compared to *NDC*.

[17] As an example, a value of 1% would indicate that the region is better off by one percentage point measured in BaU welfare compared to the *NDC* case.

[18] Compare Section 3.1.

[19] Recall that the reduction targets in *NDC-2C* emerge from a uniform scaling of emission levels in *NDC+* and do not take into account more subtle fairness considerations.

Figure 6: Differences in regional welfare under ambition levels *NDC+* and *NDC-2C* compared to *NDC* without emissions trading (*ref*)



Note.—Box-Whisker plot shows the median (line), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Outliers omitted.
Region keys: ALL - Global average; AFR - Africa; ANZ - Australia and New Zealand; BRA - Brazil; CAN - Canada; CHN - China; EUR - Europe; IND - India; JPN - Japan; KOR - South Korea; MEA - Middle East; OAM - Other Americas; OAS - Other Asia; RUS - Russia; USA - United States.

We next turn to the regional welfare impacts of increased where-flexibility through international emissions trading. Here two mechanism are of paramount importance: (i) unequivocal direct cost savings from emissions trading through the equalization of marginal abatement costs; and (ii) ambiguous indirect welfare effects through changes in the terms of trade on energy and non-energy markets that can play out both favorable or unfavorable for individual regions. More specifically, emission allowance selling countries face higher CO_2 prices under emissions trading variants compared to *ref*, while the opposite is true for allowance buying countries. These changes in the CO_2 prices will affect the cost of EITE production and thereby the scope for terms-of-trade changes in EITE trade.

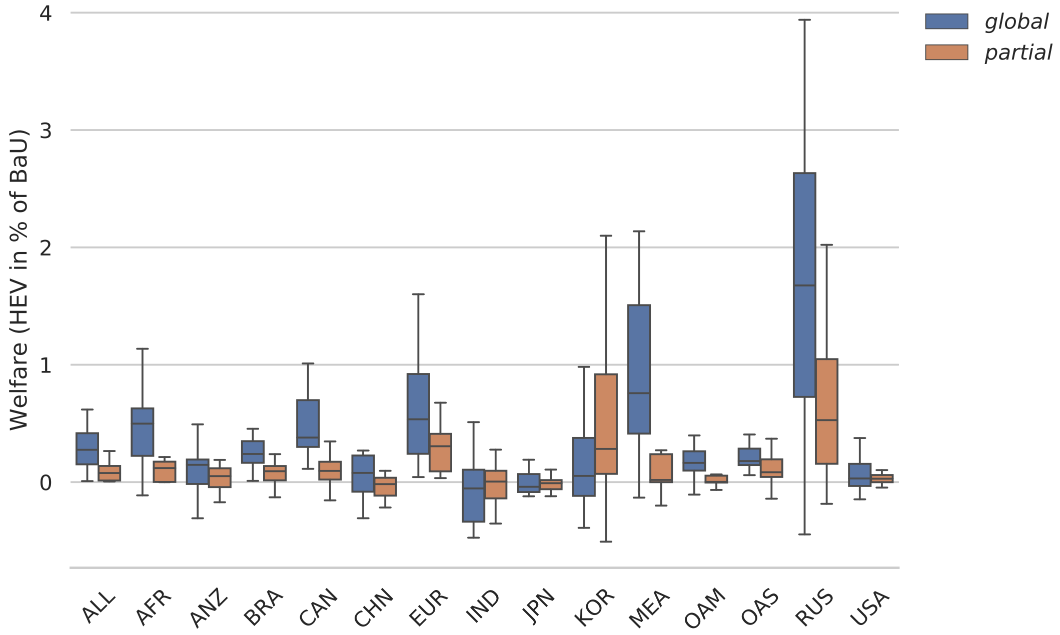
Figure 7 summarizes regional welfare impacts across models for the cases with worldwide trading schemes *global* and *partial* compared to *ref* for the case of the unconditional Paris pledges (*NDC*). We first focus on *global* and find that most regions gain through a comprehensive global emissions trading scheme as compared to the *ref* situation – gains are most pronounced for Russia, the Middle East, and Europe. However, the only regions where we unambiguously find welfare gains through global cooperation are Brazil, Canada, Europe, and Other Asia. For all other regions, at least individual models find welfare losses from engaging in comprehensive global emissions trading which points to the importance of indirect terms-of-trade effects when assessing the welfare impacts of climate policies in a more comprehensive (general equilibrium) manner.

We find, however, a robust pattern that is driven by changes in fossil fuel prices. Comprehensive global cooperation leads to a shift of global abatement to China and India, where in particular cheap abatement options via reduced coal consumption can be exploited. This increases oil and gas prices and depresses coal prices vis-à-vis *ref*, and thereby leads to a shift in regional incidence from oil and gas producers (Middle East and Russia) to coal producers. India is even worse off under *global* compared to *ref* in most models, although still with a welfare gain compared to the BaU on average. Japan is in most models slightly worse off under *global* compared to *ref*, due to higher international oil and gas prices under *global*.

South Korea again shows a huge spread in results across models. On the one hand, South Korea can gain from emissions trading as it exhibits the highest CO_2 prices under *ref* (together with Europe). On the other hand, South Korea benefits substantially from depressed oil and gas prices under *ref*, an effect that is weakened under *global*.

When only EITE sectors and the power sectors are eligible for international emissions trading (*partial*), we find that Europe, South Korea, Middle East, and Russia

Figure 7: Differences in regional welfare in *global* and *partial* compared to *ref* under *NDC*



Note.—Box-Whisker plot shows the median (line), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Outliers are omitted.
Region keys: ALL - Global average; AFR - Africa; ANZ - Australia and New Zealand; BRA - Brazil; CAN - Canada; CHN - China; EUR - Europe; IND - India; JPN - Japan; KOR - South Korea; MEA - Middle East; OAM - Other Americas; OAS - Other Asia; RUS - Russia; USA - United States.

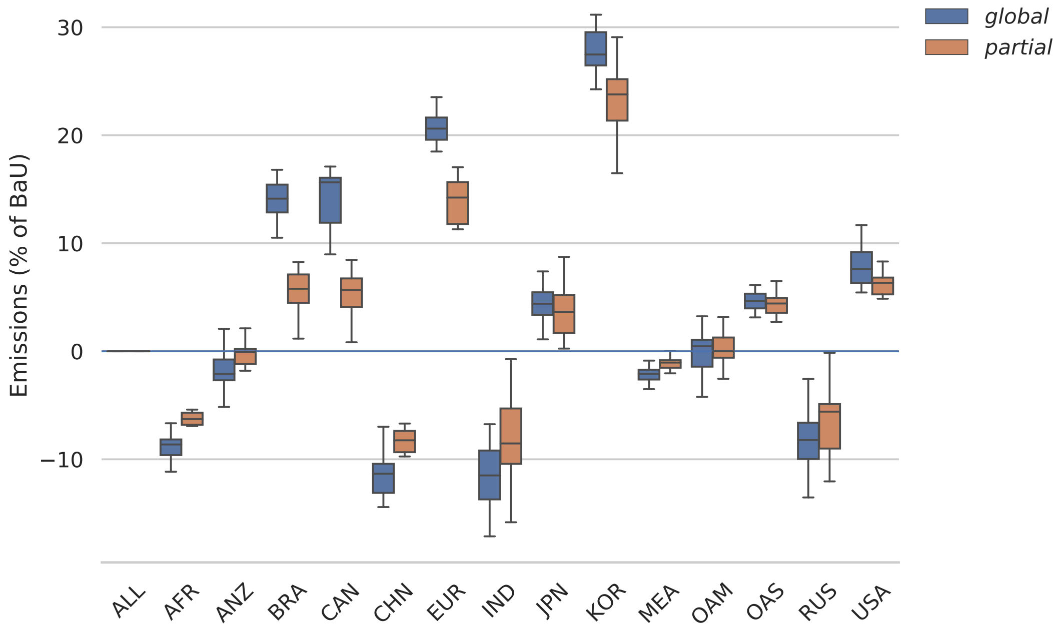
can gain most compared to *ref*. While Europe and South Korea benefit from partial trading due to their high CO_2 prices in *ref*, the Middle East and Russia benefit from a shift towards coal abatement in *partial*. South Korea is thereby the only region that prefers *partial* over *global*. The reason is that under partial trading, South Korea can reap gains from emissions trading, while the global shift from oil- and gas-related abatement towards coal is less accentuated. This is also reflected in welfare outcomes for Middle East and Russia, where we find the most pronounced gains under *global* attenuated under *partial*.

Emissions trading leads to an equalization of regional (or sectoral) CO_2 prices via exports and imports of emission allowances that constitute financial transfers between regions. For regions and sectors that form part of a trading coalition, their *ref* CO_2 price in relation to the tradable CO_2 price will determine whether the country becomes an exporter or importer of emission allowances and hence shows higher or lower emission reductions as stated in their Paris pledges. Figure 8 shows that regional buying and selling positions of emission allowances are rather stable across models: China, India, and Russia, which have the lowest CO_2 prices under *ref* (see Figure 4), become large exporters of emission allowances; South Korea, Europe, Canada, and Brazil become large importers.[20]

Figure 9 shows the differences in regional welfare in the club-trading scenarios *asia* and *eur-chn* compared to *ref*. We see that Europe and South Korea can gain from club trading, as they start off from very high CO_2 prices under *ref*. The other regions see only minor changes in economic adjustment costs triggered by club trading.

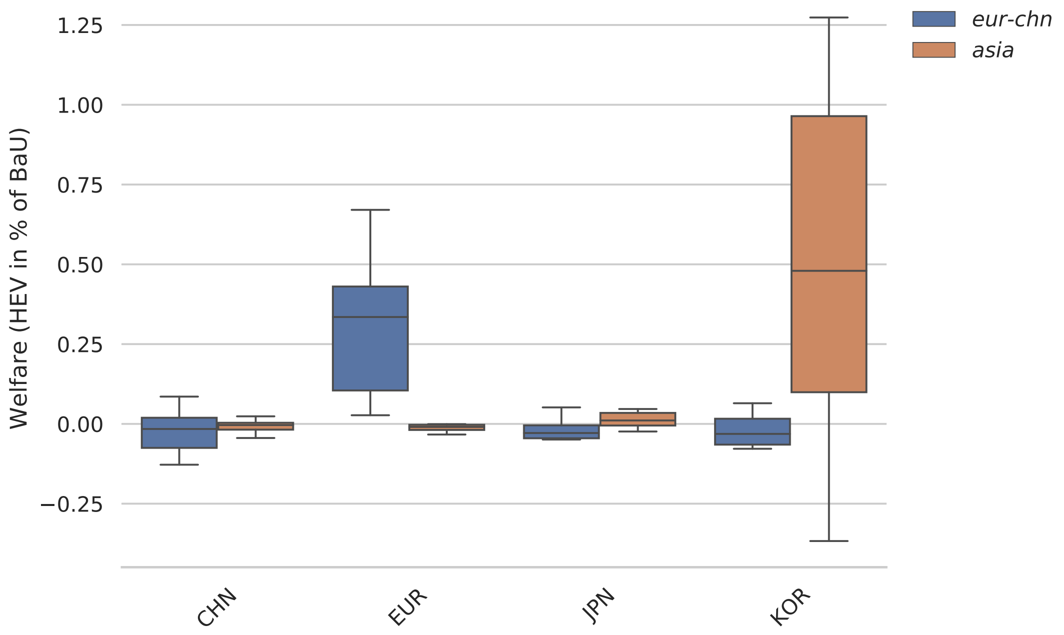
[20] Note that Brazil is a huge importer because we focus the analysis on CO_2 emissions from fuel combustion. Accounting for emissions from agriculture, forestry, and land use (AFOLU) would most likely make Brazil a net exporter of emission allowances.

Figure 8: Differences in regional CO_2 emissions in *global* and *partial* compared to *ref* under *NDC*



Note.—Box-Whisker plot shows the median (line), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Outliers are omitted.
Region keys: ALL - Global average; AFR - Africa; ANZ - Australia and New Zealand; BRA - Brazil; CAN - Canada; CHN - China; EUR - Europe; IND - India; JPN - Japan; KOR - South Korea; MEA - Middle East; OAM - Other Americas; OAS - Other Asia; RUS - Russia; USA - United States.

Figure 9: Differences in regional welfare in *eur-chn* and *asia* compared to *ref* under *NDC*



Note.—Box-Whisker plot shows the median (line), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Outliers are omitted.
Region keys: CHN - China; EUR - Europe; JPN - Japan; KOR - South Korea.

3.3 Household level incidence

Our analysis on global and regional welfare implications of Post-Paris emission pricing so far has been agnostic on the incidence across heterogeneous households *within* countries. For the political feasibility of emission pricing reforms, however, a critical question is who bears the burden of higher energy prices. Taking into account distributional effects of CO_2 pricing across heterogeneous households is thus central to the climate policy design.

Emission pricing creates costs and rents which translate into the incidence for households via changes in prices for consumption goods on the expenditure side and via changes in factor remuneration (plus potential transfers) on the income side. On the expenditure side emission pricing is often found to be regressive to the extent that it drives up prices for consumption goods for which lower-income households tend to spend larger shares of their budgets. This is typically the case for electricity, home heating fuels, gasoline, and other energy-intensive goods whose prices will overproportionally increase under CO_2 pricing. On the income side emission pricing affects the productivity and thus the remuneration to the primary factors labor, capital, and specific resources (e.g., fossil fuel resources). Lower-income households tend to get larger shares of their income through labor and transfers, while higher income households earn more through capital income. A key driver of the incidence on the income side is how governments will use revenues from emission pricing. Addressing policy concerns on how to mitigate the regressive impacts of CO_2 pricing, we focus on revenue-neutral lump-sum transfers to households in equal shares. Such a rebating scheme is clearly progressive. Since each household receives an equal share of CO_2 revenues, the recycled amount marks a larger share of additional disposable for lower-income households. If sufficiently high, the transfers can mitigate or even overcompensate the expected regressive effects of emission pricing.

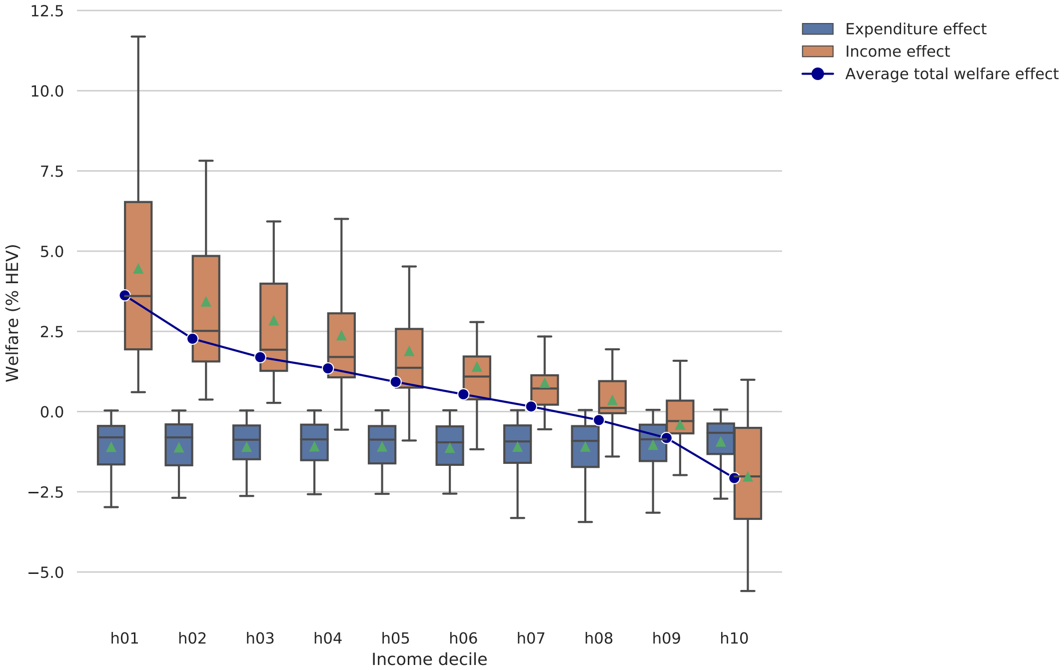
We present results for our central case scenario (*NDC/ref*) where regions meet their unconditional Paris pledges (*NDC*) through purely domestic action (*ref*). Figure 10 shows the total welfare impact on income deciles (*h01,...,h10*) as the mean across five models and 35 (partly overlapping) European countries (blue line with circle marker). On average, we find a progressive impact. While the lowest-income household gains more than 3% in real income (HEV), the highest-income household loses roughly 2%. The underlying reason becomes clear if we decompose total welfare impacts into expenditure and income effects. The Box-Whisker plots in Figure 10 summarize expenditure and income effects across models and countries. We find that the expenditure effect – although varying markedly across countries due to different levels of CO_2 prices, emission intensities, and expenditure patterns – is negative and slightly regressive throughout. The income effect, on the other hand, which includes the lump-sum rebates received by households, is strongly progressive and dominates such that the overall welfare effect is progressive.[21]

We can summarize the individual effects on different households from a societal perspective when adopting a social welfare function where we capture alternative degrees of inequality aversion. We report social welfare as changes in the equally distributed equivalent income as defined by Atkinson (1970).[22] In Figure 11 we present social welfare changes for China, Brazil, Norway, Spain, as well as the three largest European economies Germany, the United Kingdom, and France. Countries are distinguished by color, and models are distinguished by markers, as for several European countries results are available from more than one model. With an inequality aversion of zero ("Bentham") we adopt a utilitarian perspective where we are agnostic over the distribution of economic adjustment costs across different

[21] Note that only European countries are represented in the Box-Whisker plots in Figure 10. In our central case, CO_2 prices in Europe are quite high, leading to high revenues and thus a strong income effect for households through lump-sum rebates.

[22] For a given degree of inequality aversion, the equally distributed equivalent income is defined as the level of income that – if obtained by every individual in the income distribution – would enable the society to reach the same level of welfare as is the case with actual incomes.

Figure 10: Summary on decomposition of households' total welfare into expenditure and income effects across models and regions



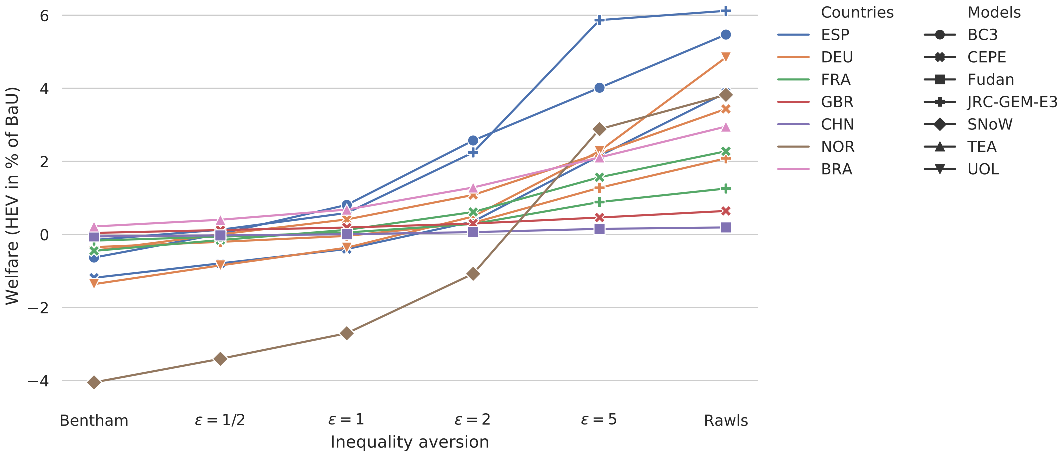
Note.—Box-Whisker plot shows the median (line), mean (green triangle), the first and third quartile (box), and Whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Outliers omitted. Graph incorporates values from the models BC3 (Spain), UOL (Germany), SNoW (Norway), JRC-GEM-E3-EUROMOD-ITT (11 European countries), and CEPE (21 European countries).

income deciles in social welfare. As we increase the inequality aversion, we find progressiveness of the lump-sum rebates in equal shares to households across all considered countries.[23] Higher degrees of inequality aversion imply higher values of social welfare. Towards a Rawlsian perspective, where only the welfare of the lowest-income household matters, the associated social welfare actually increases beyond business-as-usual levels. Norway stands out for high productivity (efficiency) losses which are due to very high CO_2 prices associated with a high emission reduction target and the low BaU emission intensity of the Norwegian economy. The redistributive effect of CO_2 pricing with lump-sum rebates to households is quite strong rendering initial efficiency losses from a utilitarian perspective into marked social welfare gains as inequality aversion increases, i.e. poorer households matter more and more. For China, on the other hand, the CO_2 pricing (at relatively low levels – see Figure 4) and lump-sum recycling involves very moderate economy-wide costs which leaves the income distribution across households relatively unaffected.

Our robust policy-relevant insight is that lump-sum recycling of revenues in equal shares to households can offset the regressive impacts of CO_2 pricing and even deliver social welfare gains ith a reduction in CO_2 emissions if inequality aversion is sufficiently high.

[23] Note that for some countries in our cross-comparison CO_2 emission pricing is already progressive without lump-sum rebates of CO_2 revenues. This can e.g. be the case when expenditure shares are rather homogeneous across households and emission pricing leads to a significantly greater impact on capital income than on labor income, burdening higher-income households stronger. However, the marked progressive effect illustrated in Figure 11 stems from the recycling mechanism.

Figure 11: Social welfare for different degrees of inequality aversion across models and regions



Note.—ESP - Spain; DEU - Germany; FRA - France; GBR - United Kingdom; CHN - China; NOR - Norway; BRA - Brazil.

4 Concluding remarks

The benefits of emission abatement will not materialize in terms of avoided climate damages before decades from now due to the inertia of the climate system. The costs of emission abatement on the other hand will occur in the short- to mid-run. It is therefore not surprising that the contemporary climate policy debate is very much focused on the magnitude and distribution of economic adjustment costs to stringent emission constraints as implied by the Paris Agreement in the pursuit of the 2°C temperature target. The United Nations Framework Convention on Climate Change (UNFCCC) has codified the challenge of international burden sharing as the principle of Common But Differentiated Responsibilities (CBDR). However, the initial top-down approach on burden sharing applied in the Kyoto Protocol failed, not at least because of the difficulties to agree on common equity principles. The Paris Agreement switched to a bottom-up approach, where countries pledge their emission reduction commitments voluntarily as so-called Nationally Determined Contributions (NDCs). The downside of the voluntary bottom-up approach is that it may not enforce sufficient collective abatement efforts to keep the average global temperature increase below 2°C from pre-industrial level. As a matter of fact, the individual abatement pledges under the Paris Agreement so far fall substantially short off what is required to meet the long-run Paris temperature target. It is thus necessary ratchet up the current NDCs to much more restrictive targets even in the short run. The unequivocal pressure to increase the ambition level in climate policy and to secure at the same time societal approval calls for climate policy designs that are cost-effective and appear as fair to the citizens. Inherently, these two central requirements are intertwined since a reduction in compliance costs can substantially relax the controversial debate on fair burden sharing. The economic discipline has identified two important instruments for decreasing overall compliance costs to national emission reduction pledges and for increasing political support to stringent climate policies.

As to cost-effective containment of climate damages, international emissions trading plays a decisive role. With purely domestic compliance to NDCs, there can be very large differences in marginal abatement costs across countries indicating a huge potential for cost savings. International emissions trading will exploit these cost savings by letting markets identify where it is cheapest worldwide to reduce emissions. As to equity concerns within societies the recycling of additional revenues from emission pricing is of critical importance. CO_2 pricing will at first glance have regressive impacts on households since poorer households tend to spend larger shares of their income on energy-related consumption categories such as electricity, heat or transport which will get more expensive. However, the regressive impacts of rigorous CO_2 emission pricing can be muted if not offset through lump-sum recycling of additional revenues to households in equal shares.

The findings of the EMF36 study confirm the potential of both instruments – international emissions trading and lump-sum revenue recycling to households – to facilitate ambitious Post-Paris climate policies that are in line with the 2°C temperature target. Under comprehensive global emission trading, the 2°C target is in reach roughly in the range of the cost that individual countries implicitly agreed to with their actual NDCs. CO_2 emission pricing can be implemented in a progressive manner when additional revenues are recycled lump-sum to households in equal shares. The progressive revenue-recycling effect dominates the regressive effects of higher energy prices. In the end, CO_2 pricing in combination with such an ecobonus can make economies not only greener but render the society also fairer in terms of overall income distribution.

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