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Global economic and environmental outcomes of the Paris Agreement

CAMA Working Paper 4/2019
January 2019

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Abstract

In this paper, we use a multi-region model of the world economy to analyze the economic and environmental outcomes that are likely to result from Paris Climate Agreement. To construct the modeling scenario, we convert the disparate emission targets for each country or region in their Nationally Determined Contributions (NDC) formulations into estimated reductions in CO_2 emissions relative to a baseline scenario with no new climate policies. We then solve for the tax rate path on CO_2 in each region that achieves the NDC-consistent emissions reductions in the target year, 2030 for most regions.

We find that if all regions achieve their NDCs, the Paris Agreement significantly reduces CO_2 emissions relative to baseline. However, the Paris policy scenario suggests that global CO_2 emissions would not decline in absolute terms relative to 2015 levels, let alone follow a path consistent with a 2°C stabilization scenario.

Comparing projected 2030 CO_2 tax rates to the same year's percent emissions abatement relative to baseline, we find that declines in CO_2 emissions do not necessarily correlate with the CO_2 tax rate. We find the climate policies result in significant macroeconomic spillovers across the global economy, meaning that macroeconomic outcomes across countries depend not only on their own commitments but also on those of the rest of the world.

We also explore how outcomes could change if select countries (United States, China and Australia) unilaterally withdraw from the agreement and undertake no new climate policies. We find that non-participation leads to economic gains (in terms of GDP) for these countries relative to participating, illustrating the challenge of forging an international agreement with participation by all major emitters and fossil fuel producers. However, we also find that if we account for the monetized climate and domestic co-benefits of emissions reductions, those countries, including Australia, are worse off if they unilaterally withdraw from the Paris Agreement than if they participate. Thus, although we find there are gross costs to participating, doing so generates net benefits for the individual country participants.

GLOBAL ECONOMIC AND ENVIRONMENTAL OUTCOMES OF THE PARIS AGREEMENT*

JANUARY 7, 2019

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1.   INTRODUCTION

The Paris Agreement, adopted by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, has now been signed by 197 countries, arguably making it the first truly global climate change agreement. It entered into force on November 4, 2016, after at least 55 Parties representing at least 55 percent of global greenhouse gas (GHG) emissions joined. The agreement aims to put the world on track to stabilize GHGs at a level that would avoid dangerous climate change, although the specific commitments made in 2015 are not enough to achieve that goal on their own.

Before and during the Paris conference, countries submitted to the UNFCCC national plans that explained what GHG or related targets they plan to achieve. Following through on these Nationally Determined Contributions (NDCs) will have direct and indirect implications for all countries, both environmentally and economically. This paper uses a global general equilibrium model to project the potential economic outcomes if countries meet their NDCs over the next decades as promised. It also explores how those outcomes could change if select countries unilaterally withdraw from the agreement and undertake no new climate policies. For example, in light of the Trump Administration's announcement that the United States will withdraw from the Paris Agreement by 2020, we run the scenarios with and without participation by the United States. We also run simulations with and without China, the world's largest GHG emitter, and Australia, an important fossil fuel exporter.

This study investigates the environmental and economic implications of the Paris Agreement using G-Cubed, a multi-country, multi-sector model of the global economy. We simulate policies that would achieve the commitments of countries in each of the regions in our model and estimate how much global carbon dioxide emissions would fall relative to what would happen without those policies. We also estimate the economic results of the policies in each region, such as how they affect GDP growth, trade, and investment flows. The goal is to understand how environmentally, and economically, ambitious countries' pledges are in absolute terms and relative to each other.

The paper proceeds as follows. Section 2 outlines the NDCs of the regions in the model - converting them into comparable form. Section 3 summarizes other studies of the Paris Agreement with coverage divided into two sections: global studies and national studies of China and the United States. Section 4 presents an overview of the G-Cubed model, which is the basis of the simulation results. Section 4 also outlines the baseline (no new policy) scenario, which projects future economic and environmental outcomes without the Paris Agreement. Section 5 presents the policy scenario results in two parts. The first part presents detailed results for the case when all regions participate in the Paris Agreement. The second part considers the

macroeconomic outcomes when individual regions withdraw from the Paris Agreement. Section 6 concludes.

2. REPRESENTING NDCS IN MODELING SCENARIOS

The formulation of the NDCs varies considerably across countries, including: the range of GHGs covered by the targets; the sectors of the economy to which targets apply; the base year used to establish targets; the year the targets are to be achieved; and the metrics of the targets themselves. To analyze these disparate targets, we first convert them into a common framework for comparison. We then aggregate them, where needed, so that they are suitable for use with the level of geographic detail available in G-Cubed, which is shown in Table 1. We follow the approach in McKibbin et al. (2011), which compared commitments in the Copenhagen Accord.

Table 1. Regions in the G-Cubed Model

Region	Region Description
Australia	Australia
China	China
Europe	Europe
India	India
Japan	Japan
OPEC	Oil-exporting developing countries
ROECD	Rest of the OECD, i.e. Canada, New Zealand and Iceland
ROW	Rest of the World
Russia	Russian Federation
USA	United States

Converting NDC targets into model-relevant emissions paths is a complex problem. In some cases, the targets are straightforward emissions levels in a particular year relative to a historic base year, but we must still specify an emissions path for the years before the target date. In other cases, such as China and India, the targets are expressed as emission intensities (i.e. emissions per unit of GDP). This requires an estimate of projected output to calculate the implied level of emissions. Where the countries in G-Cubed are aggregated into regions, we must calculate a region-wide target. This is most difficult for the Rest of the World (ROW) region, which amalgamates countries with emission targets, intensity targets, and no targets.

One limitation of this study is that the only GHG sources G-Cubed includes are CO_2 emissions from fossil energy combustion, not other GHGs or CO_2 from industrial processes. Thus, to

convert targets into the modeling simulations, we assume that NDC pledges to reduce broader CO_2-equivalent emissions will result in proportional reductions in CO_2 emissions from fossil fuels. For example, the United States' 26 percent reduction target applies to the full U.S. GHG inventory and we simulate a 26 percent reduction in U.S. energy-related CO_2. Thus, the results should be interpreted as approximate estimates of the economic adjustments under the Paris Agreement.

Table 2 summarizes the aggregated and approximated NDCs for each region in the model. For countries that offered alternative targets that would be more stringent under certain circumstances, such as assistance from developed countries, we model the target without such conditions (hence the term "unconditional reduction target" in column 7). For countries that offered a range of emissions targets, we chose the least stringent. Regions such as OPEC, ROECD and ROW involved significantly more analysis; we discuss them in the Appendix and omit them from Table 2 because it is difficult to explain their policies concisely. The reduction target shows the proposed decline in the applicable NDC's metric from the NDC's base year to the target year. For example, India committed to a 33 percent decline in all GHG emissions per unit GDP from 2005 to 2030.

Table 2. NDCs for the Regions in the G-Cubed Model

Region	GHG Coverage	Sectoral Coverage	Metric	NDC Base Year	NDC Target Year	Unconditional Reduction Target
Australia	All GHGs	All sectors	Emissions	2005	2030	-26%
China	CO_2	Energy	Emissions per unit GDP	2005	2030	-60%
Europe	All GHGs	All sectors	Emissions	1990	2030	-40%
India	All GHGs	All sectors	Emissions per unit GDP	2005	2030	-33%
Japan	All GHGs	All sectors excluding terrestrial carbon	Emissions	2013	2030	-26%
OPEC	See Appendix					
ROECD	See Appendix					
ROW	See Appendix					
Russia	All GHGs	All sectors	Emissions	1990	2030	-25%
USA	All GHGs	All sectors including terrestrial carbon	Emissions	2005	2025	-26%

Table 3 reports the CO_2 emissions targets for each region as we have approximated them for the modeling scenario.

Table 3. Targeted CO_2 Emissions from Energy Use for Regions

1	2	3	4	5	6	7
Region	2015 Emissions (MMt)	Target Year	Baseline Emissions in Target Year (MMt)	Target (MMt)	Ratio of Baseline Emissions in Target Year to 2015 Emissions	Ratio of Target to Baseline Emissions in Target Year
Australia	377	2030	457	297	1.21	0.65
China	9,610	2030	18,319	13,340	1.91	0.73
Europe	3,809	2030	4,086	2,540	1.07	0.62
India	1,982	2030	3,864	2,908	1.95	0.75
Japan	1,206	2030	1,526	876	1.27	0.57
OPEC	2,525	2030	3,550	3,212	1.41	0.90
ROECD	590	2030	742	456	1.26	0.61
ROW	5,894	2030	8,780	7,246	1.49	0.83
Russia	1,798	2030	1,933	1,541	1.08	0.80
USA	5,359	2025	5,921	4,440	1.10	0.75

The first column Table 3 lists the region of the model. The second column reports the 2015 level of CO_2 emissions in the region in millions of metric tons, as generated by the model. The third column is the target year of the NDC. The fourth column reports the model's projections of CO_2 emissions from energy use in the target year without policy intervention. This is the target year emissions in the baseline scenario, which we also refer to as the business as usual (BAU) or reference scenario. The fifth column contains the targeted level of emissions in the target year, as we have calculated it per the discussion in the Appendix. The sixth column contains the ratio of projected emissions in the baseline in the target year (2025 for the U.S. and 2030 for all others) relative to emissions in 2015. This reflects the projected growth in emissions without new policies. For example, without new climate policies, the model projects Chinese CO_2 emissions would grow by about 91 percent by the target year and European CO_2 emissions would grow by only 7 percent.

The seventh column contains the ratio of the target emissions relative to the baseline emissions in the target year. This puts in common terms the policy performance needed to hit the NDC targets. This change in emissions in the target year relative to the emissions that would have occurred without the policies to implement the NDCs provides one measure of the economic

ambition of each target. The ratios of target to baseline emissions in column seven vary from 0.57 for Japan, reflecting the greatest percent emissions reduction relative to BAU, to 0.90 for oil exporting countries. By this standard, OPEC offers a significantly less ambitious pledge than other regions. The United States is on par with China and India, and Europe and the rest of the OECD are only slightly less ambitious than Japan. However, as the modeling results will show, this measure does not fully capture the relative macroeconomic impacts of the agreement on different countries.

In addition to the targets in Table 3, the modeling scenario must specify the policies that regions adopt to achieve their targets and the emissions paths they will follow from 2015 to the target in the target year. For simplicity, we model each G-Cubed region as achieving its emissions target using taxes on CO_2 emissions from fossil fuel use. Revenues from the taxes return to households in the region in an annual lump sum rebate. We impose linearly declining annual emissions targets and calculate the CO_2 taxes necessary in each year to achieve them.[1]

3.   OTHER STUDIES OF THE PARIS AGREEMENT

The literature exploring the Paris Agreement is enormous and includes studies using a wide range of methodologies. In this section, we limit our review to studies that use large-scale computational models. Even so, the literature is large. It includes global studies, as well as studies of individual countries. Some studies were undertaken in the lead-up to the Paris negotiations to inform negotiators about proposed NDCs, but many have been undertaken since the agreement. These studies either use announced policies and measures or assume (as we do) illustrative policies implemented to hit a particular emissions target. The studies are not directly comparable because: (1) they assume different targets and different policies to reach those targets; (2) they take different modelling approaches with different assumptions and structures; (3) they focus on different aspects of the Paris Agreement, such as how the NDCs compare to policies that would be sufficient to keep warming below 2°C. This section does not aim to compare these studies, but to provide an overview on the existing literature on modeling the Paris Agreement.

3.1 Global Studies

From a modelling perspective, the global studies on the Paris Agreement fall into three main strands. The first strand uses dynamic computable general equilibrium (CGE) models, which often focus more on macroeconomic aspects of economies. An early study with the same approach as this paper, McKibbin (2015a, 2015b), uses the G-Cubed model to assess the

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[1] This approach does not minimize the intertemporal cost of the emissions reductions achieved. For that, the tax would need to start at a much higher value in 2020 than in our runs and then rise at the real rate of interest. Our taxes start lower but rise much more quickly: typically 15% to 20% per year. A cost-minimizing approach would thus have greater reductions in the near term and smaller reductions in the long term than our policies.

preliminary NDCs that countries proposed in the lead-up to the Paris climate negotiations. The study focuses on results for the United States, China, Japan, the European Union, Australia, and Canada and New Zealand, although all countries were included via the regional aggregations in the model. Under the assumption of continuation of policies in place in 2015, he finds that the Paris commitments have small negative impacts on GDP by 2030 with a loss of 0.1% for the United States, 0.02% for Japan, 0.2% for Europe, 0.8% for Canada, and 0.2 to1% for Australia.

Vandyck et al. (2016) use a global dynamic CGE model (JRC-GEM-E3), supplemented with a global partial-equilibrium energy model (JRC-POLES) for more disaggregation on energy sectors, to assess the implications of three scenarios: the baseline, the NDCs and the 2° scenario.[2] They find that the NDCs have little impact on global demand for oil and gas, and that energy demand reduction and decarbonization of power sectors are important contributors to overall emission reductions. The analysis shows that the NDC and 2°C scenarios both lead to small global GDP losses (-0.42% and -0.72% respectively). Their results also indicate that the Paris commitments of some regions are not ambitious such that their emissions targets are close to or even higher than their baseline levels in 2030. They also find that a substantial gap remains between the global emissions in the NDCs and 2°C scenarios in 2030.

Fujimori et al. (2016) assess the benefits of carbon emission trading on achieving the NDCs and the 2°C goal using a global dynamic CGE model (AIM, see Fujimori et al. 2012). They show that the global welfare loss of achieving NDCs, which is measured based on estimated household consumption change in 2030, is 0.47% without emissions trading, and falls significantly to 0.16% with emissions trading. Furthermore, achieving the 2°C target without emissions trading leads to a global welfare loss of 1.4 to 3.4 percent depending on the burden-sharing scheme, while implementing emissions trading reduces the loss to around 1.5 percent.

More recently, Kompas et al. (2018) develop an intertemporal version of the GTAP model, which allows forward-looking behavior in investment. They estimate economic impacts of different global warming scenarios in the range from 1 to 4°C for 139 countries. They follow van Vuuren et al. (2011) to translate temperature goals into emissions control policies, and conclude that while global mean temperatures could increase up to 4°C without any countervailing action to reduce emissions, implementation of the Paris Agreement would slow global warming to around 2°C by 2100. They then estimate the potential benefits of the Paris Agreement as the difference in losses between the 4°C and 2°C scenarios.

The second strand uses integrated assessment models (IAMs), which often include an environmental system in addition to economic and social components. For example, Fawcett et

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[2] See the CGE model JRC-GEM-E3 at https://ec.europa.eu/ jrc/en/gem-e3/ and the energy model JRC-POLES at https://ec. europa.eu/jrc/en/poles.

al. (2015) use a global integrated assessment model (GCAM)[3] to develop emissions pathways and then use a climate change model (MAGICC, see Meinshausen et al. 2011) to estimate probabilistic temperature outcomes. They find that the Paris scenario reduces the probability of temperature change exceeding 4°C in 2100 by 75% compared with the no-policy scenario, but it has only a chance of 8% to limit warming to 2°C in 2100.

Akimoto et al. (2016) analyze economic costs for achieving the NDCs using a global dynamic linear programming energy model (DNE21+, see Akimoto et al. 2010). They find that the marginal abatement costs of Japan and the European Union are high ($378 and $ 210 per ton CO_2 respectively) while marginal costs of China, India, South Africa and Russia are close to zero, with the United States in the middle ($85 per ton CO_2). The emissions in the NDC scenario is larger than the pathways consistent with the 2°C goal by 2100, and the size of the gap depends on the climate sensitivity.

Hof et al. (2017) estimate abatement costs of achieving the NDCs and the 2°C goal based on a bottom-up integrated assessment model (IMAGE, see Stehfest et al. 2014). They find that abatement costs are very sensitive to socio-economic assumptions. Of the ten major emitting economies, Brazil, Canada and the United States have the highest costs as a share of GDP to implement the conditional NDCs, while the costs for Japan, China, Russia and India are relatively low. They also find that allowing international emission trading could decrease global costs substantially, by more than half for the unconditional NDCs and almost by half for the conditional NDCs. The abatement costs of achieving 2030 emission levels consistent with 2°C pathways would be at least three times higher than the costs of achieving the conditional NDCs.

Kaya et al. (2015) examine the effect of uncertainty of climate sensitivity on achieving emission targets based on the energy model DEN21+ and the climate model MAGICC. They show that the global NDCs are not on track for the 2°C target with a climate sensitivity of 3°C but are compatible with the target with a climate sensitivity of 2.5°C.

The third strand uses partial-equilibrium or reduced-form energy models, which often have more detail in energy sectors. For example, Kitous and Keramidas (2015) use a global partial-equilibrium energy model (JRC-POLES) to explore the NDCs. They find that the implementation of the NDCs and prolonged efforts after 2030 result in global emissions peaking in 2035 (unconditional NDCs) or 2030 (unconditional and conditional NDCs). The emissions in the two NDC scenarios result in a global temperature increase of around 3°C by 2100.

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[3] See the GCAM model at http://www.globalchange.umd.edu/gcam/.

More recently, Parry et al. (2018) use a reduced-form energy model to project energy use and carbon emissions to 2030 for the G20 economies and then evaluate the impacts of various mitigation instruments. In their key scenario where the CO_2 tax rises in an annual increment of $5 per ton of CO_2 from 2017 onwards to reach $70 per ton by 2030, seven countries meet or exceed their NDCs, six countries would need further reductions of up to 10 percent, and another six would need further reductions of above 10 percent. This wide dispersion reflects both differences in countries' NDCs stringency and in the relative price responsiveness of emissions. Tax revenues are potentially large, typically around 1 to 2.5% of GDP. The economic welfare costs (losses in consumer surplus less government revenues) of CO_2 taxes are less than 0.8% of GDP in 2030 in all but three countries (China, India and South Africa) whose costs are 1-1.6% of GDP. Accounting for local environmental benefits (but not global warming), the net domestic welfare gains are quite large for some countries: 0.7% of GDP in Korea, 2.3% in India, 3.7% in Russia and 6.7% in China. These results suggest that many G20 countries can move ahead unilaterally with carbon pricing expecting positive net welfare gains.

To understand the implications of different modelling approaches and identify which results are robust and which are not, some authors have done comparison studies. For example, Aldy et al. (2016) use four integrated assessment models (DNE21+, GCAM, MERGE and WITCH) to assess and compare the NDCs across countries. They find that wealthier countries pledge to undertake greater emissions reductions with higher costs. They also find that marginal abatement costs vary across countries by two orders of magnitude, illustrating that large efficiency gains are available through joint mitigation efforts and carbon price coordination.

Rogelj et el. (2016) assess the implications of NDCs for global GHG emissions in 2030 based on a wide range of global NDC analyses.[4] Their comparison suggests that the studies reveal a wide range of estimates of future emissions, and they identify four key factors that contribute to the differences: incomplete coverage, uncertain projections, land-use-related emissions, and historical emissions and metrics. They conclude that the NDCs collectively lower emissions compared to current policies, but still imply a median warming of 2.6 to 3.1°C by 2100.

3.2 Single Country Studies

3.2.1 The United States

Vine (2016) draws on forecasts from the U.S. Energy Information Agency (EIA) and the U.S. Environmental Protection Agency (EPA), and estimates that GHG emissions in the United States would fall by 22% in 2025 relative to 2005. Larsen et al. (2017) model the impact of current policies on GHG emissions for the United States using the National Energy Modelling

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[4] These global NDC analyses include Climate Analytics, Ecofys, NewClimate Institute & PIK (2015), Admiraal, A. et al. (2015), IEA (2015), Boyd et al. (2015), Meinshausen (2015), DEA (2015), Climate Interactive (2015), Fawcett et al. (2015), UNFCCC (2015), Kitous and Keramidas (2015), den Elzen et al. (2015).

System developed by the EIA, and find that under current policy, the United States is on course for a 15-19% reduction in GHG emissions by 2025, which is considerably short of its 26-28% commitment in its NDC.

Chen et al. (2018) use GCAM and MAGICC models to assess the effect of the U.S. withdrawal in two scenarios: a temporary delay until 2025 and a complete stop after 2015 in mitigation actions. They find that the probability of achieving the 2°C goal would decrease by 6-9% even if the U.S. resumes mitigation efforts for achieving its NDC after 2025. Without U.S. participation, increased reduction efforts required for the rest of the world to achieve the 2 °C goal result in significantly higher global cumulative mitigation costs from 2015 to 2100.

The Energy Modelling Forum 32 examines the economic and environmental impacts of various carbon tax scenarios (tax pathways and revenue recycling options) for the United States. The results are summarized in McFarland et al. (2018). Although these exercises are not directly relevant to the Paris Agreement, they provide insights on the design of CO_2 taxes, the policy instrument we apply here. They find that CO_2 taxes must increase at a fairly high rate (5% every year) to sustain reductions in emissions as the U.S. economy grows. They also find that when the United States adopts a CO_2 tax unilaterally, international CO_2 leakage does not significantly undermine the emissions reducing objective.

3.2.2 China

Fu et al. (2015) analyze China's NDC based on a partial-equilibrium energy model for China (PECE, Renmin University and NCSC) and show that carbon intensity of GDP decreases quickly in the NDC scenario from an annual rate of 3.9% over 2005-2020 to 4.4% over 2020-2030, followed by 6.3% and 9.2% in the following two decades respectively. They point out that China faces several challenges in achieving its NDC targets, including the stage of economic and social development, the economic structure, the energy structure, technological capacity, institutional and policy constraints, etc.

McKibbin et al. (2015) assess two policies (economy-wide and electricity-only emissions trading systems) that China could adopt to achieve its NDC based on the G-Cubed model. They show that illustrative policies to achieve China's commitment of emissions peaking in 2030 imply a substantial departure from baseline emissions, even after accounting for large baseline reductions in China's emissions intensity. In their scenarios, China's real GDP would be about 1.5 percent lower than the baseline in 2030. Both policies operate mainly through reducing the use of coal. Under the economy-wide permit system, the reductions are spread throughout the economy while under the electricity-only policy they are concentrated in the electric sector. However, both policies have similar impacts on real GDP and its components. They also find that China's policies to control emissions have little effect on emissions elsewhere.

Qi et al. (2016) use a global CGE model (the China-in-Global-Energy Model) to analyze the combined impact of low-carbon energy policies and extending emissions intensity targets through 2050 implemented via a cap-and-trade program.[5] Although the policy reduces emissions significantly by 43% in 2050 relative to the no-policy reference, but China's emissions still increase by over 60% between 2010 and 2050. China's goal of peaking emissions by 2030 requires a CO_2 price higher than $25. Weng et al. (2016) use the same model to simulate carbon price paths for achieving China's NDC in different uncertainty scenarios, which can serve as the floor prices for China's national carbon emissions trading system to ensure the achievement of its NDC.

Parry et al. (2016) develop a reduced-form energy model to project carbon emissions to 2030 with exogenous projections of energy prices and GDP as inputs, and evaluate a wide range of national level fiscal and regulatory policy options for reducing carbon emissions in China. They conclude that carbon and coal taxes are the most effective policies for meeting environmental and fiscal objectives as they comprehensively cover emissions and have the largest tax base.

Timilsina et al. (2018) use a dynamic CGE model of China to simulate various schemes of carbon taxes. They find that an increasing carbon tax that starts at a small rate in 2015 and rises to a level to meet the NDC target in 2030 would cause smaller GDP loss than the carbon tax with a constant rate would do. In addition, the GDP loss due to the carbon tax would be smaller when the tax revenue is utilized to cut existing distortionary taxes than when it is transferred to households as a lump-sum rebate.

Liu et al. (2017) survey a number of recent modeling scenarios that project China's economic growth, energy mix and carbon emissions until 2050 based on a wide range of models.[6] Their analysis suggests that China's emissions will continue to grow until 2040 or 2050 and will double their 2010 level without additional policy intervention. The emissions estimates by 2030 vary significantly across models with the growth rate ranging from 21% to 119% in 2030 relative to 2010, with the median value of 77%. Peaking emissions around 2030 requires the annual emissions growth rate to be reduced by 2% below the reference level, and the emissions reduction will be largely dependent on penetration of renewable energy.

The studies summarized here use a wide variety of modeling approaches and focus on a number of global and national issues related to the Paris Agreement. This paper fits into the first strand of global studies that use dynamic CGE models. Our contribution to the literature is three-fold. First, we apply a global macroeconomic model that uniquely incorporates financial markets, transitional responses of central banks, and international capital flows driven by

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[5] See the model at https://globalchange.mit.edu/publication/16001.
[6] These include six models mentioned before (AIM, DNE21+, GCAM, IMAGE, JRC-POLES, PECE), and another six models China-MARKAL, DDPP, ERI-3E, GEM-E3, MESSAGE and WEM. See more details in their paper.

intertemporal savings and investment decisions. Importantly, a proportion of firms and households have forward-looking expectations, and this anticipation of NDC policies significantly affects short run dynamic adjustments. Second, we consider the implication of selective withdrawal from the Paris Agreement by select countries, including the United States, China, and Australia. Third, we present a broader set of measures of the economic and environmental outcomes of the Paris Agreement. We calculate the economic outcomes and welfare effects of the NDC policies, as other studies have done. We also estimate the monetized domestic co-benefits of reductions in fossil energy use and the global climate benefits (through 2030) contributed by each participating region in the model. This allows us to calculate the net domestic benefits of the agreement to each region.

Several caveats apply to our modeling study, many of which would apply to any modeling study of this kind. The caveats primarily involve necessary simplifying assumptions. For example, owing to the structure of the model, we assumed that the NDC target reductions apply only to CO_2 from fossil energy use. To the extent that a country has significant baseline shifts in land use emissions, non-CO_2 GHGs, and the like, the stringency of the target we estimate could be higher or lower than would apply in practice. Likewise it might have abatement costs for other sources that are importantly higher or lower than those for energy-related CO_2. Also, for simplicity we assumed countries achieve their NDC targets with a stylized policy: a CO_2 tax that applies to all fossil fuels and the revenue of which is rebated to households in a lump sum fashion. If countries adopt much less efficient policies or use the tax revenue differently, the macroeconomic outcomes could be different. For a modeling study of how revenue use matters, see the Energy Modeling Forum 32 project described in McFarland et al. (2018).

To construct a policy scenario, we must make assumptions about what happens in the years other than those of the Paris Agreement targets. For each region, we solved for the annual CO_2 taxes, starting in 2020, that produce a linear decline in emissions levels from 2020 baseline levels to the NDC target in the target year. After the target year, we assumed CO_2 tax rates stay at their target year levels.

A key element of the Paris Agreement is the prospect of increasing the ambition of commitments every five years. Anticipation of these future more-stringent commitments could affect the emissions levels and economic outcomes we report here. In Article 6, the Paris Agreement also allows for international transfer of "mitigation outcomes," suggesting the potential for some kind of emissions trading that could lower overall costs. We assume each region achieves its target unilaterally.

4.   MODELING APPROACH AND BASELINE PROJECTIONS

We extended the G-Cubed model to make it more suitable for analyzing the Paris Agreement.[7] The model version used here has new country coverage for India and the Russian Federation, as well as a revised regional aggregation for Europe, which now includes both Western and Eastern European economies consistent with the Paris Agreement groupings. The complete list of geographic regions in the model appears in Table 1.

The electricity sector in G-Cubed was also recently revised and now includes eight specific generation technologies: coal, natural gas, oil, nuclear, wind, solar, hydro and other (largely biomass and other renewables). A technical discussion of recent modeling improvements appears in McKibbin et al. (2015). The full list of sectors in the model is shown in Table 4.

Table 4. Sectors in the G-Cubed Model

Number	Sector Name	Notes
1	Electricity delivery	Energy Sectors Other than Generation
2	Gas utilities	
3	Petroleum refining	
4	Coal mining	
5	Crude oil extraction	
6	Natural gas extraction	
7	Other mining	Goods and Services
8	Agriculture and forestry	
9	Durable goods	
10	Nondurables	
11	Transportation	
12	Services	
13	Coal generation	Electricity Generation Sectors
14	Natural gas generation	
15	Petroleum generation	
16	Nuclear generation	
17	Wind generation	
18	Solar generation	
19	Hydroelectric generation	
20	Other generation	

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[7] See McKibbin and Wilcoxen (2009, 2013) for the details of the G-Cubed model.

The Baseline (Business as Usual) Scenario

We first solve the model from 2016 to 2100 for a baseline, or business as usual (BAU) scenario. This scenario assumes that regions continue policies they have already adopted, but do not undertake new policies to achieve their NDCs. Our approach to generating a baseline projection (which is complex in a model with rational expectations) is outlined in detail in McKibbin, Pearce and Stegman (2007). A comparison of the long-term projections with other global economic models in an earlier exercise appears in Stegman and McKibbin (2013).

The key inputs into the baseline are the initial dynamics leading into 2016 (that is, the evolution of the economy from 2015 to 2016) and subsequent projections from 2016 forward for labor force growth and productivity growth by sector and by country. We take the labor force growth from the United Nations Population Projections (2018). The productivity projections are generated following the approach of Barro (1991) and updated in Barro (2015). Over long periods of time, Barro estimates that the average catchup rate of individual countries to the world-wide productivity frontier is 2% per year. We use the Groningen Growth and Development database (2018) to estimate the initial level of productivity in each sector of each region in the model. Given this initial productivity, we then take the ratio of this to the equivalent sector in the United States, which we assume is the frontier. Given this initial gap in sectoral productivity, we then use the Barro catchup model to generate long term projections of the productivity growth rate of each sector within each country. In the case where we expect that regions will catch up more quickly to the frontier due to economic reforms (e.g. China) or more slowly to the frontier due to institutional rigidities (e.g. Russia), we vary the catchup rate over time.

The exogenous sectoral productivity growth rate, together with the economy wide growth in labor supply, are the exogenous drivers of sector growth for each country. The growth in the capital stock in each sector in each region is determined endogenously within the model.

Given assumptions about monetary policy rules, fiscal rules, and other institutional rigidities in the model, we then assume no further climate policies are adopted in the baseline beyond those that existed in 2015 prior to the Paris Agreement. When we do this exercise, we find that economic growth and energy-related CO_2 emissions for some regions may deviate from the EIA's Annual Energy Outlook (AEO, 2018) and other national official forecasts. To generate a BAU scenario that is closer to official projections, we then adjust sectoral productivity to more closely approximate the AEO and other official projections.

The GHG emissions included in G-Cubed comprise only CO_2 from fossil fuel consumption, including combustion of coal, natural gas, and oil. Figure 1 shows the model's BAU projections from 2015 to 2030 for global CO_2 emissions from energy use across the major regions in the model. These projections do not include the NDC pledges that countries made as part of the

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Paris Agreement. Importantly, they also do not include any impacts on the global economy of climate disruption, and neither do the modeling results for the policy scenarios. G-Cubed does not include the economic impact of climate damages, but later in the paper we monetize the climate benefits from the policies we model using an estimate of the social benefit of reducing each ton of CO_2.
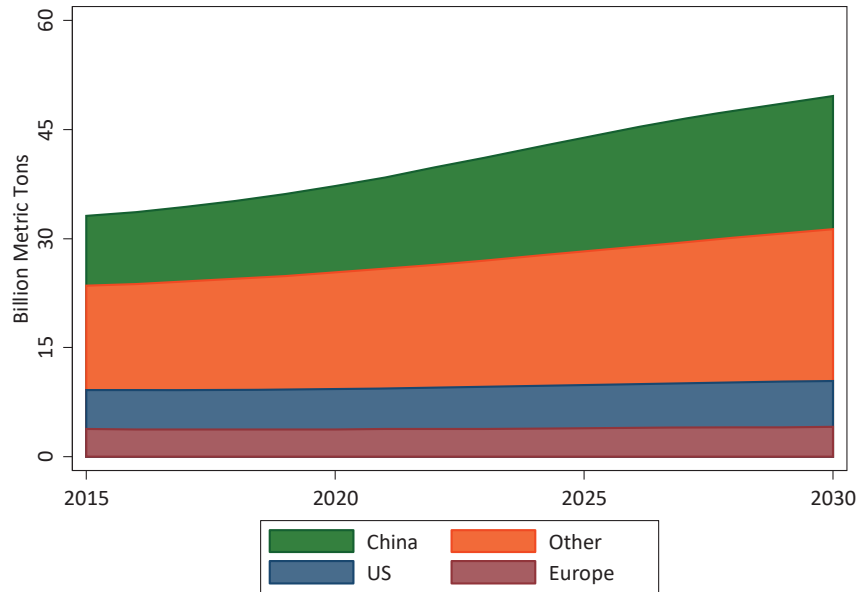
Figure 1. Global BAU CO_2 Emissions

Figure 2 presents the BAU projections for the regions in the model labeled as "Other" in Figure 1, the wedge in orange. Figure 2 illustrates the rising levels of emissions from emerging economies included in ROW and the increasing importance of India in global emissions.

Figure 2. BAU CO$_2$ Emissions for Other Regions
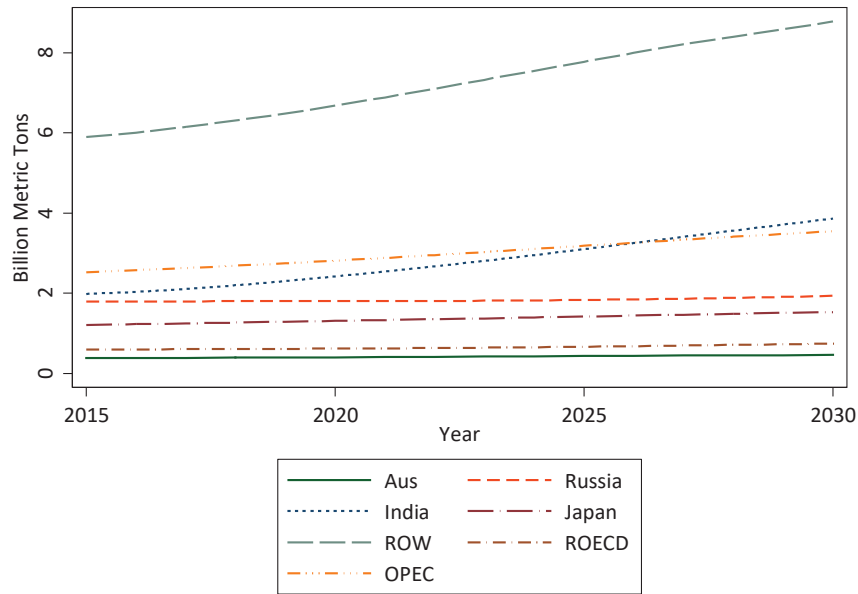
Figure 3 reports the emissions data from the previous figures as annual growth rates by region. The rates of growth in China and India, the two highest curves, stand out. While CO$_2$ emissions per capita are low in these regions, their annual growth rates are high compared to the others.

Figure 3. Annual BAU Emissions Growth Rate for Each Region
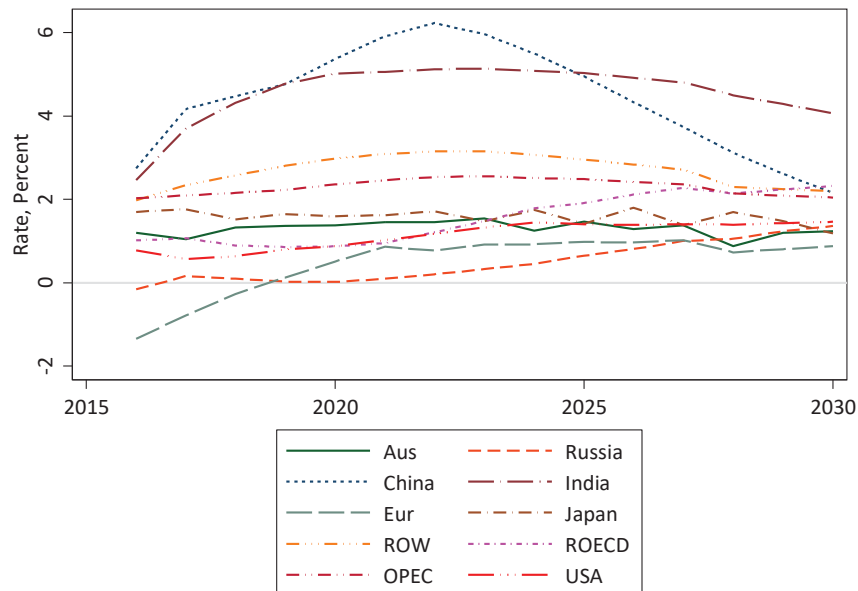
These results suggest that without the implementation of the Paris NDCs, growth in global CO$_2$ emissions from energy use would be large and clearly inconsistent with stabilizing

atmospheric GHG concentrations. We also observe an increasingly large impact from emerging countries, particularly China and India.

It should be stressed that any economic projections out to 2100 are highly uncertain. In particular there is enormous uncertainty regarding technological innovations that may occur in end-use energy efficiency, renewable electricity generation, electricity storage and transmission, biofuels, and fossil fuel supplies. Some innovations, particularly in renewable electricity generation, could lower BAU emissions and reduce the cost of reaching any given climate target. Our results thus rely to a significant extent on the assumptions used in constructing the BAU scenario. As indicated in Table 5, our baseline includes a significant amount of renewable energy penetration over the coming decades, especially in Australia, India and the United States. These results are driven by the interaction between assumptions we make regarding the rate at which costs decline and endogenous price-driven responses by energy users in the model. If the costs of renewables fall faster than we have assumed, the Paris NDCs will be easier to achieve and the impacts of the agreement (both economic and environmental) will be smaller than we report. On the other hand, if our projections for renewables are too optimistic and costs fall more slowly, impacts of the agreement would be larger.

Table 5: BAU Renewable Electricity by Region, Percent of Total Generation

Region	Renewable Electricity in 2015	Renewable Electricity in 2030	Change in Renewable Electricity 2015-2030
Australia	9.8	30.4	20.6
China	12.8	18.1	5.3
Europe	44.8	48.9	4.1
India	12.6	23.1	10.5
Japan	24.5	25.8	1.3
OPEC	2.8	2.7	-0.1
ROECD	67.8	65.3	-2.5
ROW	21.4	21.6	0.2
Russia	5.3	5.5	0.2
USA	28.4	42.7	14.3

5. OUTCOMES OF THE PARIS AGREEMENT

We start by assuming that in 2016 — when the agreement entered into force — each region explicitly announced that starting in 2020 it will impose a policy sufficient to achieve its Paris pledge. Further, we assume that each region achieves its targets in Table 3 by reducing its emissions linearly from its baseline level in 2020 to its target level in the country's target year. Finally, we assume that regions achieve their year-by-year emissions targets by imposing a series of year-by-year taxes on CO_2 emissions with revenue from the taxes returned to households via lump-sum rebates[8]. We then solve for the taxes that will be needed, and examine the economic and emissions outcomes. This "Paris" scenario will be our central set of results in the figures and tables below.

Although in practice countries may use other policies to reach their NDC goals, we use CO_2 taxes with lump-sum recycling across the board for three reasons. First, by imposing a common approach, we are able to examine how differences in outcomes depend on differences between the economies of the regions rather than on differences in the policies used. Had we used different policies in different regions, it would not be possible to determine whether differences in outcomes arose from differences in the policies or differences in the underlying economies. Second, a tax on CO_2 is the most straightforward example of a wide range of carbon pricing policies that could be used, including taxes, emissions trading, or hybrid policies. There is broad agreement in the economics literature that carbon pricing would have the lowest economic costs among policies that would achieve any given emissions target. Third, using an emissions tax provides a direct and transparent way for us to measure the marginal cost of each region's target.

In addition to examining the full Paris Agreement, we explore the implications of unilateral non-participation by three regions: the United States, China and Australia. These illustrate interesting aspects of different regions in implementing the agreement. We choose the United States in light of its announced withdrawal from the Paris Agreement by 2020; China because of its role as the world's largest emitter, and because it has a high BAU path of emissions; and Australia because fossil fuels are one of its major exports. In all three cases, we assume that regions remaining in the agreement adjust their policies as needed to continue to hit their Paris targets.

It should be stressed that our results for the non-participation cases are intended only to illustrate the economic impact of participating or not in the Agreement, all other things equal. They are not in any sense policy proposals. Moreover, they do not include international political

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[8] There is a large literature on the importance of revenue recycling. See McKibbin et al. (2015) for a summary and an analysis with the G-Cubed model.

consequences of any sort or any kind of economic retaliation against countries that withdraw, so in that sense they are likely to be overly optimistic about the benefits to non-participants of withdrawing .

5.1 Global Action

Figure 4 shows the path of global CO_2 emissions from energy use under five scenarios: BAU, Paris, and the three scenarios with a single non-participant ("US out," "AUS out," and "CHI Out"). The Paris Agreement significantly reduces emissions relative to BAU; emissions are lower than baseline by 13 billion tons by 2030. However, emissions are still not declining in absolute terms, let alone following a path consistent with a 2°C stabilization scenario.

Figure 4. Global CO$_2$ Emissions Levels under Paris and Other Scenarios
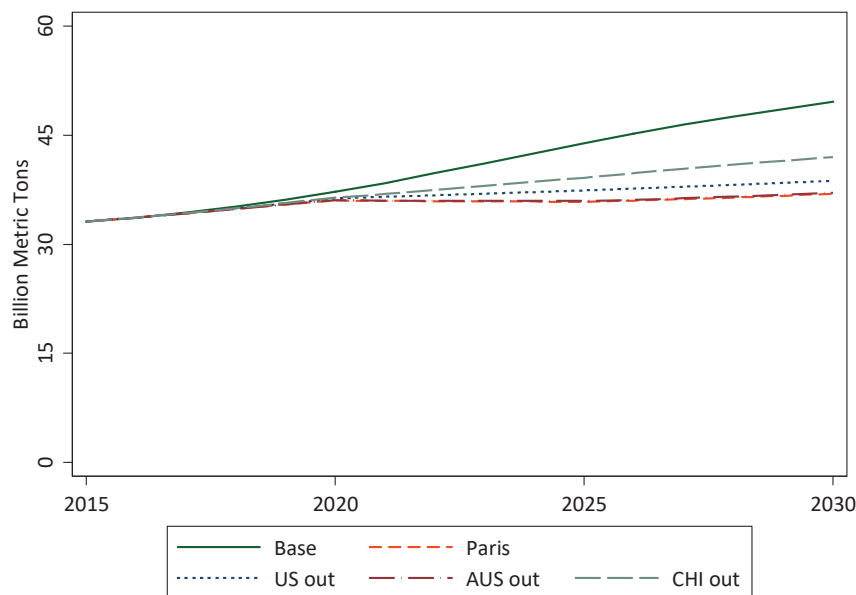
Figure 4 also shows that among the three opt-out scenarios, the biggest increase in emissions would result from the departure of China. Almost half of the reduction in global emissions comes from China's participation, so China's withdrawal would dramatically reduce the effectiveness of the agreement. Further implications of the opt-out scenarios are discussed in Section 5.2.

Figure 5 shows the change in the growth rate of emissions in each region under the Paris Agreement. Emissions begin to change in 2016 in anticipation of the CO_2 taxes that will take effect beginning in 2020. We assume the CO_2 taxes remain constant after the target year, which is 2025 for the United States and 2030 for all other regions. Once the taxes stabilize, economic growth causes each country's emissions growth to revert gradually to its baseline rate, although the level of emissions remains permanently below BAU. Two regions with

unusual trajectories are the United States, which has an earlier target year than the others, and China, whose existing policies under BAU begin sharply reducing the growth of emissions after 2020 even without additional policies to hit its NDC target.

Figure 5. Change in CO$_2$ Emissions Growth Rate under Paris relative to BAU
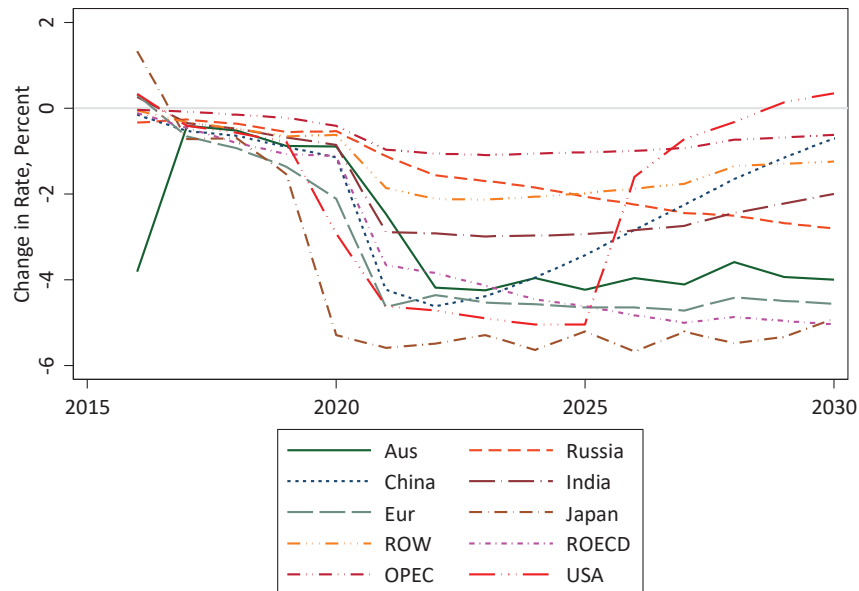
The reduction in the growth rate in emissions ranges from a low of one percent for OPEC to nearly six percent for Japan. The absolute reduction in emissions differs enormously across regions because of the scale of each country's emissions, as shown in Figure 6. The biggest reduction in emissions is from China, followed by the United States.

Figure 6. Change in CO$_2$ Emissions under Paris Relative to BAU
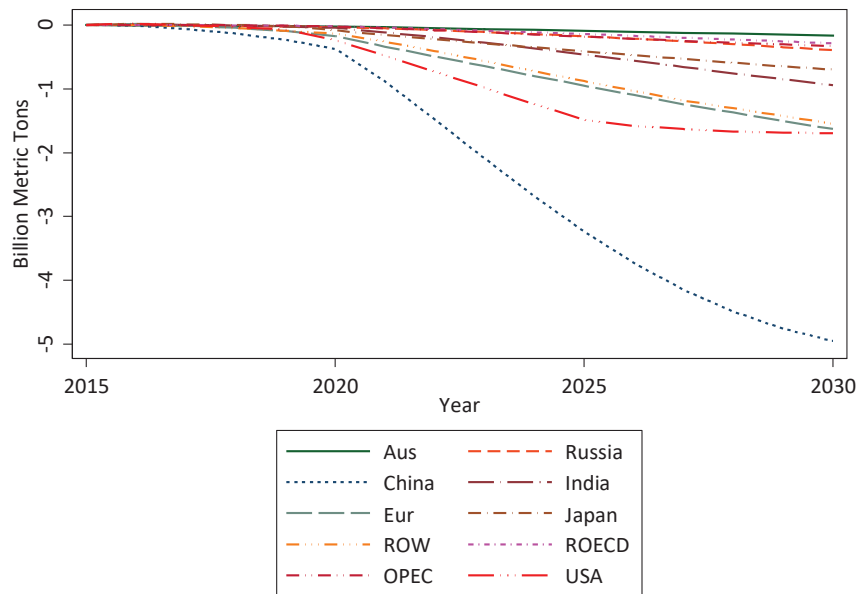
Figure 7 shows the percentage change in emissions under Paris relative to the BAU scenario. Note that this is not the change relative to a historical year's emissions (which is the formulation of many NDCs) but rather the percentage change relative to what emissions would have been without the emissions control policy. Anticipation of the taxes starting in 2020 cause declines in fossil fuel CO$_2$ between 2016 and 2020, particularly in Australia. By 2030, emissions reductions mirror the target-to-baseline figures in column seven of Table 3. For example, OPEC emissions fall by about 10 percent relative to BAU, and Japanese emissions fall by almost half. U.S. emissions are down by about 25 percent by its target year of 2025 and remain constant thereafter.

Figure 7. Percent Change in CO$_2$ Emissions under Paris Relative to BAU
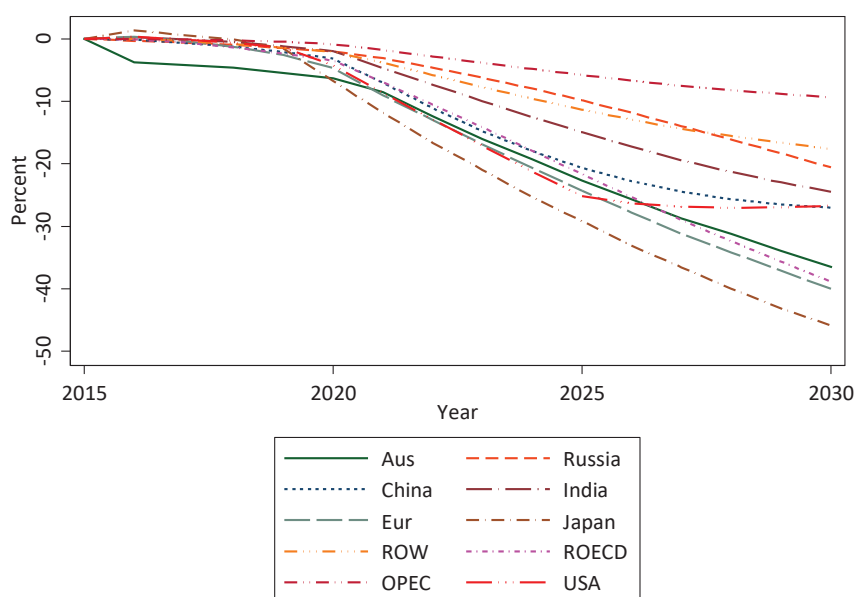
Figure 8 shows the CO$_2$ tax trajectory for each region. We express all dollar values in this paper in constant 2015 dollars. Owing to anticipation, by 2020 almost all regions' emissions are already below BAU, and therefore their initial CO$_2$ taxes in 2020 are zero. This is not the case for the United States, because financial capital flows into the United States at rates above BAU between 2016 and 2020 as returns on investment in the United States go up relative to other regions. The U.S. tax is therefore positive in 2020: $US 2. In all regions, the tax increases over time until the target year, at which point it levels off by design. By 2030, CO$_2$ taxes vary by an order of magnitude across regions, from $US 5 in Russia and Australia to $US 44 in India. With only five years of policy implementation before its 2025 target year, the U.S. tax is higher than in other regions, leveling off at $US 26 per ton.

Comparing the 2030 tax rates in Figure 8 to the 2030 percent emissions abatement in Figure 7, we see that the percent decline in emissions does not necessarily correlate with the tax rate. For example, Japan's emissions decline by 46 percent relative to BAU, but its CO$_2$ tax is the fourth lowest at $US 16. India and the United States share a common target reduction of 25 percent, but India's tax is $US 18 (about 70 percent) higher than that in the United States.

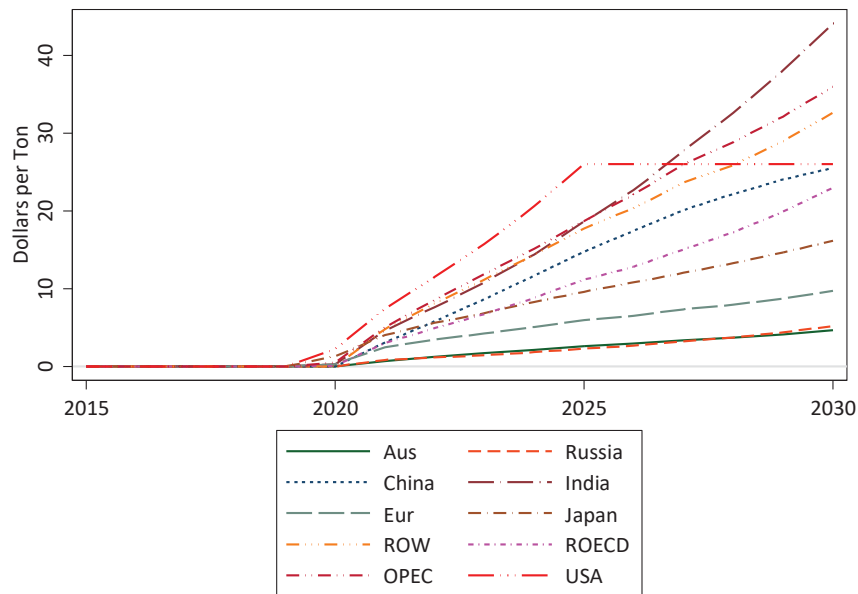**Figure 8. Tax Rates on CO$_2$ under Paris**

Figure 9 shows the change in GDP relative to BAU for all regions. Recall that in G-Cubed, neither the baseline nor the policy scenario account for the economic effects of climatic disruption. Owing to the anticipation of the policy, GDP falls for some regions beginning in 2016 even though the actual taxes do not take effect until 2020. GDP is below BAU for all regions between 2020 and 2030 and it falls most for OPEC and Russia, which rely heavily on fossil fuels as both a domestic energy source and as an export. In the period prior to 2020, Australia experiences relatively large GDP declines owing to anticipation of its own policies and those of the rest of the world. However, over time, the increased penetration of renewables and lower use of fossil fuels along Australia's baseline path reduce its losses relative to other regions (see Figure 3, where Australia's emissions growth is among the lowest of the regions during the years between about 2024 and 2030). The United States experiences a decline of about one half of one percent of GDP in its target year of 2025 relative to its baseline real GDP growth from 2015 to 2025 of over 20 percent.

Figure 9. Change in Real GDP under Paris Relative to BAU
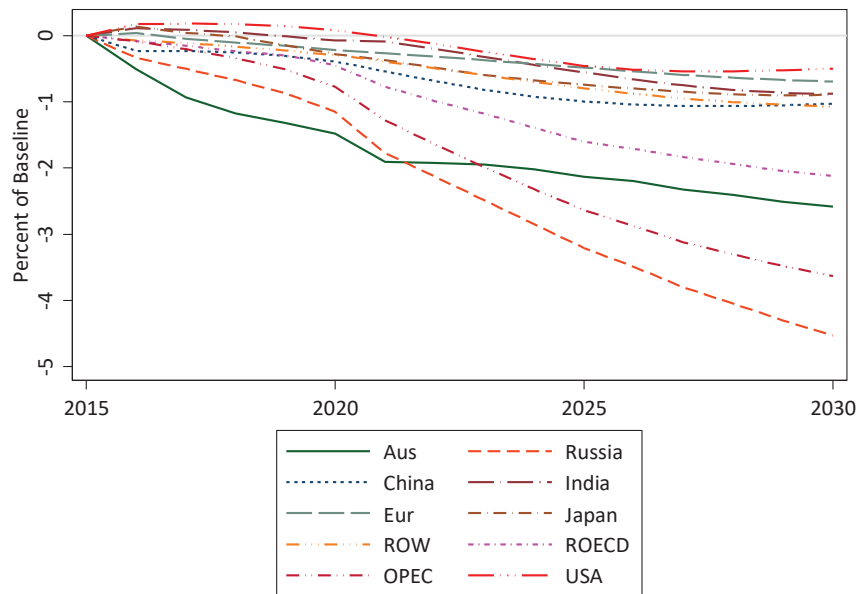
We examine the change in the components of GDP across regions in the next few charts. Figure 10 shows the change in private consumption relative to BAU. Initially, consumption rises (except in Russia and Australia) and then gradually falls. Three main factors drive this path for consumption. First, revenue from the CO_2 tax goes back to households via lump sum rebates. In the model, only 30 percent of consumers are forward-looking (i.e. 70 percent are liquidity constrained), and therefore the additional household income from rebates raises consumption for a number of years (until the tax is high enough to slow the economy significantly). Second, the tax reduces investment because the after-tax return on capital in fossil fuel sectors falls. Even though investment in renewables rises, the investment decrease in fossil fuel sectors and fossil-fuel-intensive activities dominates that in the short run, so total investment falls. As investment declines, firms reduce retained earnings and hence provide relatively larger dividends to households, which helps to boost consumption further. Third, the fall in real interest rates causes forward-looking households to discount their future income at a lower rate, which tends to raise wealth, and thus consumption, in the near term.

Figure 10. Change in Private Consumption under Paris Relative to BAU
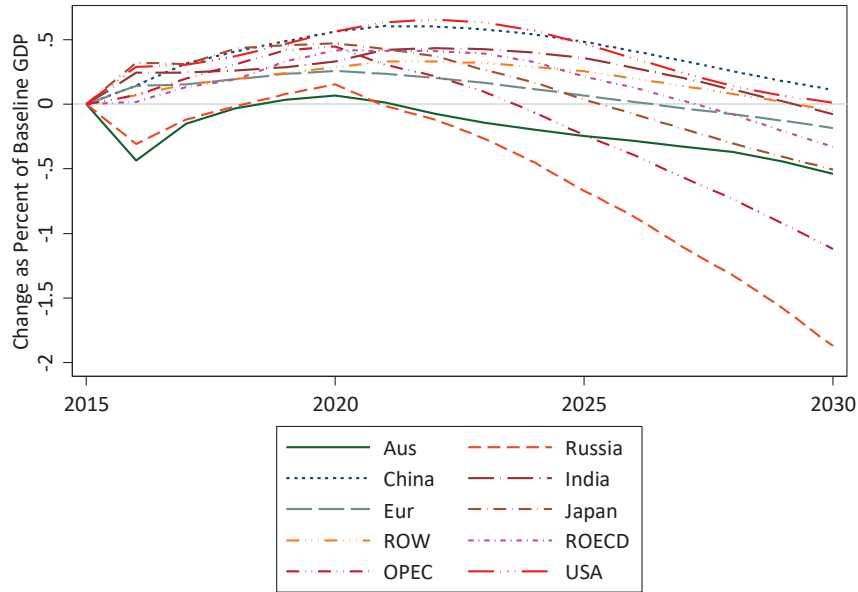

Figure 11 reports the change in total investment under Paris relative to BAU. For most regions investment falls immediately in 2016 in anticipation of the policy; the only exception is the United States where, as noted above, capital inflows raise total investment. Investment levels remain below BAU throughout the simulation, but start to recover after the target years.

Figure 11. Change in Total Investment under Paris Relative to BAU
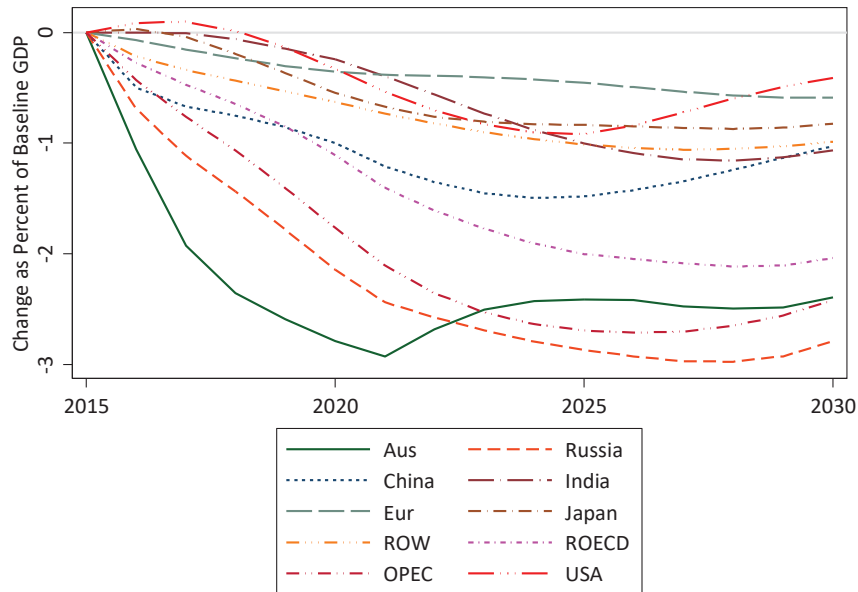
Figure 12 shows the change in each region's trade balance (exports minus imports). Regions that experience relatively large falls in investment experience outflows of financial capital, which depreciate their real exchange rates, increase exports, and decrease imports, thus strengthening their trade balances. Regions that attract foreign capital, such as the United States, experience the reverse: an appreciation of the real exchange rate and a decline in the trade balance. Because Australia relies heavily on fossil fuels for its own use and as a source of export revenue, it experiences a large fall in investment, a significant capital outflow, and the largest depreciation of the real exchange rate (see Figure 14).

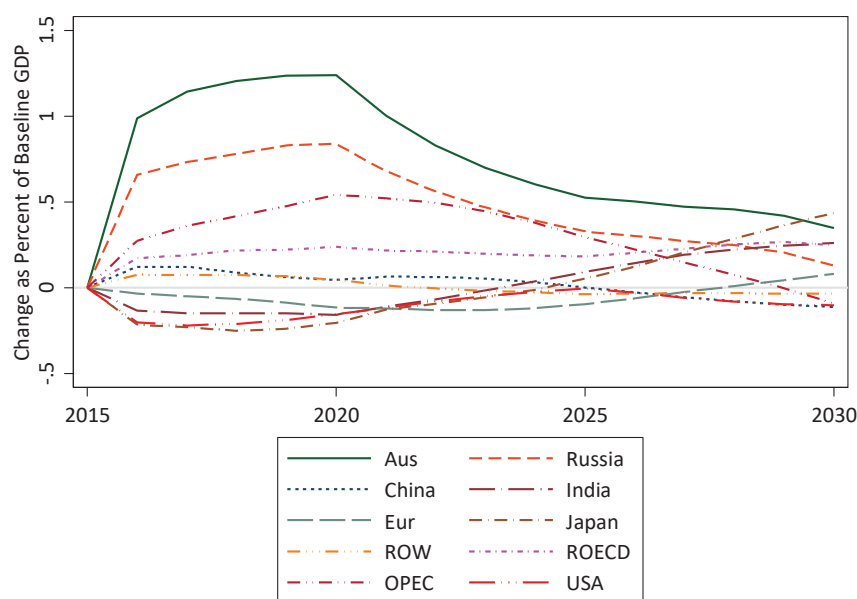**Figure 12. Change in Trade Balance under Paris**

Figure 13 shows short run interest rates in each region. In the long term, the real interest rate is determined by the marginal product of capital in each region. In the short term, the real interest rate is the policy interest rate set by the central bank in each region minus the change in expected inflation. In the model, each region's central bank sets the policy rate by following a Henderson-McKibbin-Taylor Rule.[9] Interest rates will rise if either output growth or inflation are above the central bank's targets for these variables. The central banks in some regions also target the exchange rate (China, Russia, and ROW).

The CO_2 tax has two impacts on these monetary rules. First, it causes energy prices to rise, which increases inflation and, other things equal, would cause central banks to raise interest rates. Second, it slows economic growth which, other things equal, would cause central banks

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[9] See Henderson and McKibbin (1993) and Taylor (1993).

to reduce interest rates. The monetary rules embedded in the model involve explicit weightings of these factors, and the effects on interest rates play out differently in different countries depending on the relative magnitudes of the impacts on inflation and growth. In some cases, central banks tighten policy because the inflation effect dominates (the United States, Europe, India) or because they are partially pegging to the U.S. dollar (China). In other regions, they loosen monetary policy because the falling output dominates (Australia, Russia, and ROECD). Over time, however, the falling marginal product of capital causes all real interest rates to fall.

Figure 13. Change in Short Term Real Interest Rate under Paris Relative to BAU
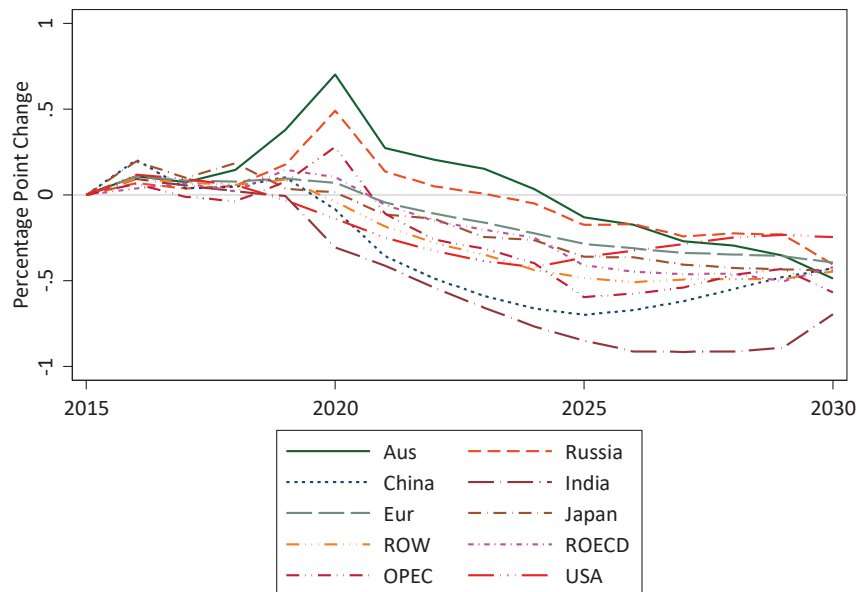

Figure 14 shows effects on real exchange rates. The real depreciation of the Australian currency is notable. Australia is a large exporter of coal and gas, and the implicit tax on Australia's exports through the CO_2 tax causes a substantial loss in the terms of trade in both the short and long run.

Figure 14. Change in Real Effective Exchange Rates under Paris Relative to BAU
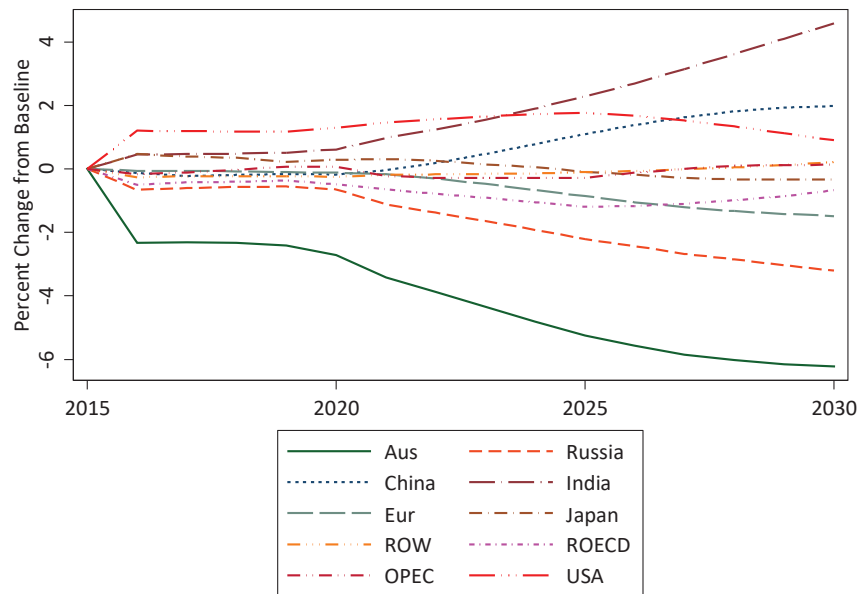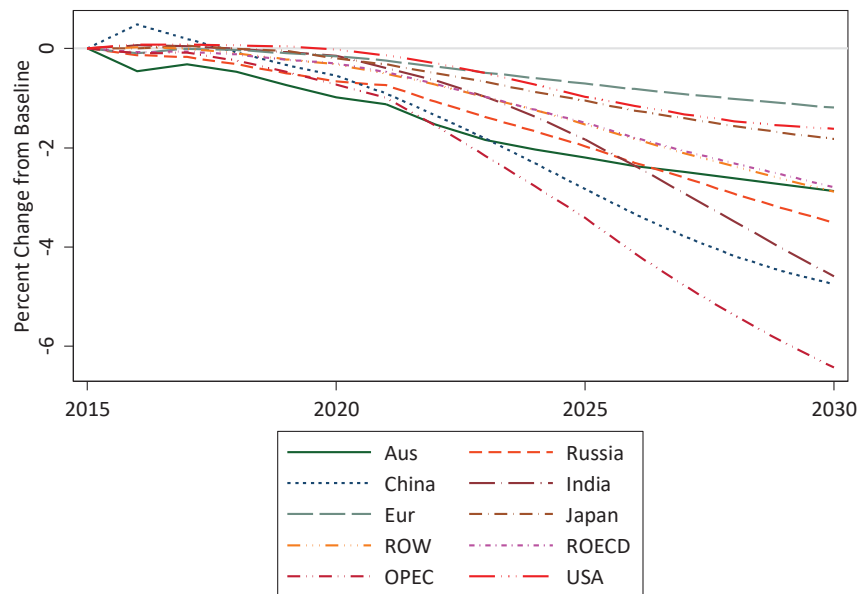

Figure 15 shows that real wages fall globally because of the CO_2 tax. As the capital stock falls in all regions, the marginal product of labor and the real wage fall as well.

**Figure 15. Change in Real Wages under Paris Relative to BAU**

The change in employment is shown in Figure 16. The largest and longest-lasting employment loss relative to BAU is in Russia because global demand for its fossil fuels falls sharply. In contrast, Australia's employment drops during the period prior to the imposition of the policy and then rebounds quickly as workers shift from the fossil fuel industries into other sectors of the economy, including the expanding renewables industry. This structural adjustment is supplemented by a fall in the real wage, which gradually returns employment to its longer run path.

Figure 16. Change in Employment under Paris Relative to BAU
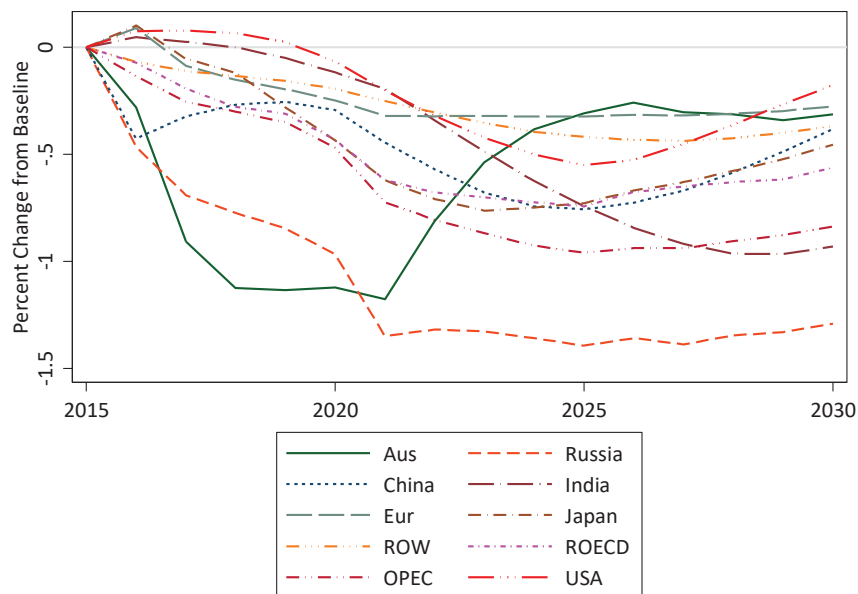
The welfare effects of the Paris policy scenario appear in Figure 17. We measure the effects by computing an intertemporal equivalent variation (EV) for each region: that is, the change in wealth, at baseline prices, that is equivalent to the policy's impact on households' intertemporal utility in each region. To put the EVs in context, we report each as a percent of baseline wealth. Figure 17 shows that participating in the Paris Agreement creates positive economic welfare benefits for China, India, Japan, ROW, and the United States, but negative economic welfare effects for Australia, OPEC, the rest of the OECD, and Russia. Europe is largely unaffected. The figure shows that the economic welfare effects range from -1.7 to +0.8 percent of baseline wealth.

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Figure 17. Equivalent Variations as a Percent of Baseline Wealth under Paris
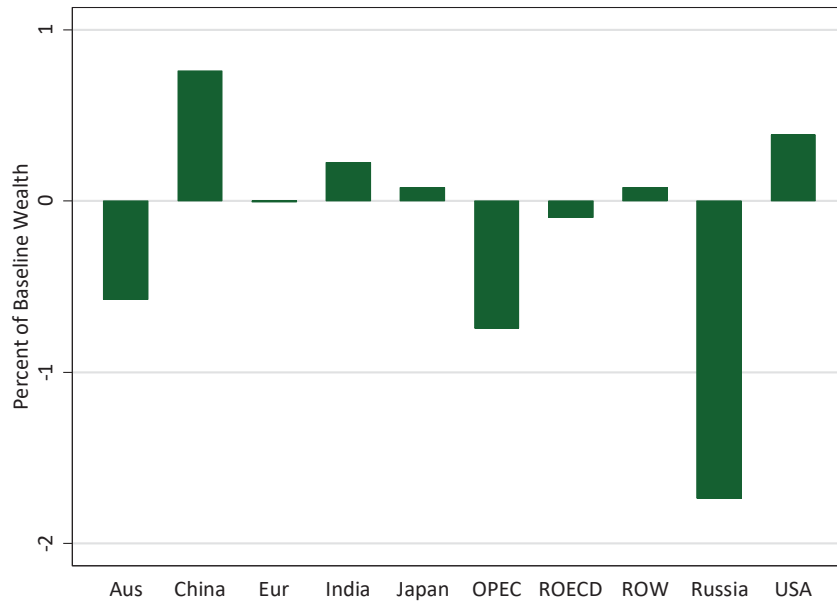
As with the other economic outcomes shown so far, the EVs in Figure 17 do not account for the benefits of reduced climatic disruption or local environmental and other benefits that result from the decline in fossil fuel combustion. These domestic ancillary effects, also known as co-benefits, vary by fuel. For coal and natural gas, they are primarily reductions in mortality risks from air pollution. For gasoline and road diesel, the benefits also include reduced road congestion, traffic accident risk, and road damage. These benefits may be more efficiently achieved by other policies, but to the extent they arise from the CO_2 tax, they are relevant constituents of the overall net effects of the tax.

Parry et al. (2015) enumerate the domestic non-climate external costs associated with fossil fuels in countries around the world. The authors estimate a price on CO_2 that would be in countries' own interest, i.e. the price that would internalize those external costs. They use country-level estimates of non-CO_2 damages by fossil fuel product and simple rules of thumb for the responsiveness of fuel use to CO_2 pricing. Table 6 provides the per-ton domestic co-benefit values we used, which in some cases are rough aggregations of the Parry et al. (2015) values to match the regions in the model.

**Table 6. Values of Domestic Co-Benefits from Reduced Fossil Fuel Use***

Region	Co-Benefits, $ per Metric Ton of CO_2 abated	Notes
Australia	$11.50	Australia
China	$63	China
Europe	$52	Rough average of European countries
India	$30	India
Japan	$35	Japan
OPEC	$57.50	Average for large emitters
ROECD	$25	Based on Canada
ROW	$30	Rough average of developing countries
Russia	$85	Russia
USA	$36	United States

* After Parry et al. (2015), Figure 7.

We applied the per-ton dollar values in Table 6 to the reductions in CO_2 emissions in each year through 2030 to approximate the streams of co-benefits in each region or country.[10] We then took the present value of each region's stream to obtain co-benefit measures that we can add to the EVs in Figure 17. Figure 18 shows each of the following in billions of 2015 U.S. dollars: the EVs of the NDC policies; the present values of the domestic co-benefits; and the sum of the two (in blue). The figure shows that for most regions, the welfare effects of the emissions control policy are small (positive or negative) relative to the domestic co-benefits. All regions except Australia and OPEC experience positive net benefits from participating in the Paris Agreement.

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[10] As noted earlier, this calculation is a first-order approximation that does not account for interactions between changes in environmental conditions and decisions about production and consumption. Moreover, it is driven entirely by non-climate externalities, so it is a lower bound on the overall benefits from reducing emissions.

Figure 18. Economic and Ancillary Domestic Welfare Effects under Paris Relative to BAU through 2030
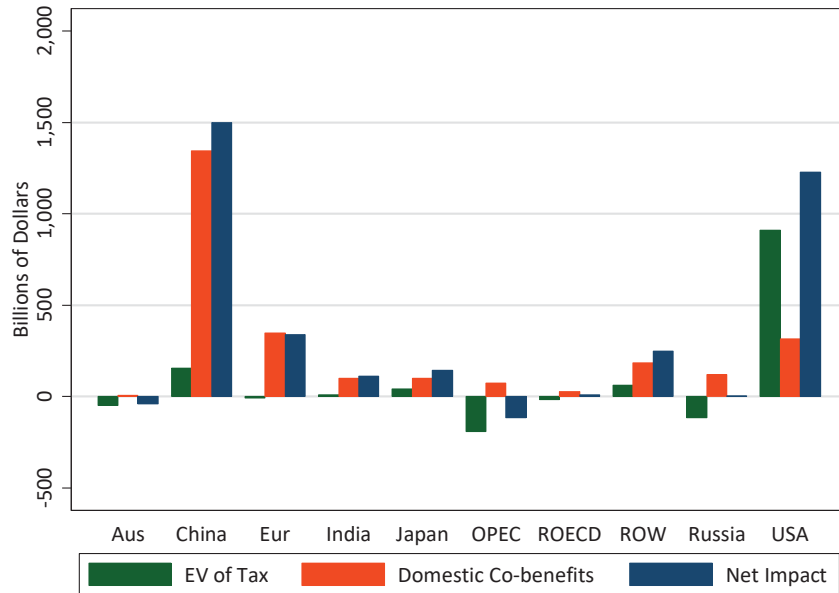
The domestic co-benefits shown in Figure 18 do not include the value of decreased climate change. Climate change benefits are captured in Figure 19, which shows the *global* benefits produced by each region's reduction in CO_2 emissions using a social cost of carbon equal to $US 42. To be clear, these are global benefits, not the benefits to individual regions: the value for the United States, for example, indicates that its emissions reductions contribute about $370 billion in benefits to the *global* community. The benefits produced by China's participation are the largest of all at $896 billion and account for about 40 percent of the total.

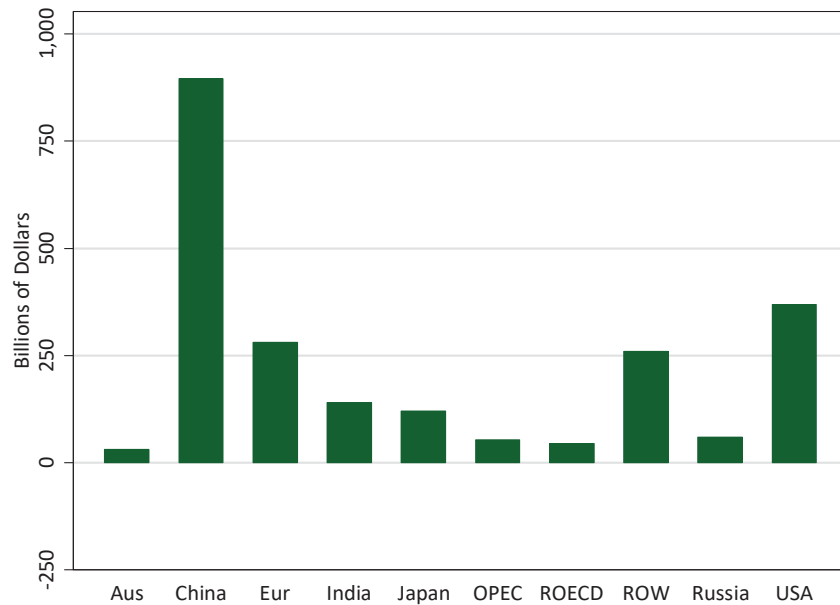**Figure 19. Global CO$_2$ Benefits Generated by Each Region under Paris**

Table 7 presents several measures of the economic impact of the NDCs across regions: the tax rate in 2030, which reflects the marginal cost of the NDC; the percent reduction in emissions relative to BAU, which shows the proportional contribution to the overall goal of reducing emissions; the percent reduction in GDP relative to BAU, which is a rough measure of the average cost of the policy; the equivalent variation as a percent of baseline wealth, which indicates the welfare impact of the CO$_2$ tax alone; and the net impact, including domestic co-benefits, also expressed as a percent of baseline wealth. Bold figures indicate the most ambitious (or least favorable) row in each column.

Table 7. Alternative Measures of Stringency of the NDCs

Region	CO$_2$ Tax Rate in 2030, $US	Change in 2030 Emissions, %	Change in 2030 GDP, %	EV, % of Baseline Wealth	Net Impact, % of Baseline Wealth
Australia	5	-37	-2.6	-0.6	**-0.5**
China	26	-27	-1.0	0.8	7.3
Europe	10	-40	-0.7	0.0	0.2
India	**44**	-25	-0.9	0.2	2.2
Japan	17	**-46**	-0.9	0.1	0.3
OPEC	36	-9	-3.6	-0.7	**-0.5**
ROECD	23	-39	-2.1	-0.1	0.1
ROW	33	-18	-1.1	0.1	0.3
Russia	5	-21	**-4.5**	**-1.7**	0.1
USA	26	-27	-0.4	0.4	0.5

The relative ranking of regions from most to least stringent varies considerably with the measure used. This is not at all apparent from the NDCs in Table 2. India's CO$_2$ tax rate in 2030, for example, is the highest by far, but its reduction in GDP is toward the middle of the group. After accounting for domestic co-benefits, India has one of the best overall outcomes. In contrast, Russia experiences the largest reduction in GDP and has the worst EV outcome, but is still better off overall after accounting for co-benefits. The country gaining the most from the agreement is clearly China, which has a positive EV and, after accounting for domestic co-benefits, has the largest overall net gain by far. The only regions that experience an overall loss are Australia and OPEC, where co-benefits are relatively small and do not offset the negative EV associated with the Agreement.

5.2 The Impacts of Non-Participation

This section explores the impacts of selected regions withdrawing from the agreement. As described above, the regions that are the focus of this section are China, the Unites States, and Australia. Each region is assumed to withdraw unilaterally, with all other regions achieving their NDC targets.

Figure 4 indicates the effect each region's withdrawal on global emissions of CO$_2$. China has a major impact; its withdrawal reduces the impact of the agreement by about half. The United States also has a large impact, but it far smaller than that of China. Australia's domestic emissions, in contrast, are small relative to China and the United States. Since its exports of

fossil fuels are taxed whether or not Australia itself participates in the agreement, Australia's withdrawal has little impact on global emissions.

Figure 20 shows the emissions outcomes from each region under the four different policy scenarios. Note that by assumption regions that stay in the Paris Agreement continue to meet their NDCs even when one region withdraws.

Figure 20. Change in CO_2 Emissions under Paris and Withdrawal Scenarios in 2030 Relative to BAU
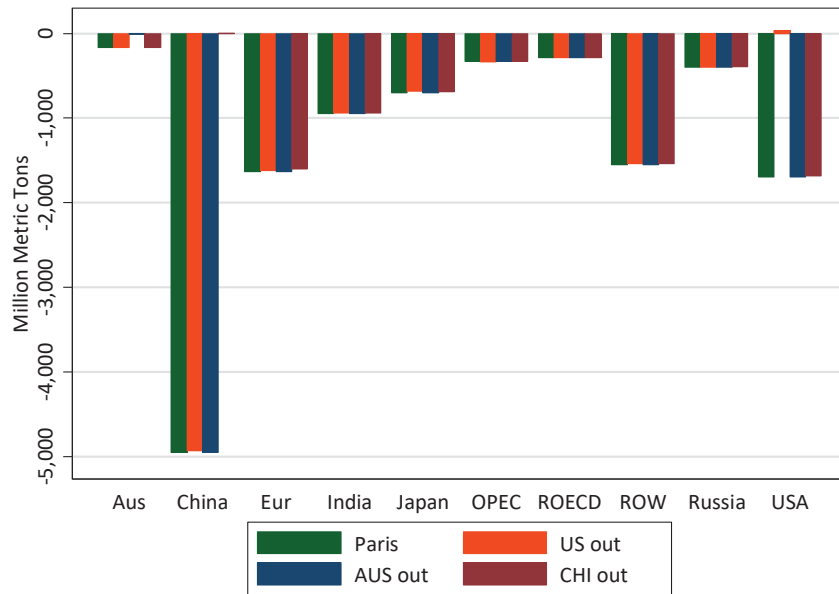

Figure 21 shows GDP impacts in 2030 by region under Paris and the three withdrawal scenarios. For both the all three countries, withdrawing from the agreement still results in lower GDP than baseline. For China and the United States, the resulting change is small: non-participation comes close to eliminating the GDP impact. For Australia, however, the Paris Agreement still has a significant impact on GDP even when Australia does not participate. These losses occur because Australia's exports of fossil fuels are still subject to the CO_2 tax in other regions, and the revenue is collected outside Australia.

Figure 21. Change in Real 2030 GDP relative to BAU under Policy Scenarios
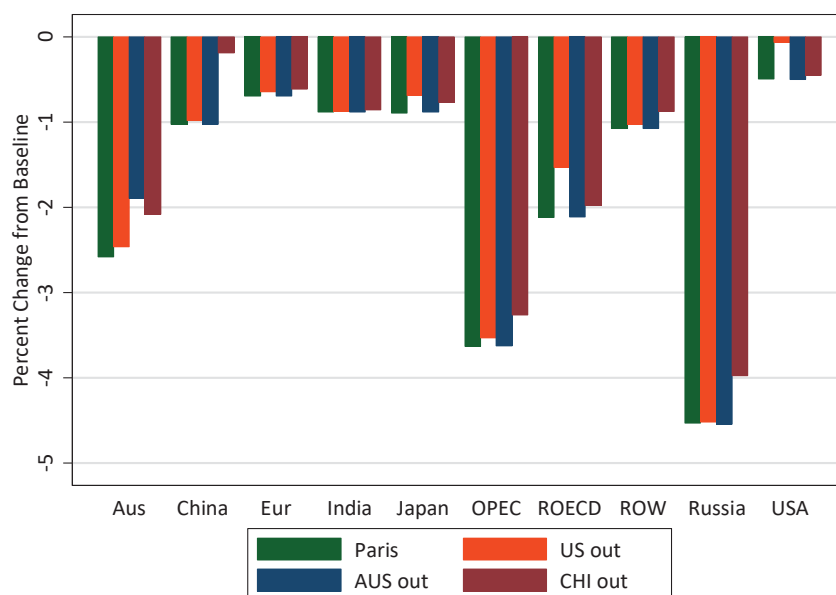
Importantly, the values in Figure 21 are changes in the level of GDP relative to BAU many years in the future (2030), and they are generally small: about a typical year's GDP growth or less. To put these values in perspective for our selected countries, Figure 22 shows their real GDP levels relative to 2015 under the BAU (Base), Paris, and withdrawal scenarios. The figure makes clear that the economic impacts of the agreement are small compared to the underlying growth of GDP in all three economies. There is little to be gained in terms of GDP for each region by withdrawing from the agreement. More importantly, we show below that a more complete accounting framework that includes environmental co-benefits indicates that participating in the Paris Agreement is in the self-interest of almost all regions—that is, that countries withdrawing from it make themselves worse off.

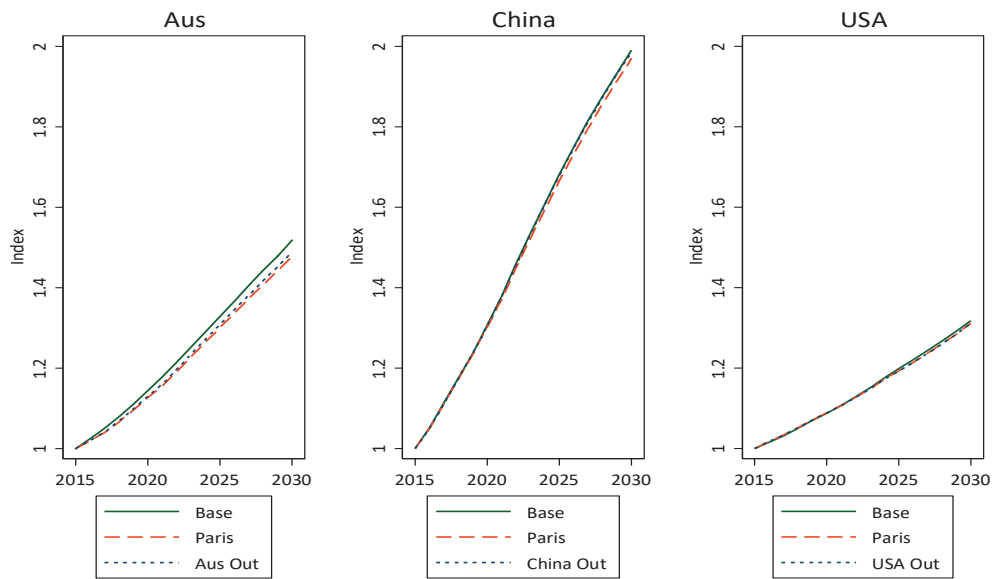**Figure 22. Real GDP Relative to 2015 Values for Selected Regions**

Figure 23 shows the equivalent variations by region through 2030 under the Paris Agreement and the alternative withdrawal scenarios. The results for the Paris Agreement scenario reframe the results shown in Figure 18 from billions of dollars to percent of baseline wealth. Figure 23 allows comparison of the relative welfare effects of the policy scenarios, not counting the domestic co-benefits shown in Figure 18 or global climate benefits. Even abstracting from those important benefits, all three countries are better off participating in the agreement than withdrawing. The welfare effects of the NDC policies lead to positive or negative outcomes for most regions of less than one half of one percent of baseline wealth.

Figure 23. Equivalent Variations Relative to Wealth under Policy Scenarios
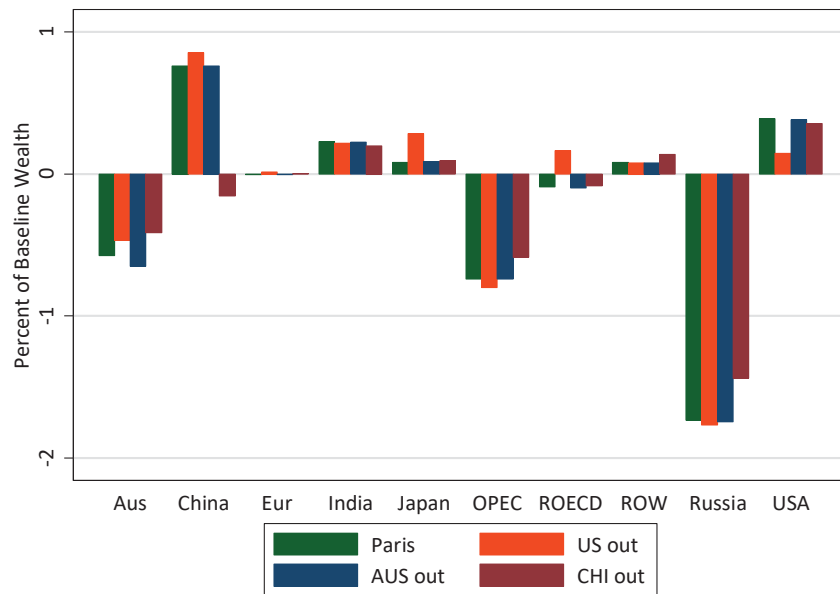

Figure 24 adds the present value (through 2030) of the domestic co-benefits of achieving the NDCs to the EV values in Figure 23. Once we add in the domestic co-benefits, nearly all of the policy outcomes are positive, with the exception of Australia and OPEC. Note the difference in the scales of the vertical axes of Figure 23 and Figure 24. Accounting for domestic co-benefits increases the estimated benefits of achieving the NDCs for some regions by one to two orders of magnitude, particularly for China, India, and Russia. Also, this addition does not change the result that none of the three regions is better off if it unilaterally withdraws.

Figure 24. EVs and Domestic Co-Benefits Relative to Wealth under Policy Scenarios
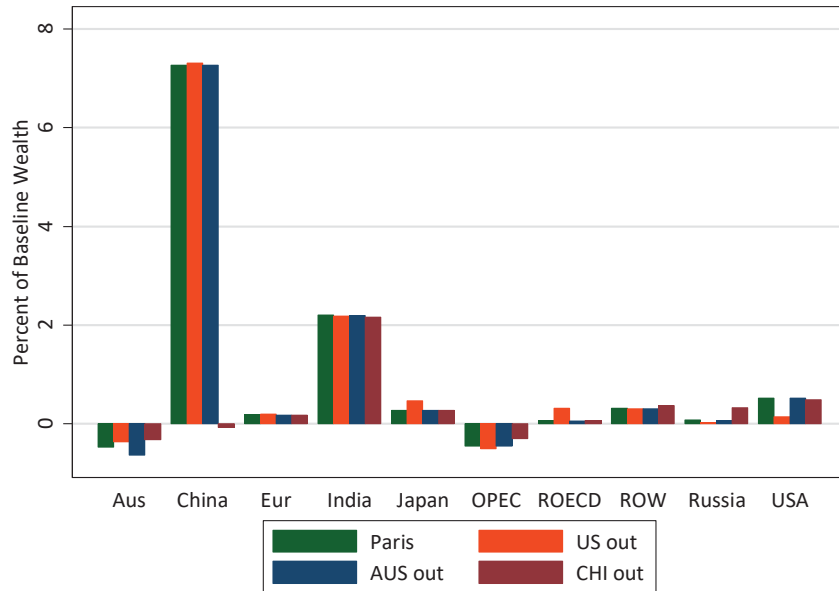

Figure 25 shows the present value of CO_2 benefits for the world under each policy scenario. The figure sums the benefits of emissions abatement through 2030 relative to the no-policy baseline. Under the Paris Agreement the present value of environmental benefits globally is around $US 2.25 trillion. The largest environmental gains come from the participation of China and the rest of the world (the green bars labeled "Other"). The unilateral withdrawal of the United States has a more significant environmental cost to the world than the economic gains to the United States of withdrawing. More importantly, the gain in GDP for the United States from withdrawal is smaller than the environmental benefits foregone by withdrawing.

Figure 25. Total PV of CO$_2$ Benefits through 2030 by Policy Scenario

Emissions through 2030
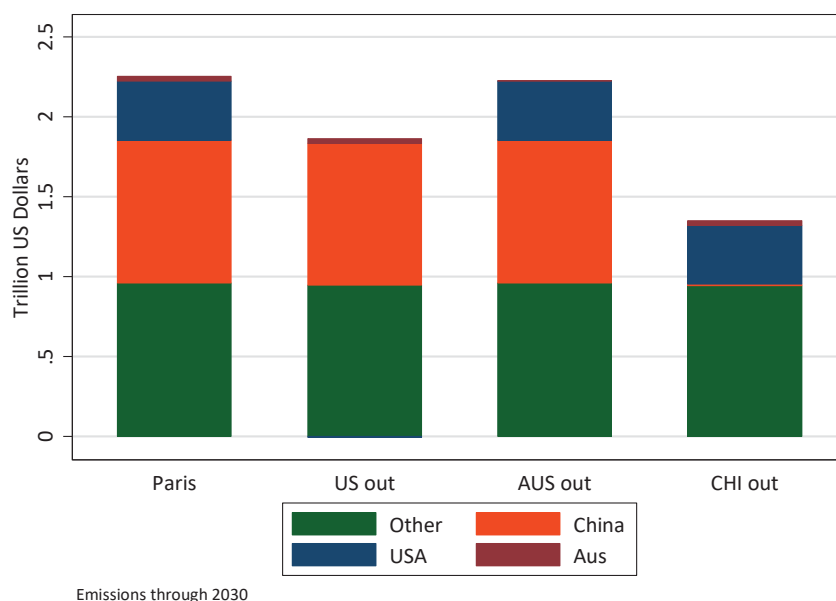
6. CONCLUSION

This study explores the global economic and environmental implications of the NDCs that form the basis of the Paris Agreement on climate change. Although many scientists argue that the targets in the Paris Agreement are not sufficient to reach the stated goal of limiting global warming to 2°C, we find that the targets in the NDCs have significant implications for global outcomes and for individual regions. In particular, we find that the differential targets across regions correspond to very different levels of impact, whether measured by the emissions taxes required, or the effects on GDP and welfare that result.

In addition, we observe that co-benefits from reductions in conventional pollutants are sufficiently large that even without accounting for reductions in climate change, every region receives a net benefit from participating in the agreement. Second, we note that the globe's two largest CO$_2$ emitters, China and the United States, are both better off participating in the agreement than withdrawing from it; in both countries, the equivalent variation of participating is larger than that of withdrawing. Finally, we end by observing that the climate benefits produced by the Paris Agreement are very large even though it does not stabilize emissions. Assuming the social value of a metric ton of CO$_2$ abated is $42 US, the global climate benefit of the Paris Agreement through 2030 is $2.25 trillion in present value.

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Table 2 contains the targets calculated for each region in the G-Cubed model. The targets for OPEC and ROW depend on the G-Cubed baseline because most of OPEC countries and some of ROW countries set their NDCs relative to 2030 BAU and thus we assume the G-Cubed baseline as their BAU emissions (see more details below).

We calculate the NDC targets by making a number of assumptions. We start with the NDCs each country submitted to the UNFCCC. For each NDC,

(1) We assume that all countries targeting GHGs will reduce their energy-related CO_2 proportionally to the overall scope of emissions pertinent to their targets. We do not adjust for expected changes in other GHG sources and gases, so our estimated targets may be more or less stringent than they will be in practice owing to baseline trends in non-energy sectors.
(2) We source all emissions data over the period from 1990 to 2015 from the U.S. Energy Information Administration.
(3) We target the unconditional NDCs or the least ambitious target in a range of proposed targets. If any country does not have an unconditional NDC, we assume the conditional NDC as the target.

For individual countries in the G-Cubed model, Table 3 in the text reports the NDC we calculate. Estimated targets for Australia, Japan, and the United States require only the above three assumptions. Other countries and regions involve more complicated or subjective analysis.

(1) Russia expresses its NDC target relative to 1990, but Russian emissions data starts from 1992, so we substitute its 1992 data for 1990.
(2) China has a target in terms of emissions intensity of GDP, and we calculate its emissions target as follows:
    (a) China aims to double its real GDP by 2020 from 2010, and the National Energy Administration of China assumes for energy consumption forecasting that Chinese GDP will grow at 5.5% each year from 2021 to 2030.
    (b) China targets to reduce its carbon intensity by 60% by 2030 relative to 2005.
    (c) Given China's GDP and total CO_2 emissions in 2005, we calculate China's emissions intensity in 2005 and then the target emissions intensity in 2030.
    (d) Given China's GDP target, we calculate the implied emissions target in 2030.
(3) India also has a target in terms of emissions intensity of GDP, but we don't have official forecasts for GDP, so we solve in the G-Cubed model for the CO_2 tax rates required to

achieve the targeted emissions intensity in 2030 and obtain the projected emissions level in 2030.

(4) Europe consists of all countries in the European Union, and Norway and Switzerland. The European Union submits its NDC target as a whole. We calculate its emissions target as follows:

  (a) For eight countries without emissions data in the reference year (1990) including Croatia, Estonia, Germany, Latvia, Lithuania, Slovakia, Slovenia and Switzerland, we use their earliest data for their 1990 emissions. As the earliest data for those countries are available in either 1991, 1992 or 1993, so this approximation would not have much bias.

  (b) We calculate the emissions target for the European Union, Norway and Switzerland respectively, and add them up to get the target for the region.

(5) ROECD consists of three countries and each has a straightforward NDC target relative to a historical year, so we calculate the emissions target for each country and then add them up to get the target for the region.

(6) OPEC countries fall into two groups: one group has NDCs, and the other has no NDCs.

  (a) All countries with NDCs set their targets relative to 2030 BAU, so we use the G-Cubed baseline emissions as their BAU emissions.

  (b) We disaggregate the aggregate OPEC BAU emissions in 2030 across all countries based on their emissions shares in 2015.

  (c) We calculate each country's target given their BAU emissions in 2030, and keep unchanged the emissions of those countries without NDCs, and then added them up.

(7) ROW consists of all countries that are not included in the above regions, and its target calculation is complicated.

  (a) We first categorize all ROW countries into three groups:

   • Type 1 - Countries that set their NDCs relative to 2030 BAU;

   • Type 2 - Countries that set their NDCs in levels relative to historic years;

   • Type 3 - Countries that set their NDCs in terms of emissions intensity of GDP relative to historic years;

   • Type 4 - Countries without NDCs.

  (b) We use actual emissions in 2015 to calculate the share of each above group in total ROW emissions.

  (c) We disaggregate the total 2030 emissions of ROW in the G-Cubed baseline for the four groups based on their shares in 2015.

  (d) For Type 1 countries, we calculate their targets based on their 2030 BAU emissions.

  (e) For Type 2 countries, we calculate their targets given the historical data,

  (f) For Type 3 countries (Chile, Malaysia and Singapore), we have different treatments. We directly obtain an estimate of emissions for Chile from Climate Action Tracker. For Malaysia, we assume a constant growth rate of GDP (4%) over the period from 2016-2030 based on its recently historical growth rates, to give an estimate for GDP in 2030,

and then calculate emissions given the intensity target. We exclude Singapore from ROW because its official emissions data is not consistent with the EIA data.

(g) For Type 4 countries, we assume the BAU emissions to be their target emissions.

(h) We add up emissions targets of the four types of countries to get the target for the region.