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Transparency, Policy Surveillance, and the Comparison of Mitigation Efforts

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Abstract

This paper synthesizes the work in a research program focused on the transparency and comparability of mitigation efforts in multilateral climate change policy. We take as our starting point the emerging international architecture, which creates demand for practical mechanisms to compare domestic efforts to mitigate global climate change. How do countries decide whether and to what degree pledges by their peers—often expressed in different forms that stymie obvious apples-to-apples comparison—are sufficient to justify their own actions now and more ambitious actions in the future? We describe a number of desirable features of metrics that might be used for ex ante comparisons of proposed pledges and ex post assessments of subsequent actions delivering on those pledges. Such metrics should be comprehensive, measurable, and universal. In practice, however, no single metric has all these features. We suggest using a collection of metrics to characterize and compare mitigation efforts, akin to employing a suite of economic statistics to illustrate the health of the macroeconomy. We illustrate the application of a suite of metrics to several countries' mitigation pledges using four modeling platforms. We also describe how countries increasingly employ complex suites of policies, rather than the cost-effective, economy-wide policies modelers are used to examining. This suggests new challenges and opportunities to use modeling tools to evaluate these realistic policy contexts.

Key Words: emissions mitigation, international environmental agreements, modeling analysis, policy surveillance, comparability of effort, nationally determined contributions

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1. Introduction

Nearly every country in the world has submitted a pledge to mitigate its greenhouse gas emissions—a so-called nationally determined contribution—as a part of the 2015 Paris Agreement. The pledges take on many different forms: targets relative to a historic base year emissions (with heterogeneity in the choice of base year), percentage improvements in the ratio of carbon dioxide to gross domestic product (GDP), percentage abatement versus a "no-policy" reference (or "business-as-usual") case, a specified year by which national emissions will peak, renewable power goals, energy efficiency goals, afforestation goals, and more. The Paris Agreement represents the culmination of a transition toward a pledge-and-review regime initiated in the 2009 Copenhagen climate talks. The near-universal participation in the mitigation pledging exercise in the Paris framework signals an important first step in implementing this new regime. The design and implementation of the review of the pledges—so-called transparency in the Paris Agreement—is equally critical to the success of the Paris Agreement.

This pledge-and-review approach creates significant demands for a well-functioning transparency regime. Given the discretion left with sovereigns regarding the form and timing of their mitigation contributions, assessments of the mitigation pledges are necessary to determine

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their emissions impacts and, hence, environmental benefits. In the context of the periodic global stocktaking called for in the Paris Agreement—that is, whether the aggregate efforts to mitigate greenhouse gas emissions are adequate given the long-term temperature goals in the Paris Agreement and previous multilateral climate agreements—and the opportunities for countries to update their mitigation pledges, governments and stakeholders will naturally focus on the comparability of efforts among countries.

To build confidence among countries, there needs to be a common understanding of how pledges expressed in different forms stack up against one another. Similar efforts among similar countries would likely be seen as a "fair" deal, likely a necessary condition for countries both to live up to their pledges now and to increase ambition in the future (Ostrom 1998; Barrett 2003; Cazorla and Toman 2003). Comparable mitigation effort costs across countries also could represent a relatively cost-effective agreement and help level the playing field internationally for energy-intensive industries (e.g., Aldy et al. 2010). This interest in comparability of effort is emerging in domestic politics, both from environmental advocates who believe that such assessments can enable a ratcheting up of ambition and from business leaders concerned about the potential adverse competitiveness impacts of climate change policy.

Transparency and comparability can promote the stability and increase the ambition over time of an international climate policy agreement. Without the means for coercing climate action by other countries, transparent commitments coupled with transparent reviews serve to enhance the credibility and likelihood that a country will deliver on its pledge (Schelling 1956). International institutions to facilitate transparency—through the collection, analysis, and dissemination of information on countries' commitments—can lower the costs of international agreements and facilitate their legitimacy (Keohane 1998; Bodansky 2007). Rigorous reviews of voluntary commitments can deter countries from deviating from their pledges and reassure countries that their partners will deliver on their commitments (Chayes and Chayes 1991). Such a voluntary pledge-and-review approach can result in broader participation than the old Kyoto-style model to international agreements (Victor 2007; Pizer 2007).

Leveraging transparency and review to enable the comparison of mitigation efforts can drive more ambitious mitigation pledges over time. In an array of negotiating contexts, from international trade to local common pool resource management, the demonstration of reciprocal actions has often resulted in fewer deviations from agreements and positive reactions by members of the agreement (Simmons 1998; Ostrom 1998). Thus the challenge in the international climate policy context is to implement policy surveillance tools that can credibly demonstrate the extent to which comparable countries are undertaking comparable emissions mitigation efforts.

This paper serves as a synthesis of a research program focused on the transparency, policy surveillance, and comparability of mitigation efforts in international climate policy. We draw from an array of papers that we have authored or coauthored on the importance of transparency in a pledge-and-review regime (Aldy 2013, 2014, 2015; Aldy et al. 2016b), as well as on the role for economics in informing the comparability of mitigation effort (Aldy and Pizer 2016; Aldy et al. 2016a, 2016b). We also incorporate key insights from related literatures in international relations, political economy, and energy-economic modeling to present the current research landscape and scope out next steps that could inform the implementation of transparency and review under the Paris Agreement. In particular, countries are increasingly turning to a variety of sector-specific policies, rather than an economy-wide carbon tax or cap and trade. This poses new challenges to modelers attempting to represent national actions, as well as to analysts considering the right way to compare efforts.

The next section describes the need and role for analysis of mitigation pledges as a part of the transparency of the Paris Agreement. Section 3 explains the importance of demonstrating the comparability of effort in multilateral agreements. In Section 4, we present our framework for metrics of comparability effort, as well as a template for organizing this information in both ex ante and ex post reviews of mitigation pledges. Section 5 reviews the initial analyses undertaken by four modeling platforms in producing comparability metrics of the Paris Agreement pledges. These analyses are premised on least-cost implementation of countries' nationally determined contributions—that is, economy-wide carbon pricing. Section 6 describes the domestic mitigation programs in countries' Paris Agreement pledges and places this in the context of the literature on mitigation policies that diverge from cost-effective implementation. In Section 7, we present our approach for extending the modeling platforms to address the mix of mitigation policies constituting major economies' domestic climate policy programs. Section 8 concludes with thoughts for future research and policy implications.

2. Transparency: The Role for Analysis

The emissions mitigation pledges incorporated in the submitted intended nationally determined contributions (INDCs) take many different forms. As with the pledges made in the 2009 Copenhagen Accord and 2010 Cancun Agreements, countries intend to contribute through limiting their economy-wide greenhouse gas emissions to a percentage of a historic base year (e.g., the European Union, the United States), through percentage reductions from a no-policy forecast of future emissions (e.g., Colombia, Korea), or through reductions in the carbon intensity of economic output (e.g., China, Singapore), among other additional policy objectives. Assessing and comparing these pledges requires the use of economic analysis for several reasons.

First, those pledges based on reductions from a forecast emissions level are, by construction, a reflection of a model-based forecast of emissions. Such a forecast could reflect various economic and energy assumptions in a structural model of a country's economy or a statistical forecasting model based on analyses of the historic relationships between emissions and economic activity, as well as other potential emissions drivers. In either case, countries have reported their emissions forecasts through the year 2030 when describing their contributions as percentage reductions from the business-as-usual forecast. Transparent emissions forecasts are a necessary condition for converting a percentage reduction from a business-as-usual pledge into an estimated emissions impact of the contribution.

Second, the emissions intensity-based pledges explicitly require economic data in constructing the pledged outcome measure, carbon dioxide emissions per unit of GDP. Estimating the emissions impact of this type of pledge requires a forecast of the country's GDP. Determining whether this reflects a meaningful deviation from what would have happened otherwise would require a forecast of the business-as-usual carbon intensity.

Third, an integrated analytic framework employing an internally consistent set of data and modeling assumptions would produce metrics that permit apples-to-apples comparisons among INDCs. Countries may report on various metrics in their INDCs, but such reporting may be selective and reflect country-specific data assumptions and methods that likely hinder cross-country comparisons. Based on past efforts at climate transparency through the national communications processes, countries may satisfy United Nations Framework Convention on Climate Change (UNFCCC) guidelines and still produce measures of mitigation effort that are not comparable with those produced by other countries (Thompson 2006). Self-reported metrics will yield apples-to-oranges comparisons that would undermine the understanding of countries' intended contributions and misinform the policy process.

Fourth, the cross-border impacts of INDCs through energy markets and international trade can be accounted for only in multicountry models. Any given country's energy prices, trade flows, and investment opportunities will reflect not only its mitigation program pursuant to its INDC but also the mitigation efforts in other countries (Akimoto et al. 2016). Country-specific assessments of mitigation pledges will fail to account for these impacts and produce potentially misleading emissions, energy prices, and economic impacts from an INDC. Note that the assignment of "effort" associated with such transnational effects remains unclear.

Fifth, economic analyses of INDCs can help focus attention on policy learning (Aldy 2013). Most energy-economic models estimate the least-cost way of mitigating emissions, which is through a carbon price. This can illustrate opportunities for pursuing more cost-effective policies in those countries that may otherwise employ a suite of non-market-based policy instruments. It may also highlight options for bilateral linking of domestic mitigation programs that could also improve cost-effectiveness.

Finally, analyses of INDCs at the pledging stage can facilitate the identification of the data and modeling needs for ex post review of the performance of countries in delivering on their INDCs. An effective ex post review will likely require planning for the data collection and analysis before countries begin implementing their mitigation programs.

3. Comparability

The heterogeneity in the forms of emissions pledges and the variation in the design and implementation of domestic emissions mitigation policies highlight the importance of developing metrics to assess and compare mitigation efforts. Drawing from Aldy and Pizer (2015, 2016), we describe a set of principles for informing the selection of comparability metrics and an evaluation of common metrics employed to assess mitigation effort.

3.1. Principles for Selecting Comparability Metrics

We identify three principles to help inform the selection of metrics to use in comparing nations' mitigation efforts (see also Aldy and Pizer 2016).

- *Comprehensiveness*. An ideal metric should be comprehensive, characterizing the entire effort actively undertaken by a country to achieve its mitigation commitment. Such a metric would clearly reflect all climate-related policies and measures and exclude nonpolicy drivers of climate outcomes. It should take on similar values for countries undertaking similar mitigation efforts.
- *Measurability and replicability*. A metric should be measurable and replicable. The ability to replicate a given metric without subjective assumptions, using available public information, enhances the credibility of review. An emphasis on observable characteristics of effort, such as emissions, energy and carbon prices, or use of particular

zero-carbon technologies, also creates an incentive for countries to undertake actions that can be measured this way. This further facilitates transparency.

- *Universality*. Metrics should be universal. Given the global nature of the climate change challenge, metrics should be constructed for and applicable to as broad a set of countries as possible.

In practice, there will be trade-offs among principles in identifying and constructing the metrics. For example, changes in emissions levels over time may be measurable and universally available in all countries, but this measure may not comprehensively represent mitigation effort. Mitigation cost may be a more comprehensive measure of effort but is not easily measured.

3.2. Illustrations of Metrics

Mitigation efforts can be measured many different ways, and the nations of the world are far from agreeing on a single way to do so. But the strengths and weaknesses of popular metrics begin to emerge when we examine how they stack up against our basic principles. These metrics fall into three general categories, with a focus on emissions, prices, or costs. Emissions and other physical measures are typically the outcomes that matter for the environment. Prices on carbon and energy taxes reflect the economic incentives created by government policies to reduce emissions and energy use. They are also relevant for distributional impacts within countries and trade impacts across countries. Cost metrics measure useful economic resources diverted away from current consumption and nonclimate investment and toward abatement.

3.2.1. Emissions and Related Metrics

We noted that an early comparability metric was emissions relative to 1990 levels, as specified in the Kyoto Protocol. More recently, countries including the United States and Japan have focused on emissions relative to 2005 levels. Ultimately, choices like this come down to each country's interest in achieving a more favorable baseline. For example, Russia's use of 1990 baseline is particularly advantageous given its economic (and emissions) collapse in 1991 and relative stagnation since then. One popular approach to dealing with the particular influence of economic activity is to focus on emissions intensity (tonnes of CO_2 per GDP). Before the 2009 Copenhagen talks, China and India each proposed emissions goals structured as percentage reductions in the ratio of emissions to GDP (as did the Bush administration in 2001). Such metrics can ensure that a country is not penalized as a climate laggard simply because of faster economic growth nor rewarded simply because of economic decline.

Unfortunately, emissions intensity as a measure of mitigation effort is confounded by several issues. Growing countries tend to experience a decline in emissions intensity owing to technology improvements and changing economic structures rather than to deliberate mitigation efforts. It is difficult to know what level of intensity improvement represents effort versus growth effects. Also, faster-growing countries typically experience a faster decline (Aldy 2004; Newell and Pizer 2008). This makes it difficult to compare countries growing at different rates. It also means that countries growing faster or slower than expected will find it easier or harder, respectively, to meet a target. One could instead compare levels of emissions intensity rather than trends, but this involves the problematic conversion of local currencies into a single currency.

In recent years, regulators in some developing countries have become more interested in emissions goals specified as percentage reductions from a forecast level in a future year. While more comprehensive than other emissions metrics in theory, in practice, calculating the emissions forecasts requires subjective judgments. If the forecast comes from the government setting the goal, there is an obvious incentive to make the forecast high in order to make the target seem more ambitious than it truly is. Even if the forecast is unbiased, comparing a goal with forecast emissions is only more comprehensive in a *prospective* analysis. Retrospectively, comparing observed emissions with a forecast can still confuse mitigation efforts with other, nonmitigation events that affect emissions. A comprehensive retrospective metric would compare observed emissions with an analysis of what emissions would have been absent mitigation policies—in essence, a retrospective forecast.

3.2.2. Carbon and Energy Prices

An observed carbon price bears a direct connection to effort, as it measures the economic incentive to reduce emissions created by a country's mitigation policies; it should also reflect marginal cost. Comparing carbon prices across countries measures the degree to which a country is undertaking more or less expensive per-ton mitigation efforts. Since countries implement domestic carbon taxes and tradable permit markets in their local currencies, comparisons will require the use of currency exchange rates, which would raise questions about the appropriate rates. (This would also be an issue in comparisons of emissions intensity). Moreover, explicit carbon prices will not reflect mitigation efforts associated with nonprice policies, such as efficiency standards and renewable mandates, and most carbon prices are not applied to all of a country's emissions. A country also may undermine the effectiveness of the carbon price by adjusting taxes downward for firms covered by the carbon price, through so-called fiscal cushioning.

Alternatively, one could consider implicit (or effective) carbon prices that estimate the average cost of abatement associated with a specific climate policy or collection of policies. Such implicit prices have the advantage of potentially being applied to a broader set of policies but the disadvantage of not being directly observed. Instead, they are produced by model simulations. Implicit prices also do not reflect actual impacts on energy prices, which are often the focus of those concerned about economic competitiveness, as well as a necessary incentive for improving end-use energy efficiency.

This leads us to consider energy prices directly. Energy prices are transparent and measurable with high frequency. They would permit a net assessment of all price-based policies (including carbon pricing) and thus can mitigate concerns that a country is engaging in fiscal cushioning and speak directly to competitiveness concerns and incentives for end-use efficiency. Energy prices, however, would again fail to capture effects from nonprice regulations and would be a poor measure of effort for countries with significant nonprice policies, including the United States (see Burtraw 2015 for further discussion of US greenhouse gas regulations).

3.2.3. Economic Costs

Ultimately, concern about the costs of combating climate change represents what may be the most significant impediment to serious action by countries around the world. Costs are also closely aligned with most economists' notions of effort. A metric to compare effort based on costs—expressed as a share of national income or per capita—could be used to examine whether comparable countries bear comparable costs from their actions. A metric based on the cost of actual policies would have the potential disadvantage of rewarding costly but ineffective policies. A complementary metric could be used to examine the cost of achieving the same emissions outcome with the least costly policy (see McKibbin et al. 2011 for an illustration of this approach). This would highlight the potential advantages of policies that reduce more emissions with lower mitigation costs over other policies. Estimating costs, however, requires economic assumptions and detailed modeling frameworks for evaluating economic changes in specific sectors and national economies.

3.3. Synthesis of Metrics

No single metric scores well against all the principles. Table 1 illustrates the challenges for each type of metric in satisfying our three design principles. Those easily measured—

emissions levels and intensity compared with historic levels—do not discriminate between effort and happenstance. Prices provide an observable snapshot for certain policies but not others. Emissions abatement and abatement costs probably best represent effort but require subjective assumptions and modeling to estimate. Credible differences in opinion over assumptions will produce different results, complicating any comparison and potentially undermining confidence in the transparency and review regime. The necessary modeling tools are also quite limited outside of the largest developed and developing countries.

With these considerations in mind, it is easy to see why we recommend a portfolio of metrics and why considerable work remains to construct the more comprehensive measures of abatement and cost. Such an approach would mirror how analysts describe the health of the macroeconomy with a suite of economic statistics that includes GDP, the unemployment rate, the inflation rate, and interest rates.

4. Framework for Comparability

Drawing from Aldy et al. (2016a), we have developed a template for organizing and presenting information for various comparability metrics. Table 2 serves as an illustration of this template. This framework identifies the data and analysis needs for constructing metrics to evaluate countries' mitigation pledges. Each column represents a major economy, with a brief description of each country's mitigation program in the first row. The left half of the table focuses on the ex ante analysis of comparability of efforts. For example, a table based on this template could be used to organize information on the intended nationally determined contributions announced by countries in the lead-up to the 2015 Paris talks (and in subsequent rounds of negotiations). The first row of the table would list briefly each country's INDC, and the subsequent rows would depict the estimated measure for each of the metrics. As the template shows, some of the metrics will be directly observed, others will require a baseline forecast, and still others will require modeling analyses.

The right half of the table presents a template for an ex post analysis, such as the review portion of the pledge-and-review regime in the current international climate negotiations. This could also serve as the basis for an interim review once a country has begun implementing its domestic mitigation program but before its target year (e.g., 2025 or 2030). In these cases, the summary of a country's climate program is the implemented contribution, rather than what it intended to do under the INDC. Some of the metrics that are modeled in the ex ante review would be directly observed in the ex post review. Nonetheless, a number of metrics, such as baseline emissions and economic activity, will require counterfactual forecasts and economic modeling even in an ex post exercise. So long as the review of efforts addresses measures beyond physical emissions outputs or observed market prices, economic tools will need to be employed to quantify efforts in a manner that will permit comparisons. Standard economic tools may be employed even for observed metrics, such as aggregating observed energy prices over various fuels over time, to construct a summary of prices. Economic tools may also serve to illustrate the impacts of interactions across countries from the implementation of each country's individual INDCs.

5. Comparability Analysis: Assuming Cost-Effective Domestic Implementation

Aldy et al. (2016b) undertook an analysis of the Paris Agreement mitigation pledges with the use of four integrated assessment models: DNE21+, GCAM, MERGE, and WITCH. These modeling platforms permitted an assessment and comparison of the mitigation pledges among major economies. These models differ in terms of regional, technological, sectoral, and economic representation. They simulated the contributions submitted as of mid-February 2016 and assumed cost-minimizing attainment of the INDCs' emissions goals. While the form of contribution varied among the countries being evaluated, the models produced a consistent set of emissions, price, and cost metrics. The paper quantified the economic costs of mitigation scaled by GDP and the carbon tax for each country to achieve its pledge cost-effectively (marginal abatement costs). The paper reported metrics averaged between 2025 and 2030, given the variation in INDC target years.

5.1. Modeling Methods and Assumptions

Following are the methods and assumptions for each of the four models in this analysis: DNE21+, GCAM, MERGE, and WITCH.

5.1.1. DNE21+

Dynamic New Earth 21 Plus (DNE21+) is an energy and global-warming mitigation assessment model developed by Research Institute of Innovative Technology for the Earth (RITE) (Akimoto et al. 2010, 2012). The model is an intertemporal linear programming model for assessment of global energy systems and global warming mitigation in which the worldwide costs are to be minimized. The model represents regional differences and assesses detailed energy-related CO_2 emissions reduction technologies up to 2050. When any emissions restriction (e.g., an upper limit of emissions, emissions reduction targets, targets of energy or emissions intensity improvements, or carbon taxes) is applied, the model specifies the energy systems whose costs are minimized, meeting all the assumed requirements, including production for industries such as iron and steel, cement, paper and pulp, transportation by motor vehicle, and other energy demands. The energy supply sectors are hard-linked with the energy end-use sectors, including energy exporting and importing, and the lifetimes of facilities are taken into account so that assessments are made with consistency maintained over the energy systems. Salient features of the model include analysis of regional differences among 54 world regions while maintaining common assumptions and interrelationships, a detailed evaluation of global warming response measures that involves modeling of about 300 specific technologies that help suppress global warming, and explicit facility replacement considerations over the entire time period. The model assumes energy efficiency improvements of several kinds of technologies, cost reductions of renewable energies, and carbon dioxide capture and storage (CCS) for the future within the plausible ranges based on the literature.

5.1.2. GCAM

The Global Change Assessment Model (GCAM) is an open-source model primarily developed and maintained at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (Fawcett et al. 2015). GCAM combines dynamic-recursive models of the global energy, economy, agriculture, and land-use systems with a reduced-form climate model, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC). Outcomes of GCAM are driven by assumptions about population growth, labor participation rates, and labor productivity in 32 geopolitical regions, along with representations of resources, technologies, and policy. GCAM operates in five-year time steps from 2010 (calibration year) to 2100 by solving for the equilibrium prices and quantities of various energy, agricultural, and greenhouse gas (GHG) markets in each time period and region. GCAM tracks emissions of 16 GHGs endogenously based on the resulting energy, agriculture, and land use systems. GCAM is a technology-rich model containing detailed representations of technology options in all of the economic components of the system. Individual technologies compete for market share based on their technology characteristics (efficiency in the production of products from inputs), cost of inputs, and price of outputs. The market share captured by a technology is based on an implicit probabilistic (logit) model of market competition. This formulation is designed to represent decision making among competing options when only some characteristics of the options can be observed.

5.1.3. MERGE

The Model for Evaluating the Regional and Global Effects of GHG Reduction Policies (MERGE) is an integrated assessment model describing global energy-economy-climate interactions with regional detail. It was introduced by Manne et al. (1995) and has been continually developed since; a recently published description is in Blanford et al. (2014). MERGE is formulated as a multiregion dynamic general equilibrium model with an energy system of intermediate detail and a reduced-form representation of the climate. It is solved as a sequential joint nonlinear optimization with Negishi weights to balance interregional trade flows. The economy is represented as a top-down Ramsey model in which electric and nonelectric energy inputs are traded off against capital and labor, and production is allocated between consumption and investment. The energy system includes explicit technologies for electricity generation, refining, passenger vehicles, and other nonelectric energy supply, with a resource extraction model for fossil fuels and uranium.

5.1.4. WITCH

The World Induced Technical Change Hybrid Model (WITCH) is an energy-economy-climate model developed within Fondazione Eni Enrico Mattei’s (FEEM's) Sustainable Development research program (Bosetti et al. 2006). The model divides the worldwide economy into 13 regions, whose main macroeconomic variables are represented through a top-down intertemporal optimal growth structure. This approach is complemented with a bottom-up description of the energy sector, which details the energy production and provides the energy input for the economic module and the resulting emissions input for the climate module. The endogenous representation of research and development (R&D) diffusion and innovation processes is a distinguishing feature of WITCH, allowing the model to describe how R&D investments in energy efficiency and carbon-free technologies integrate the currently available mitigation options. The model can be used to evaluate the impacts of different climate policies on the optimal economic response over the century for the different regions. These regions can behave as forward-looking agents optimizing their welfare in a noncooperative, simultaneous, open membership game with full information, or the model can be constrained such that a global social welfare planner finds a cooperative first-best optimal solution. In this game-theoretic setup, regional strategic actions interrelate through GHG emissions, dependence on exhaustible natural resources, trade of oil and carbon permits, and technological R&D spillovers.

5.2. Comparison of Models' Main Exogenous Assumptions and Baselines

The models' assumptions were not harmonized, in order to maintain the models' own sets of assumptions for the main exogenous drivers, such as population and to some extent GDP.

The four models show similar patterns for business-as-usual emissions, population, and economic activity through 2030. The geographic distribution is also very similar across models.

GHG emissions differ across models, since this in an output parameter that depends on a variety of factors, including energy prices and technoeconomic specification for the energy technologies. Global emissions are nonetheless similar across models, and somewhat above 60 gigatons of carbon dioxide ($GtCO_2$) by 2030, in line with the central projections of the Intergovernmental Panel on Climate Change (IPCC 2014).

5.3. Description of INDCs and Their Implementation in the Models

Each modeling team reviewed each country's mitigation pledge in its INDC submission (http://www4.unfccc.int/submissions/INDC/), and all modeling runs assume simultaneous implementation of all INDCs. Implementation is assumed to minimize the costs necessary to achieve the emissions goal established in a particular country's INDC—that is, an economy-wide carbon price (tax). Many of the INDCs require economic forecasts to translate into emissions levels as countries such as China and India have submitted mitigation pledges in terms of reductions in emissions intensity. The effective emissions levels for these INDCs are estimated using the models' GDP forecasts coupled with the INDCs' specified emissions intensity reductions. Using an internally consistent set of economic and emissions forecasts can circumvent the potential problem in both comparing mitigation efforts and assessing aggregate effects that arise when countries use different economic and energy price assumptions in their forecasts. For models representing the land use sector, the emissions reductions are implemented by applying the same tax as for the energy system.

To enable an apples-to-apples comparison and avoid potential bias owing to variation in target years, the paper focuses on the 2025–2030 average in the modeling results with the exception of results from MERGE, which reports output in 10-year time steps. For multicountry regions in the models, national pledges are converted to emissions limits, and these are aggregated to the regional level. The following describes model-specific elements in the evaluation of the INDCs.

5.3.1. DNE21+

The implementation of the INDCs was carried out via emissions caps on total country and (where countries are aggregated) regional levels of GHGs. The forecasts were developed by RITE. Economic forecasts are consistent with the reference forecasts published by the International Energy Agency (IEA) and the US Energy Information Administration (EIA). Business-as-usual (BAU) emissions forecasts are comparable to other energy-economy and Integrated Assessment Model (IAM) forecasts, except that DNE21+ excludes explicit, existing climate policies. In contrast to EIA and EIA emissions forecasts, the DNE21+ approach gives credit to countries for those existing carbon-pricing policies when measuring emissions changes and costs against BAU forecasts. Each country or region implements its INDC with an economy-wide carbon price necessary to meet the emissions caps.

5.3.2. GCAM

Countries achieve their INDCs by means of a uniform price on carbon across sectors. All 2025 and 2030 INDC goals are assumed to be met. The reference, BAU scenario does not include new climate policies implemented after 2010. The approach is consistent with many reference scenarios in the literature, including those in the IPCC Fifth Assessment Report (AR5). The INDC scenarios include, where appropriate, the countries' 2020 Copenhagen goals and 2025/2030 INDC goals. The supplemental information from Fawcett et al. (2015) provides extensive detail on the reference and INDC scenarios.

5.3.3. MERGE

The following countries and regions have CO_2-equivalent emissions targets for 2030 based on their INDCs: the United States, the European Union, China, India, Japan, Russia, South Korea, and South Africa. For the United States, its 2025 target is extrapolated to 2030 to conform to the 10-year time step of the model. China's target is specified in terms of CO_2-only emissions intensity of GDP, and its carbon dioxide emissions peak in 2030. Where appropriate, 2020 targets based on the Copenhagen goals are assumed for these countries. An economy-wide carbon price is employed within each country (or region, in the case of the EU) to deliver on the INDC emissions goal.

5.3.4. WITCH

The implementation of the INDCs was carried out via emissions caps on the total regional level of GHG, with the exception of China, where the limit was established only for CO_2 as in the INDC. The reference case used was shared socioeconomic pathway 2 (SSP2), with

BAU future projection, except when the BAU level was explicit in the INDC. The 28 member states of the EU (EU-28) are divided into two regions for which the same relative emissions target has been set, and they are allowed to freely trade emissions permits. The reported emissions include emissions from land use, which are deduced from the market biomass price; in this setting, these emissions are taxed at the same rate as the energy sector. The historical emissions used for reporting were from the World Bank's World Development Indicators and the UN's Food and Agriculture Organization (for land use) databases. Each country or region implements its INDC with an economy-wide carbon price necessary to meet the emissions caps.

5.4. Metrics

For emissions-based metrics, GHG emissions are defined as the sum of the six Kyoto gases, thus excluding aerosols. DNE21+ assumes the INDC target is achieved by emissions reductions excluding land use emissions, which are not modeled. The GDP used in the intensity calculations is based on market exchange rates. Prices in the models are expressed in 2005 US$ and measured at the secondary level for energy, which we have converted to 2015 US$ using the GDP implicit price deflator. Economic costs are expressed as a share of GDP.

5.5. Social Cost of Carbon Distribution

The US government (USG) produced 150,000 social cost of carbon (SCC) estimates for the year 2030 based on a 3 percent discount rate in its 2015 update of the SCC (USG 2015). The USG SCC estimates reflect the consideration of various degrees of parameter uncertainty in the three deterministic integrated assessment models used in the USG exercise. Figure 2 presents the mean SCC and the 10th and 90th percentiles of the SCC distribution for 2030, converted from 2007 to 2015 US$ using the GDP implicit price deflator (CEA 2016). While this represents one way of illustrating uncertainty in the SCC, it is important to recognize alternative approaches to incorporating uncertainty in the modeling framework—such as in dynamic stochastic general equilibrium models—which may better represent how uncertainty influences the social cost of carbon.

5.6. Distribution of Cost-Minimizing Path to Limiting Warming to 2°C

The IPCC AR5 scenario database includes 186 marginal abatement cost estimates for all model runs that would limit warming to no more than 2°C with at least a 50 percent probability (https://secure.iiasa.ac.at/web-apps/ene/AR5DB/). Figure 2 also presents the mean value and the

10th and 90th percentiles of this distribution for 2030, converted from 2005 to 2015 US$ using the GDP implicit price deflator (CEA 2016).

5.7. Caveats in Comparing Modeling Estimates to SCC and Cost-Minimizing Path to Limiting Warming to 2°C

Figure 2 compares the modeling estimates of the INDCs using the four modeling platforms with the USG SCC estimates and the IPCC AR5 scenario database for model runs that would limit warming to no more than 2°C with at least a 50 percent probability. These comparisons are intended to be illustrative, but it is important to recognize several caveats. First, the underlying reference assumptions in our models differ from the underlying assumptions used in the SCC analyses and the AR5 modeling scenarios. The consideration of uncertainty also differs among these sets of analyses. Second, the SCCs represent the benefit of the first unit of emissions abatement, while the marginal costs represent the costs of the last unit of abatement. These differences may be small for modest levels of emissions abatement but large for globally significant levels of emissions abatement. Finally, the modeling analyses and those in the AR5 modeling scenarios assume idealized, economy-wide carbon-pricing policies. Thus the reported marginal and total costs of abatement in our modeling analyses and the AR5 scenarios may be lower than those associated with actual policy implementation.

5.8. Modeling Results

Figure 1 shows the estimated emissions reductions from business as usual in the major economies alongside marginal abatement cost and cost as a share of GDP. The results illustrate differentiated effort, with wealthier countries generally mitigating more emissions. Emissions reductions correlate well with marginal costs but not with total economic costs, in line with the empirical literature. The DNE21+ model estimates higher total economic costs for South Africa (2.1 percent), which primarily reflects that model’s cross-border spillovers—including falling demand for South African coal—anticipated by near-global implementation of INDCs. Japan, a country with low emissions and fewer mitigation options than other industrialized countries, shows costs as a percentage of GDP that are comparable to those of the United States and the EU, but fewer emissions reductions and significantly higher marginal costs (in GCAM and DNE21+).

Figure 2 compares marginal costs across countries. This figure highlights the potential gains to international emissions trading and how mitigation efforts compare with global benefit estimates and 2°C pathways. The considerable variation in marginal costs suggests large gains from international cooperation: when simulating cost-minimizing global attainment of the Paris INDCs, the DNE21+, MERGE, and WITCH models estimate a global carbon price of US$7–28/t$CO_2$ (2015$). Important institutional developments to promote joint mitigation measures among countries, including international emissions trading or carbon tax coordination, could deliver significant economic gains.

Figure 2 also compares the INDCs' marginal abatement costs with the SCC and the cost-minimizing path to limiting warming to 2°C. The global carbon prices appear to be well below the mean SCC (SCC = US$57/t$CO_2$ [2015$] in 2030) but consistent with the lower end of the SCC distribution. Likewise, the marginal abatement costs fall below the mean cost associated with a cost-minimizing path to limit warming to 2°C. These comparisons may indicate insufficient ambition in the Paris Agreement in terms of global welfare and the long-term temperature objective. However, some countries bear marginal costs exceeding the mean marginal benefits or the mean cost-minimizing level of a 2°C objective, such as Japan and the EU as modeled by DNE21+.

To illustrate how mitigation effort varies with wealth, Figure 3 plots the estimated policy costs (both marginal costs and total cost expressed as a share of GDP) against per capita income. The figure reveals two regional clusters—one consisting of emerging and developing economies and the other of high-income countries. As a measure of the distributional impacts of INDCs, a burden elasticity of income is computed: the variation in policy costs (either marginal or total) for a percentage point increase in per capita income. For marginal abatement costs, the estimated burden elasticity is 1.1 (SE = 0.25, statistically significant at 0.1 percent level), suggesting relatively progressive distributional impacts of INDCs. When measured using total costs, however, the burden elasticity of income is below unity (0.42) and not statistically significant (SE = 0.25). Higher marginal costs do not necessarily imply higher total policy costs; trade-exposed and carbon-intensive countries (e.g., many developing economies) tend to experience higher GDP losses for a given carbon price, as already shown by Stern et al. (2012). The models' estimates represent only the mitigation costs; they do not account for climate benefits or local air quality cobenefits. Nonetheless, there is significant variation across countries and models. Model assumptions matter.

Table 3 includes additional metrics that are less comprehensive than the cost and emissions reduction from BAU measures and show how some metrics naturally favor certain countries. Measuring emissions versus a 1990 base year is unfavorable to emerging countries and those with faster population or economic growth (e.g., the United States). With a 2005 base year, the United States and EU appear comparable, and for reductions from 2025–2030 forecast levels, countries are more comparable (but with the income gradation noted above). The carbon and energy price metrics suggest comparable price increases for the United States, EU, and Japan. While the MERGE model estimates lower carbon prices for these countries than the other models, each model shows fairly comparable carbon prices among this high-income group. China, India, South Africa, and Russia have much smaller comparable price impacts. Emissions intensity tends to favor faster-growing economies; China's INDC shows a reduction in emissions intensity similar to that of the United States.

6. Domestic Mitigation Programs in INDCs

One issue that Aldy et al. (2016b) do not address is the *actual* policy implementation used to meet the INDCs. That is, while one approach is to compare the commitment assuming cost-effective implementation, another is to consider the commitment in light of actual policies. This may be important to understand whether, in fact, the commitment will be achieved; to examine costs and impact of actual implementation; or to examine international trade and spillover effects (which will differ depending on implementation). Such analysis has only rarely been considered.

6.1. Academic Literature on the Impacts of Non-Cost-Effective Emissions Mitigation Policies

Most studies of national-level mitigation policies assume economy-wide prices. The main exceptions would be, in the United States, the use of the EIA's National Energy Modeling System (NEMS) to examine more detailed energy-related policies, as well as various partial-equilibrium sectoral analyses. Indeed, even the EIA NEMS analysis, while economy-wide, does not consider market equilibrium outside of energy markets.

An early effort to bridge this divide was Pizer et al. (2006). This paper uses a collection of sector-based models in conjunction with a computable general equilibrium (CGE) model of the economy to examine and compare sector-based or nonprice polices at an aggregate level. The sector-based models are used to calibrate the implementation of nonprice policies in the CGE model. The paper examines the relative costs of different policies designed to achieve the same level of emissions reductions. The authors look at different nonprice policy tools in different sectors, including renewable portfolio standards (RPS) in the electricity sector, Corporate Average Fuel Economy (CAFE) standards in the transportation sector, and a "uniform percentage rollback" policy in the industrial sector. The CGE model used is a comprehensive representation of the US economy that captures all energy and fossil fuel use. The results show that policies like RPS and CAFE turn out to be considerably more expensive than broad-based market alternatives. At an aggregate reduction of 5 percent, marginal welfare costs are more than 10 times higher when fuel economy standards and an RPS for power plants are imposed with both sectors facing equal percentage reductions (0.016 percent of GDP for economy-wide carbon pricing and 0.19 percent for the latter policies).

More recently, the Energy Modeling Forum 24 study included a set of policy scenarios designed to compare economy-wide market-based and sectoral regulatory approaches of potential US climate policy (Fawcett et al. 2014). Several policy architectures are explored in this study: cap-and-trade scenarios of varying stringency, isolated transportation sector policies, isolated electricity sector policies (separately, renewable portfolio and clean energy standards), combined electricity and transportation regulatory scenarios, and combined electricity and transportation regulatory scenarios plus a cap-and-trade policy. The authors find that for similar levels of abatement, a cap-and-trade policy that places a price on all greenhouse gas emissions is more cost-effective than sectoral or regulatory approaches that are limited in coverage and therefore more prescriptive in how emissions reductions are to be achieved. For example, the approach featuring regulation plus cap and trade is 62 percent more costly in the US Regional Energy Policy (USREP) model and 230 percent more costly in the Environment Canada Integrated Assessment Model (EC-IAM) model than with cap and trade alone. Furthermore, when sectoral and regulatory policies are combined with a cap-and-trade policy, the allowance price may be reduced compared with the cap-and-trade policy alone. While prices range from US$67 to US$168 per ton in 2050 for cap and trade alone, that range falls to US$44–US$118 when regulation is imposed on top of a cap-and-trade policy. This may hold political appeal—by making costs less transparent—but it does so by increasing aggregate costs of mitigation and weakening innovation incentives.

Rausch and Karplus (2014) examine the *distribution* of economic impacts under regulatory versus market-based approaches to climate change in the United States. The authors use the USREP model to model the US economy by region, income category, and sector-specific technology deployment opportunities. They quantify heterogeneity in the national response to regulatory policies, including a fuel economy standard and a clean or renewable electricity standard, and compare these with a cap-and-trade system targeting carbon dioxide or all greenhouse gases. The results show that the regulatory policies substantially exceed the cost of a cap-and-trade system at the national level. That is, welfare loses for the various policies range from 1.1 percent for policies for coal, RPS, and fuel economy standards to just 0.5 percent for the cap-and-trade system. They further show that the regulatory policies yield large cost disparities across regions and income groups, which are exaggerated by the difficulty of implementing revenue recycling provisions under regulatory policy designs.

6.2. Illustrations of Domestic Mitigation Programs in Countries' Mitigation Pledges

In order to examine something other than efficient, economy-wide carbon pricing, it is necessary to closely examine various national documents, such as INDCs and biennial reports, to understand the implemented and planned implementation of national policies and measures. In this section, we characterize the policies described in those documents for a small set of major developed and developing countries. It is also important to recognize that some countries have established technology-specific or sector-specific goals—subtargets of the national contribution in a country's INDC—that may imply the means of policy implementation but lack such specific details.

6.2.1. United States

The US INDC commits to an economy-wide reduction of GHG emissions by 26–28 percent below 2005 levels by 2025.[1] The INDC indicates several policy options that the United States will employ to achieve these targets. The major policy instrument is through a variety of uses of the Clean Air Act (CAA). The first is by using the CAA to regulate emissions from new and existing coal-fired power plants (described below). The Department of Transportation and Environmental Protection Agency (EPA) also intend to promulgate post-2018 fuel economy standards for heavy-duty vehicles under the CAA. Finally, under the CAA, EPA is developing standards to address methane emissions from landfills and the oil and gas sector. These policy actions are motivated in part by the Obama administration's goal to reduce methane emissions 40 percent below 2005 levels by 2025 (Executive Order 13693).

The US Climate Action Report 2014[2] and the president's Climate Action Plan contain more detailed policy positions on how the United States will reach its emissions reduction targets set out in its INDC. The first point is elaborating on the regulation of new and existing power

1 http://www4.unfccc.int/Submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf.

2 https://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/2014_u.s._climate_action_report[1]rev.pdf.

plants through the use of the Clean Power Plan (CPP). The CPP provides states flexibility to develop and implement plans that ensure the power plants in their state—either individually, together, or in combination with other measures—reduce CO_2 emissions consistent with a nationwide target of a 32 percent below 2005 levels by 2030.[3] The Obama administration has also set a goal to double renewable electricity generation from wind and solar once again by 2020. To meet this ambitious target, tax credits for renewable power were extended for five years, the president directed the Department of the Interior to permit more renewable energy projects on public lands, and the Obama administration set a new goal to install 100 megawatts (MW) of renewable power in federally assisted housing by 2020. The plan also requested increasing funding for clean energy technology across all government agencies by 30 percent, to approximately $7.9 billion. This includes investment in a range of energy technologies, from advanced biofuels and emerging nuclear technologies to clean coal.

6.2.2. India

India proposed to lower its emissions intensity of GDP by 33–35 percent below 2005 levels by 2030, increase the share of non–fossil based power generation capacity to 40 percent of installed electric power capacity by 2030 (equivalent to 26–30 percent of generation in 2030), and create an additional (cumulative) carbon sink of 2.5–3 $GtCO_2e$ through additional forest and tree cover by 2030 in its INDC.[4] This builds on India's Copenhagen pledge to reduce the emissions intensity of GDP by 20–25 percent below 2005 levels by 2020. With India's continued and forecast economic growth, these targets will translate into an increase in overall emissions but potentially lower than in a no-new-policy counterfactual.

Details on India's INDC implementation appear in its second national communication to the UNFCCC[5] and National Action Plan on Climate Change.[6] These reflect the low-carbon growth strategy in India's 12th Five-Year Plan. To finance clean energy, India imposed a US$1 per ton tax on domestically produced and imported coal. The tax revenues will fund research and innovative projects in clean energy technologies and environmental remediation programs. The

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3 https://www.epa.gov/cleanpowerplan/fact-sheet-clean-power-plan-overview.

4 http://www4.unfccc.int/Submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf.

5 http://unfccc.int/resource/docs/natc/indnc2.pdf.

6 http://www.cseindia.org/userfiles/National%20Action%20Plan%20on%20Climate%20Change.pdf.

tax has been raised several times since its inception in 2010, with a recent budget proposal calling for a tax increase to approximately US$6 per ton of coal in 2017.

India has set several renewable technology–specific goals as part of its plan to increase non–fossil fuel energy generation by 40 percent by 2030. In 2014, the Indian government announced that it would increase the solar ambition of its National Solar Mission to 100 gigawatts installed capacity by 2022, representing a 30-fold increase over the 2014 level of solar installation. The government also announced its intention to bring solar power to every home by 2019 and invested in 25 solar parks. The 12th Five-Year Plan proposes a National Wind Energy Mission, similar to the National Solar Mission, and the Indian government recently announced plans to boost wind energy production to 50,000–60,000 MW by 2022.

A third major pillar of India climate policy involves changes to the transportation sector. With vehicle ownership expected to continue to rise with per capita income, the transportation sector will continue to be a major source of GHG emissions. In early 2014, India announced a new vehicle fuel-economy standard (Indian Corporate Average Fuel Consumption standard) of 4.8 liters per 100 kilometers (49 miles per gallon) by 2021–2022, a 15 percent improvement. Additionally, India has established a goal to increase the share of biofuels in gasoline to 20 percent. Major public mass transportation improvements across Indian cities are also planned.

6.2.3. China

China's INDC[7] pledges to lower its carbon dioxide emissions per unit of GDP by 60—65 percent from 2005 levels by 2030. To help achieve this goal, China has also pledged to increase its share of non–fossil fuels in primary energy consumption to 20 percent and increase forest stock volume by 4.5 billion cubic meters relative to its 2005 level. China's INDC also calls for peaking of CO_2 emissions by 2030, while making the best effort to peak early. Carbon emissions trading pilots have been initiated in 7 provinces and cities and low-carbon development pilots in 42 provinces and cities. These pilot programs will serve as the basis for the rollout of a national cap-and-trade program.

To contribute to its goal of peaking emissions, China has set limits on total coal consumption. The National Development and Reform Commission published the Rules on Implementing the Action Plan on Prevention and Control of Air Pollution in Beijing-Tianjin-

[7] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf.

Hebei and Neighboring Area, which will reduce coal consumption in Beijing, Tianjin, and Hebei and Shandong Provinces by 83 million tons by the end of 2017. By cutting consumption and identifying clean alternatives, Guangdong Province, Jiangxi Province, and Chongqing have pledged to cut the proportion of coal in their energy consumption to less than 36 percent, 65 percent, and 60 percent, respectively, by 2017.

A major key to seeing overall emissions peak is by increasing carbon sinks throughout China through the use of various forestry policies. The State Forestry Administration has accelerated the implementation of the Program for National Forestation (2011–2020). In 2013, 91.5 million mu (23,522 square miles) of forest and 2.52 billion trees were planted, surpassing the target for the year. More than 300,000 mu (77 square miles) of carbon sink forestation had been created by 2013. Forest cultivation subsidies, which were being tested in pilot areas, are now being implemented on a nationwide basis. The central fiscal budget allocated 5.8 billion yuan (US$856 million) to cultivating 118 million mu (30,373 square miles) of forest, surpassing the target for that year.[8]

6.2.4. South Africa

The INDC for South Africa[9] focuses on a transition from business as usual to a peak, then plateau, and eventual decline in its GHG emissions trajectory. South Africa states that its emissions will range between 398 and 614 million metric tons of carbon dioxide equivalent (CO_2e) between 2025 and 2030, conditional on external financing. This would represent a 20–82 percent increase from 1990 levels of emissions[10] and would presumably be the peak emissions for South Africa.

South Africa has a few policies in place that will help mitigate GHG emissions, including a carbon tax on new vehicles, a tax rebate for energy efficiency, and subsidies to promote solar water heaters. Several policy instruments are also under development, including a carbon tax, desired emissions reduction outcomes for specific sectors, company-level carbon budgets, and regulatory standards and controls for specifically identified GHG pollutants and emitters. In respect to mitigation and adaptation efforts, and as a developing country, the scale and ambition

8 http://en.ccchina.gov.cn/archiver/ccchinaen/UpFile/Files/Default/20141126133727751798.pdf.

9 http://www4.unfccc.int/Submissions/INDC/Published%20Documents/South%20Africa/1/South%20Africa.pdf.

10 www.climateactiontracker.org.

of South Africa's contribution will also be dependent on the extent of international support, such as through funding, capacity building, and technology transfer.[11]

In 2009, the National Energy Regulator of South Africa (NERSA) announced South Africa's first Renewable Electricity Feed-In Tariff (REFIT), which designates Eskom as the single buyer from independent power producers. The key aim of REFIT is to facilitate meeting the 2013 renewable energy target. The technologies included in the REFIT program and tariffs are wind, concentrated solar power, small hydro (1 MW), solid biomass, and biogas. Given the low price of electricity in South Africa, the impact of REFIT on the viability of renewables projects could be significant. Regulations are being finalized to implement the REFIT program, and rules for a Cogeneration Feed-In Tariff (COFIT) program to support cogeneration are under development.

6.2.5. European Union

The European Union set its INDC[12] target of 40 percent reduction in GHG emissions by 2030 compared with 1990. This comes with pledges to supply 20 percent of energy, as a share of total EU gross final energy consumption, from renewable energy sources by 2030. This is supplemented by a target to achieve a minimum of 10 percent renewable energy in transportation. The EU also aims to improve energy efficiency and reduce total energy consumption by 20 percent by 2020 compared with a business-as-usual baseline.

To achieve its goals, the EU has a wide range of policies, as outlined in the EU's and member states' national communications to the UNFCCC.[13] In the transportation sector, regulations will lower CO_2 emissions of new passenger cars by 40 percent and emissions of new light commercial vehicles by 28 percent by 2020 relative to 2007 levels. Fuel suppliers are also required to reduce life-cycle GHG emissions per unit of energy by up to 6 percent by 2020 compared with 2010.

The EU Emissions Trading System (EU ETS) recently started its third phase (2013–2020). The EU ETS covered on average 41 percent of total EU-28 GHG emissions during the period 2008–2012. Because of the financial crisis, the significant use of emissions reduction

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11 http://unfccc.int/resource/docs/natc/zafnc02.pdf.

12 http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Latvia/1/LV-03-06-EU%20INDC.pdf.

13 https://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/eu_nc6.pdf.

credits from abroad, and member states' ambitious renewable power subsidies, a surplus in allowances has accumulated in recent years that has contributed to a drop in allowance prices.

In addition to the EU ETS, EU member states have taken on binding annual targets for each year from 2013 to 2020 and committed to reducing their GHG emissions from the sectors not covered by the EU ETS, such as housing, agriculture, waste, and transport (excluding aviation). Additional policies in these sectors include the EU's Common Agricultural Policy (CAP). The new CAP, covering the period 2014–2020, will further enhance the existing policy framework for sustainable management of natural resources, both contributing to climate change mitigation and enhancing the resilience of farming to the threats posed by climate change and variability. In the industrial sector, the EU is regulating the emissions of fluorinated gases, and a current proposal would strengthen this regulation.

6.2.6. Japan

Japan committed to reduce its GHG emissions 26 percent below 2013 levels by 2030.[14] The country plans to cut energy-related CO_2 emissions, which represent approximately 90 percent of the country's GHG emissions, by 25 percent. Japan's non-CO_2 GHG reduction targets include methane, 12.3 percent; N_2O, 6.1 percent; fluorinated gases, 25 percent; and removals from land use, land-use change and forestry (LULUCF) activity, 2.6 percent.

In the transportation sector, Japan aims to increase the share of highly efficient next-generation vehicles—hybrid, electric, plug-in hybrid, clean diesel, and compressed natural gas vehicles—by 50–70 percent by 2030.[15] Japan will employ government procurement of and tax credits for electric vehicle purchases to promote demand for next-generation automobiles. It will also review regulations on fuel-cell vehicles and hydrogen infrastructure.

Additionally, the government of Japan will promote the "greening" of the tax system through energy and vehicle taxes. Japan operates a credit offset scheme called the J-Credit System, which is similar to an emissions trading scheme. This policy creates incentives for investment in energy-saving equipment, renewable energy, and carbon sinks through appropriate forest management.

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[14] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf.

[15] https://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/nc6_jpn_resubmission.pdf.

6.2.7. Russia

Russia pledges to limit its GHG emissions to 25–30 percent below 1990 levels by 2030 in its INDC.[16] Its mitigation program is briefly outlined in its First Biennial Report[17] and Russian Climate Doctrine.[18] GHG emissions reduction efforts focus on promoting carbon sinks, improving energy efficiency across the economy, and developing renewable and alternative energy sources. Russia plans to employ financial and tax incentives to promote these GHG reductions.

7. Comparability Analysis: Extending Modeling Tools to Assess Domestic Programs

The limited literature to date highlights the difficulty of trying to represent a somewhat realistic implementation of national policies under the Paris Agreement. Yet that is precisely what is necessary to provide countries and stakeholders with the necessary feedback to enable increasingly stronger national commitments going forward. Countries need to understand the consequences of the actual policies implemented, not just a stylized representation of the pledged targets.

On the one hand, this will require the enhanced use of multisector, multiregional models, if not the enhancement of the models themselves. As Pizer et al. (2006) highlight, it is possible to represent complex policies in more simplified models, but the parameters of that representation may need to be calibrated from an analysis using a more detailed model. It will be important to model such policies in global multiregional, multisector frameworks in order to implement sectoral policies in multiple countries simultaneously and to assess net-of-trade impacts on national well-being.

On the other hand, this will require more sophisticated thinking about how to construct and interpret comparability metrics. When a country chooses to implement a nonprice policy with higher societal costs, it may be doing so for a variety of reasons related to other economic concerns, political interests, or bad policymaking. Is that important from a comparability standpoint? For example, a country might prefer to avoid a high carbon price for trade reasons or

[16] http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx.

[17] http://unfccc.int/files/national_reports/biennial_reports_and_iar/submitted_biennial_reports/application/pdf/1br_rus_unoffical_translation_eng.pdf.

[18] http://www.kremlin.ru/events/president/news/6365.

to avoid redistribution from high energy using consumers and firms. Does that matter? Can we relate such concerns and choices to observable metrics? Also, while measuring trade effects is important, how do we interpret them? Should we consider stand-alone implementation of national policies without trade effects alongside global implementation with trade effects? What would that tell us?

8. Conclusions

Analyses that compare climate change pledges and actions across countries are increasingly relevant as we transition to unilateral pledges of domestic action and policy within international negotiations. The emerging architecture calls for countries to state what they intend to do, form views about the adequacy of each other's efforts, and react accordingly as they implement policies and make further pledges in the future. This is increasingly complicated as we confront the actual policies countries intend to use, rather than stylized and idealized policies.

No single metric comprehensively measures effort, is easily measured, and is universally available for all countries. Moreover, each country will prefer to emphasise measures that improve its own appearance. This makes it unlikely that an official metric will emerge. Instead, countries will advertise and utilize the metrics they prefer. Analysis is necessary to translate among metrics, particularly harder-to-measure metrics.

Compiling data and conducting this analysis of metrics will require a serious, transparent, and legitimate process (Aldy 2013, 2014). As negotiators attempt to elaborate such a process under the Paris Framework, independent researchers can fill in the gap. An array of easily available metrics could be developed and data collected by existing international organizations to facilitate comparisons.

Unofficial but independent expert analysis could further synthesize these data to estimate metrics that require forecasts and modeling. In turn, stakeholders and other users could provide feedback on the feasibility, integrity, and precision of available metrics and estimates. This enables further refinement and improved estimates going forward. In addition, the work on developing metrics for ex ante comparisons of effort can inform the data collection and analysis needs for ex post reviews. The retrospective review of pledges will be more informative and more effective if countries plan in advance for such reviews by implementing data collection and dissemination protocols. Given that Paris is just the beginning of an ongoing process of policy commitments, these refinements and improvements can ultimately feed into greater confidence and stronger ambition among all countries.

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Tables and Figures

Table 1. Synthesis of Metrics and Principles

Metric	Comprehensive	Measurable/replicable	Universal
Emissions levels	A poor estimate of effort because it conflates natural trends	Yes; public domain data for energy and fossil CO_2 available	Fossil CO_2 data exist for all countries; additional work needed for all GHGs
Emissions intensities	Better than emissions levels, as it controls for economic trends, but a noisy signal	Yes; public domain data for energy and fossil CO_2 available	Yes for fossil CO_2/GDP; additional work needed for GHG/GDP
Emissions abatement	Most comprehensive among emissions-related metrics	Challenging—requires modeling tools/subjective choices to determine counterfactuals	No, few modeling platforms evaluate more than ~10 countries
Carbon prices	Captures effort per ton but says little about tons	Explicit: yes; implicit: requires detailed analyses	No, given few explicit carbon (C) pricing policies; modeling tools necessary for implicit C prices
Energy prices and taxes	Inadequate for nonenergy emissions; fails to account for nonmarket regulatory instruments	Yes, but unclear how to aggregate	Yes, but requires more detailed data collection than currently in public domain
Abatement costs	Best measure of effort, still requires benchmarking	Challenging—requires modeling tools/subjective choices to determine counterfactuals and to model costs	No, few modeling platforms comprehensively evaluate more than ~10 countries

Source: Aldy and Pizer (2016).

Table 2. Information Sources for Comparability Metrics

	Ex ante analysis			Ex post analysis		
	US	EU	China	US	EU	China
INDC description	2005 –26% to –28% by 2025	1990 –40% by 2030	Peaking by 2030, CO_2/GDP goal	Implemented contributions (TBD)		
Emissions						
vs. historical year	<directly observed>		<requires modeling>	<directly observed>		
vs. future year BAU	<requires forecast>		<requires modeling>	<requires modeling>		
Target year GHG/GDP	<requires forecast>		<requires modeling>	<directly observed>		
Δ (GHG/GDP) 2015–25	<requires forecast>		<requires modeling>	<directly observed>		
Δ (GHG/GDP) 2015–30	<requires forecast>		<requires modeling>	<directly observed>		
Price						
CO_2	<requires modeling>		<requires modeling>	<carbon pricing: directly observed; other policies: require modeling >		
Fossil energy	<requires modeling>		<requires modeling>	<directly observed>		
Electricity	<requires modeling>		<requires modeling>	<directly observed>		
Cost						
$ cost vs. BAU	<requires modeling>		<requires modeling>	<requires modeling>		
$ cost/GDP	<requires modeling>		<requires modeling>	<requires modeling>		

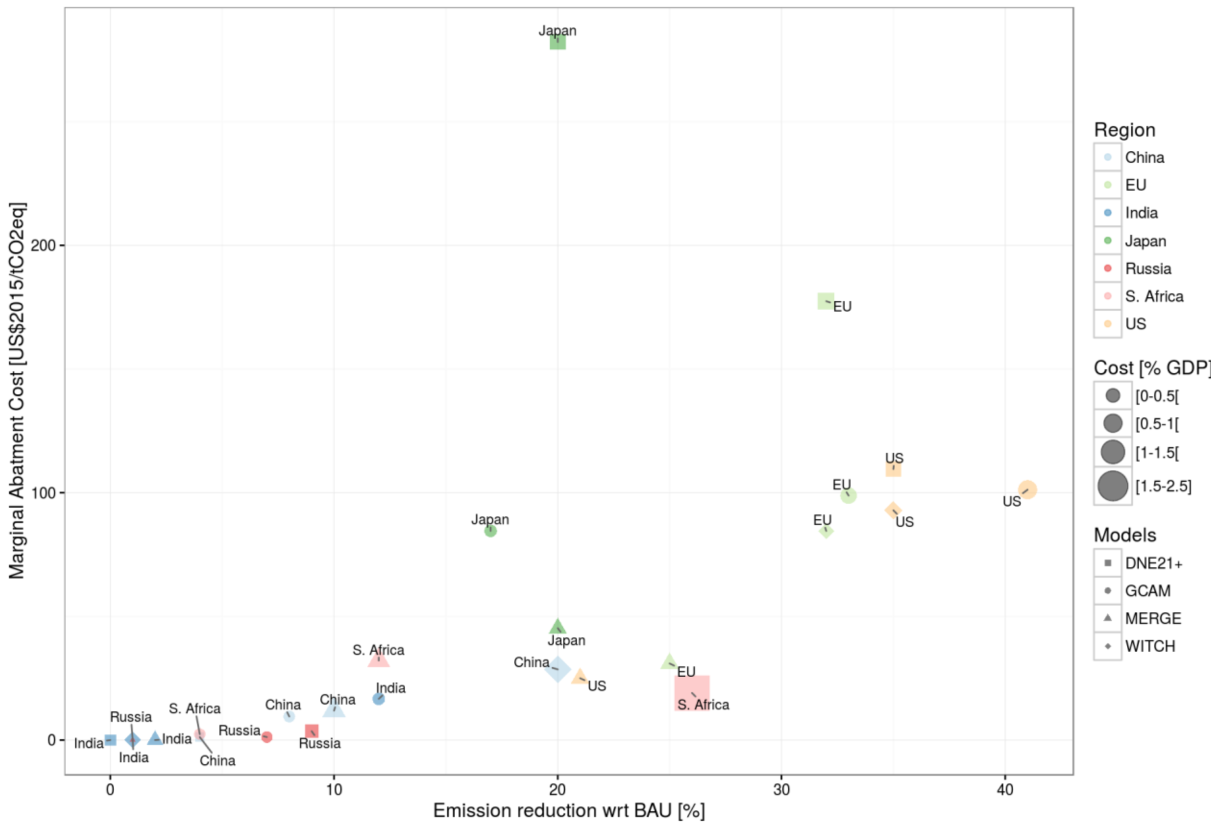
Source: Aldy et al. (2016a).

Table 3. Ex Ante Assessment of the INDCs of Select Countries, Average over 2025–2030

		GHG average annual emissions 2025–30				GHG annual change (%)		CO_2 price	Energy price change (%)			Cost
		Level	vs. 1990	vs. 2005	vs. BAU	2015–25	2015–30	($/t$CO_2$)	Electricity	Gasoline	Nat. gas	(% GDP)
US	DNE21+	5,091	–18	–30	–35	–4.38	–4.03	109	38	35	70	0.42
	WITCH	5,140	–5	–26	–35	–5.50	–4.29	101	38	53	72	0.76
	GCAM	4,358	–29	–34	–41	–4.83	–4.83	100	40	56	83	0.84
	MERGE	5,407	–7	–22	–21	–2.70	–3.68	40	48	22	28	0.28
EU	DNE21+	3,733	–35	–30	–32	–2.73	–3.30	177	30	28	44	0.59
	WITCH	3,720	–32	–30	–32	–4.43	–4.39	116	12	39	91	0.51
	GCAM	3,500	–38	–32	–33	–3.73	–3.73	100	28	55	81	0.57
	MERGE	3,836	–30	–25	–25	–1.98	–3.01	45	29	29	31	0.31
China	DNE21+	17,353	338	109	–4	–4.62	–4.31	1	–5	–2	0	–0.20
	WITCH	16,526	413	91	–20	–4.39	–4.02	33	46	15	25	1.60
	GCAM	13,809	149	49	–8	–4.16	–4.05	12	9	5	7	0.04
	MERGE	13,086	250	77	–10	–3.83	–3.65	23	31	14	16	0.72
India	DNE21+	6,366	389	206	0	–1.83	–1.80	0	–4	–3	0	0.00
	WITCH	4,577	278	115	–1	–2.72	–2.61	0	0	–2	–1	0.59
	GCAM	5,007	220	121	–12	–2.65	–2.62	19	16	9	13	0.13
	MERGE	4,787	308	135	–2	–2.42	–2.52	0	2	6	7	0.12
Japan	DNE21+	1,107	–13	–21	–20	–3.29	–3.54	283	48	49	36	0.47
	GCAM	1,139	–12	–21	–17	–2.27	–2.24	91	40	46	69	0.13
	MERGE	1,037	–12	–23	–20	–1.87	–2.23	43	26	25	29	0.22
h Afric	DNE21+	525	50	18	–26	–2.38	–3.20	19	33	4	0	2.11
	GCAM	503	10	–12	–4	–1.00	–0.98	2	2	1	1	0.01
	MERGE	543	33	13	–12	–2.08	–2.38	39	49	32	27	0.64
Russia	DNE21+	2,383	–29	12	–9	–5.12	–5.00	4	9	2	11	0.23
	GCAM	2,481	–26	7	–7	–2.09	–2.23	2	3	0	0	0.01
	MERGE	1,767	–43	–12	–1	–2.17	–1.97	0	1	4	4	–0.47

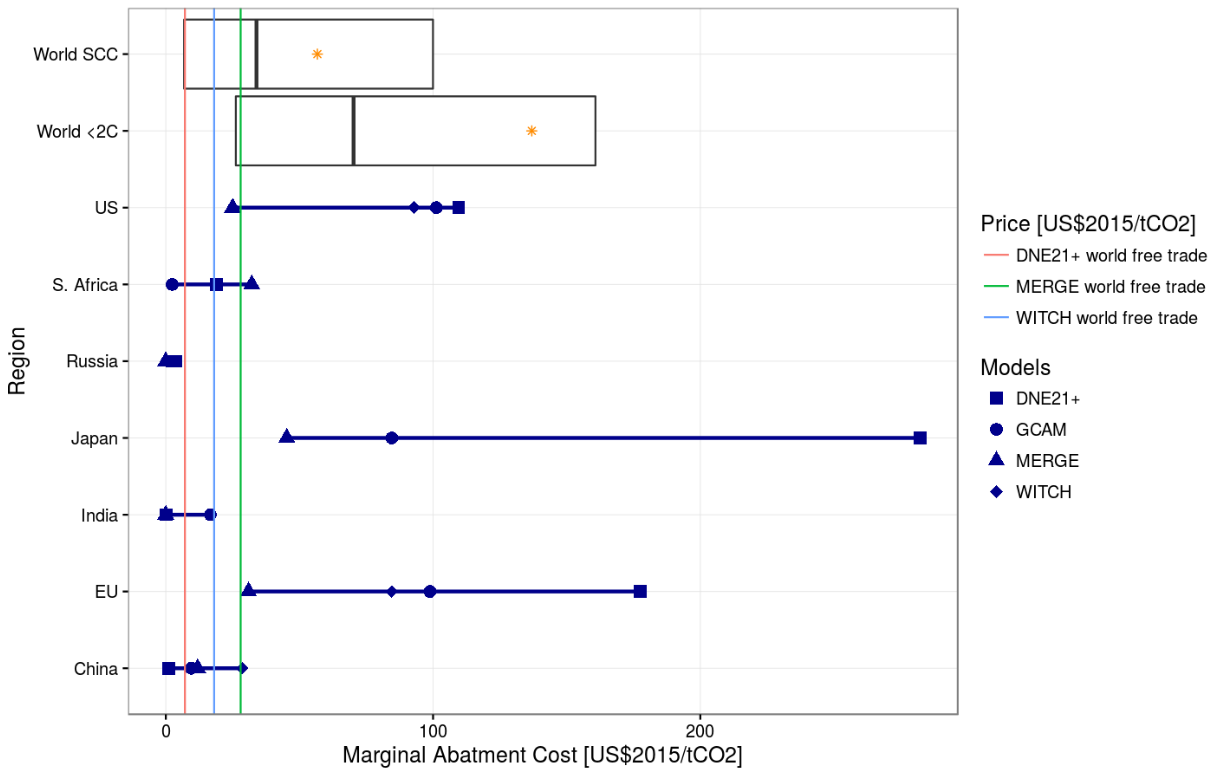
Notes: For the US, China, and Russia, we have employed the midpoint in their INDC range. Marginal cost is aggregated based on mitigated emissions. MERGE results are 2030.
Source: Aldy et al. (2016b).

Figure 1. Average 2025–2030 Mitigation Costs in Relation to Emissions Reductions with Respect to BAU for the 4 Models and 7 Major Economies



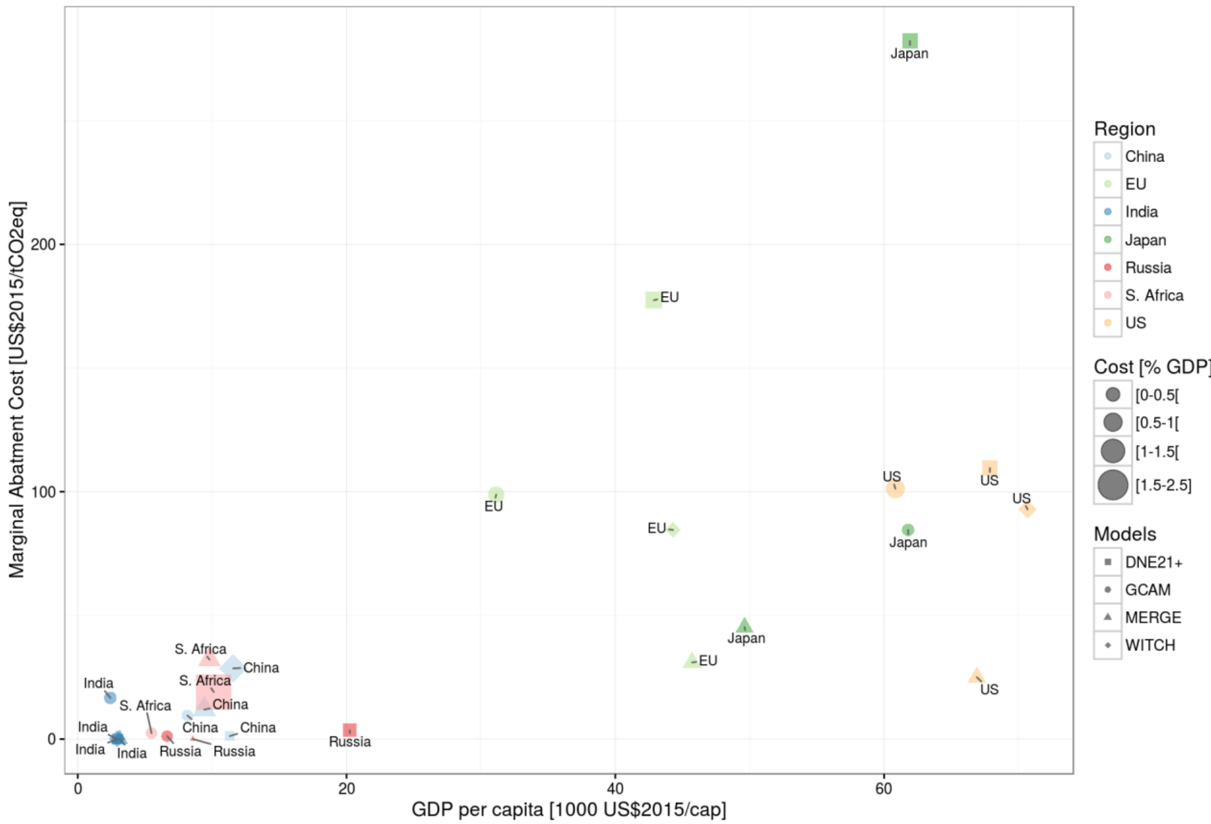
Source: Aldy et al. (2016b).
Note: % GDP losses proportional to the size of the markers.

Figure 2. Average 2025–2030 Marginal Abatement Costs for the 4 Models



Source: Aldy et al. (2016b).
Notes: The boxplot shows the ranges of the USG social cost of carbon and the marginal abatement costs in 2030 for scenarios consistent with 2°C, as in the IPCC AR5 database. The orange stars represent the mean, and the boxes show the 10th, 50th, and 90th percentiles. Refer to Sections 5.5 and 5.6 for details on the SCC and cost-minimizing path to limit warming to 2°C distributions. The red, blue, and green lines show the marginal costs predicted by three models (DNE21+, MERGE, and WITCH), assuming an international carbon market with free trade of CO_2 permits or harmonized global carbon tax.

Figure 3. Average 2025–2030 Mitigation Costs in Relation to Average 2025–2030 per Capita Income for the 4 Models and 7 Major Economies



Source: Aldy et al. (2016b).
Note: % GDP losses proportional to the size of the markers.