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# Carbon Abatement Costs

*Why the Wide Range of Estimates?*

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# **Carbon Abatement Costs: Why the Wide Range of Estimates?**

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## **Abstract**

Estimates of marginal abatement costs for reducing carbon emissions derived from major economic-energy models vary widely. Controlling for policy regimes, we use meta-analysis to examine the importance of structural modeling choices in explaining differences in estimates. The analysis indicates that particular assumptions about perfectly foresighted consumers and Armington trade elasticities generate lower estimates of marginal abatement costs. Other choices are associated with higher cost estimates, including perfectly mobile capital, inclusion of a backstop technology, and greater disaggregation among regions and sectors. Some features, such as greater technological detail, seem less significant. Understanding the importance of key modeling assumptions, as well as the way the models are used to estimate abatement costs, can help guide the development of consistent modeling practices for policy evaluation.

**Key Words:** climate models, carbon tax

**JEL Classification Numbers:** Q4, Q25, D58

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# Carbon Abatement Costs: Why the Wide Range of Estimates?

Carolyn Fischer and Richard D. Morgenstern\*

## Introduction

The estimated costs of reducing carbon emissions to Kyoto commitment levels vary by a factor of five or more (Weyant and Hill 1999; Lasky 2003). Not surprisingly, this variability in cost estimates undermines support for mandatory policies to curb carbon emissions, as policymakers generally are reluctant to adopt a major program without an understanding of its true costs. In the face of such disparate estimates, the Intergovernmental Panel on Climate Change (IPCC) Third Assessment (2001) calls for “further development of a consistent analytical structure and a format for reporting the main assumptions that underlie costing results, including ... economic growth ... technological development ... flexibility of policies... [and other factors].”

To glean additional insights from the reported (divergent) model results, this paper identifies a number of factors that may explain the differences and assesses the quantitative importance of these factors via a meta-analysis of recent energy-economic model simulations.<sup>1</sup> Overall, the goal is to focus analytic attention on those variables found to be most critical, thereby narrowing the range of uncertainty associated with carbon abatement costs. Notwithstanding the obvious statistical limitations of any meta-analysis based on a small number of underlying studies—including the present one—we believe this technique can generate certain insights that may help clear the fog surrounding carbon abatement costs.

At the outset, we distinguish four principal factors likely to contribute to the differences in estimates of carbon mitigation costs, roughly following the IPCC framework:

1. Projections of base case emissions, which determine the quantity of abatement required to meet fixed Kyoto targets;

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<sup>1</sup> A meta-analysis, or analysis of analyses, uses statistical techniques to investigate a group of studies. Early applications of meta-analysis were in the fields of psychology, natural sciences, and education. See Glass (1976).

2. Structural characteristics of the models, including sectoral and technological detail, the representation of substitution possibilities, international linkages, and optimization techniques;
3. The climate policy regime considered (especially the degree of flexibility allowed in meeting the emissions constraints); and
4. The consideration of averted climate damages or ancillary benefits from reductions in conventional pollutants associated with carbon mitigation.

The earliest systematic attempt to assess the quantitative importance of these different factors was a paper published by Repetto and Austin (1997, hereafter R/A) in the run-up to the Third Conference of the Parties (COP 3) of the United Nations Framework Convention on Climate Change. Widely discussed in policy circles at the time, the R/A paper used meta-analysis to explain the range of cost estimates (measured by GDP loss) available in the (then) existing literature. Overall, differences in policy regimes (e.g., emissions trading and revenue recycling) emerged as key factors in their analysis, as did the consideration of ancillary benefits. However, structural modeling issues were not examined in detail.

Following COP 3, which established the targets and timetables of the Kyoto Protocol, the Stanford Energy Modeling Forum organized a series of comparative analyses (EMF-16) of the economic and energy sector impacts of the proposed provisions. Highlighting marginal abatement costs rather than GDP loss as the cost measure for comparison, EMF-16 also revealed a wide range of estimates. However, with the harmonization of policy regimes and other relevant assumptions, the remaining variation in costs is solely attributable to differences in baseline assumptions or structural characteristics of the individual models. Our focus is on the relative importance of these factors in explaining the substantial remaining cost variation.

The organization of this paper is straightforward. Section II offers more detailed background of the R/A analysis and subsequent EMF-16 model simulations, as well as some recent qualitative analyses comparing the structural characteristics of the different models. Sections III and IV present the data and results of the meta-analysis. Section V offers concluding observations.

## **Background**

The relative abundance of independent, peer-reviewed estimates of carbon mitigation costs reflects the importance attached by modelers (and funders) to this issue. R/A and EMF-16 represent two attempts to examine the differences among the models, in part by controlling for

varied policy assumptions. Typically, meta-analysis compares statistical results across different data sets. In this case, it is used to compare results from different models using (more or less) the same data set, namely national accounting information.

R/A based their meta-analysis on a relatively large sample: 162 pre-Kyoto runs from 16 different energy-economic models published in the period 1983–1997. The models differ in the reduction goals examined and in the time periods forecast, although all fall between 2000–2050. R/A adopted a nonlinear formulation and regressed the percentage change in GDP loss on a number of variables reflecting both policy assumptions and model characteristics.<sup>2</sup>

Despite their transparent approach, R/A treated multiple observations from the same energy-economic model as if they were independent data points.<sup>3</sup> Since some models systematically generate higher estimates than others, such an approach can yield downwardly biased standard errors. Interestingly, even with this potential bias, R/A report the presence of a noncarbon backstop technology as the only significant variable addressing structural model characteristics. Arguably, the R/A analysis was hampered by the limited model simulations available at the time to serve as inputs for their meta-analysis. Furthermore, during the pre-Kyoto era, a greater focus was placed on identifying the role of policy assumptions and ancillary benefits, as the emissions targets had yet to be established.

The EMF-16 organizers assembled more than a dozen major models and developed a comparative analysis of the economic and energy impacts of the Kyoto Protocol. Each modeler was asked to simulate up to 15 explicitly defined policy scenarios for meeting the Kyoto targets and timetables, including a reference baseline, no trading, Annex I trading, “double bubble,” full global trading, and a variety of options involving limited trading, clean development mechanism (CDM), and sinks, as well as some long-run concentration target scenarios.

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<sup>2</sup> Specifically, the following independent variables were included: the percentage reduction in CO<sub>2</sub> emissions; whether the model is a macro or computable general equilibrium (CGE) type; whether it includes a constant-cost, noncarbon backstop technology; the number of primary fuel types recognized for possible inter-fuel substitution; whether the model allows for product substitutions; whether revenues from the policy instrument are recycled to reduce existing distorting taxes; whether averted climate change damages are included; whether averted air pollution damages are included; the number of years available to meet the abatement target; and whether joint implementation or global emissions trading is incorporated.

<sup>3</sup> R/A report that as many as 24 observations came from a single model (Jorgenson and Wilcoxon) and as few as three observations came from another model (Markal-Macro). The average was slightly more than 10 observations per model.

One of the choices facing the EMF-16 organizers was how best to measure costs when comparing the model results. Aggregate cost measures, such as GDP loss or a more comprehensive indicator such as the change in welfare, commonly are used for this purpose, as they best measure the burden of economic dislocations. Unfortunately, aggregate measures are more difficult to compare across models. Measurement differences can be attributed to the effect of pre-existing taxes, the manner in which carbon taxes revenues are recycled, and other components that are explicitly included in some models but not others—ancillary benefits and averted damages, for example.<sup>4</sup> Aggregate cost measures also are quite sensitive to baseline projections of emissions and GDP, which differ substantially among the models.

Measures of marginal abatement costs (e.g., the carbon tax or permit price) also are commonly used in model comparisons. The form and magnitude of the substitution and demand elasticities, the representation of capital stock turnover, and energy demand adjustments, as well as the base case emissions, all are embedded in these estimates. As Weyant and Hill (1999) note, “the information embedded in [these curves] ... is an extremely valuable starting point in the process of understanding model differences” (page *xxxvi*). Clearly, the carbon price also is a variable of direct interest to policymakers.

Gherzi and Toman (1999) examined the detailed structural characteristics of a number of economic-energy models, as well as their key policy assumptions, and developed an analytic framework for comparing them. They documented information about structural elements in three areas: equity, technical change, and international linkages. The rich set of simulation results from EMF-16, combined with the Gherzi/Toman analysis and the greater availability of information documenting the individual models, forms the basis of our meta-analysis.<sup>5</sup>

### Meta-analysis Data

We chose our dependent variable to be the natural logarithm of marginal abatement cost, as revealed by the equilibrium permit prices. With the use of logs, the coefficients can be interpreted as the percentage change in carbon prices from a one-unit increase in the independent variable (either a percentage point in the abatement rate, or the characteristic identified by the

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<sup>4</sup> For a review of the differences among welfare impacts, domestic carbon permit prices, and GDP, see Bernstein et al. (1999).

<sup>5</sup> Some minor corrections and modifications have been made to the original Gherzi and Toman results based on specific information obtained from authors of the models.

dummy variable). For each of four regions and eleven models, information on the percentage abatement and marginal costs is drawn from two distinct policy scenarios: *No Trading* and *Annex I Trading*.<sup>6</sup> After accounting for missing information, this yields a total of 80 observations.<sup>7</sup> Although data were available for other policy scenarios, including a “double bubble” and “global trading,” these involved a variety of additional assumptions across models regarding supplementarity, CDM costs, sinks, and other factors. We chose to restrict ourselves to the two Annex I-related scenarios for which the underlying policy assumptions were most consistent.<sup>8</sup>

The resulting data points for the United States are depicted in Figure 1. Although they may evoke domestic marginal abatement cost curves, such a characterization is not technically correct. Rather, the curves connect data from two distinct international policy scenarios. As Klepper and Peterson (2003) argue, domestic abatement costs are not independent of the levels of abatement undertaken in the rest of the world. World energy prices are an important link, and the strength of the cost dependence is influenced by trade structures, elasticities, and other factors. Manne and Richels (2001) and others have demonstrated, for example, that in an international system in which a large emitter like the United States does not abate, marginal abatement costs in other Annex I nations may be reduced significantly.

In effect, then, we have data drawn from two sets of different domestic cost curves. One set reflects the cost of individual countries achieving their targets independently, in an equilibrium in which all Annex I countries also abate carbon emissions according to the Kyoto framework, without emissions trading. The other set reflects the collective achievement of the Annex I targets via emissions trading. Indeed, given the availability of substantial numbers of permits from Russia (“hot air”) via emissions trading, the latter scenario represents a much lower collective abatement target and thereby a very different international context for domestic abatement choices. As a result, we believe that both data points can be included in the meta-analysis without violating the assumption of independence.<sup>9</sup>

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<sup>6</sup> Where possible, we use original source data reported in the *Energy Journal* special issue articles. Implicit price GDP deflators were obtained from the *Economic Report of the President* (2004) to harmonize prices to \$1,990.

<sup>7</sup> Only nine of the EMF-16 models had sufficient modeling descriptions and price data for all four regions. Two more EMF models (CETA and Oxford) are added for the U.S. regressions. Oxford also is used for the EU and Japan analyses.

<sup>8</sup> Hawellek et al. (2004), in a different meta-analysis, do include the global trading scenario.

<sup>9</sup> If we ignore this Klepper-Peterson argument for pooling the data and consider only a single scenario with 40 observations, the results are very similar. The fit is slightly better using the Annex I Trade scenario and poorer with the “No Trade” scenario.



The dummy variable ANNEX\_I is used to estimate the magnitude of the savings associated with emissions trading. Since the cost of the emissions reductions needed to reach the Kyoto targets depends on both the starting and the ending points, the variable ABATEMENT, modeled as a percentage reduction, captures variations in both baseline emissions and the expected amount of abatement.<sup>10</sup> The square of this term is included to account for potential nonlinearities in marginal abatement costs.

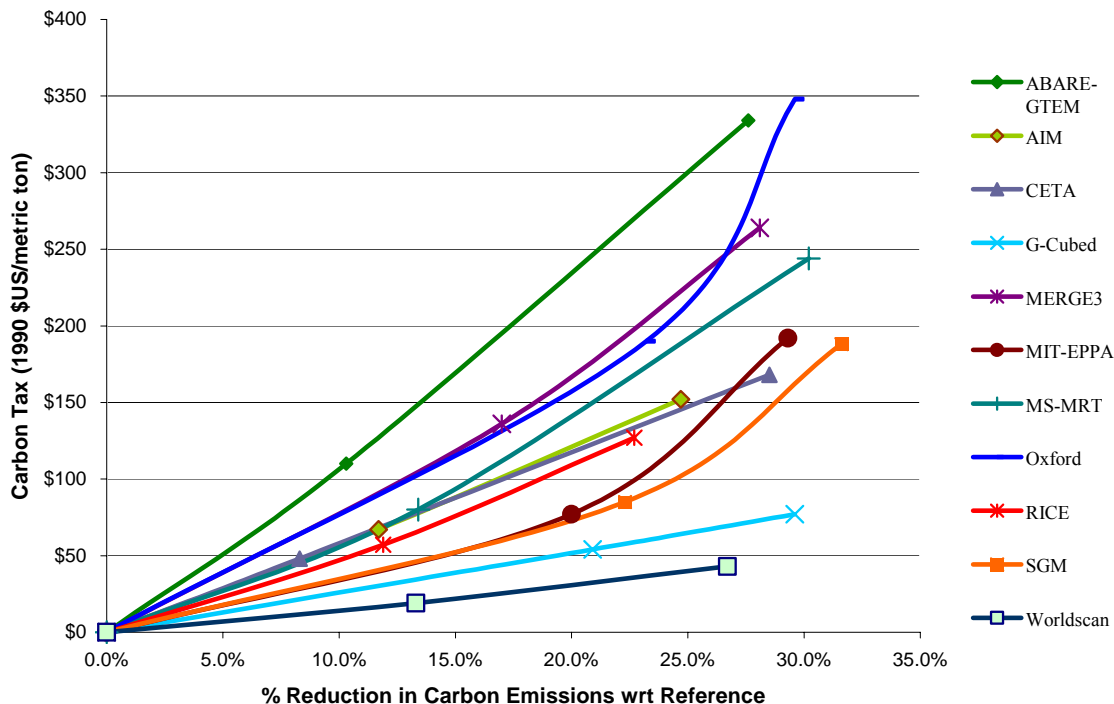


Figure 1: EMF-16 Model Predictions of Marginal Abatement Costs for the United States Derived from the “No Trade” and Annex I Trading Scenarios<sup>11</sup>

Based on analyses by Gherzi and Toman (1999) and Weyant and Hill (1999), we created eight structural plus three regional variables representing different approaches adopted in the various models (Table 1).

<sup>10</sup> In earlier analyses, a variable reflecting different baseline assumptions among the models did not prove to be statistically significant and was dropped from the reported regression results.

<sup>11</sup> See text for derivation of cost curves.

**Table 1: Definition of Variables**

<b>Dependent variable:</b>	
MC	(Natural log of) Marginal abatement cost (equilibrium carbon price) in \$1990
<b>Independent variables (target related):</b>	
ABATEMENT	% abatement from baseline
ANNEX I	1 if Kyoto targets are met with emissions trading, 0 if without
<b>Independent variables (structural and regional):</b>	
REGIONS	Number of countries/regions in model
NONENERGY	Number of nonenergy sectors in model
ENERGY	Number of energy supplies in model
HOUSEHOLDS	1 if households infinitely lived, 0 otherwise
BACKSTOP	1 if noncarbon backstop available, 0 otherwise
TECHNOLOGY	1 if model incorporates technological detail, 0 if exogenous
ARMINGTON	1 if Armington specifications <sup>12</sup> for trade, 0 otherwise
PERFECTMOBILITY	1 if perfect capital mobility, 0 if separate regional returns or no capital mobility
EU	1 if European Union, 0 otherwise
CANZ	1 if Canada, Australia or New Zealand, 0 otherwise
JAPAN	1 if Japan, 0 otherwise

Within EMF-16, the Oxford model, the single macro-econometric approach included in the group, generated the highest marginal abatement costs.<sup>13</sup> Even though R/A showed that macro models tend to estimate higher abatement costs than computable general equilibrium formulations, we do not include a dummy for this factor since it only would serve as an indicator of a single model.

### Meta-analysis Results

The results of our meta-analysis, based on ordinary least squares, are reported in Table 2. Since multiple observations are drawn from the same model, we cluster the observations using a robust variance estimator.<sup>14</sup> Due to limited degrees of freedom, interaction terms are omitted. However, we note that these effects may be present—that is, assumptions about international linkages may have greater impacts if there is greater geographic or economic disaggregation.

<sup>12</sup> These characterizations apply to the bulk of the internationally traded goods. Some goods, like electricity or distributed gas, may not be traded across regions. Other goods, like oil, still may be modeled as perfect substitutes in models with Armington assumptions for final goods and other inputs.

<sup>13</sup> Most of the other models were of the multisector CGE type, and a few used aggregate production/cost function equilibrium methods. A characteristic of a macro model is that it allows for monetary policy responses.

<sup>14</sup> As calculated via the “CLUSTER” command in STATA, which is documented in Hardin (2002).

**Table 2: Results of the Meta-analysis**

Ln (Marginal Costs)	
ABATEMENT	0.070* (2.93)
ABATEMENT SQUARED	-0.001 (-1.73)
ANNEX1	-0.625** (-4.4)
REGIONS	0.160** (6.98)
HOUSEHOLDS	-0.741* (-2.48)
BACKSTOP	1.336** (5.64)
NON ENERGY	0.087* (2.6)
ENERGY	0.082** (5.79)
TECHNOLOGY	-0.140 (-1.05)
ARMINGTON	-1.068** (-4.06)
PERFECT MOBILITY	1.538** (4.81)
Dummy_EU	0.346* (2.49)
Dummy_CANZ	0.086 (0.96)
Dummy_Japan	0.482** (4.8)
Constant	1.122 (1.72)
Observations	80
R-squared	0.912
Robust t-statistics in parentheses	
* significant at 5% level;	
** significant at 1% level	

### ***Results for Variables Related to Abatement Targets***

ABATEMENT: As expected, the meta-analysis finds that marginal costs rise with abatement levels. *Ceteris paribus*, a one percentage-point increase in abatement implies a 7 percent increase in marginal costs. Furthermore, marginal abatement costs appear to be approximately linear over the estimated range.<sup>15</sup> However, the relationship between percentage abatement and costs is likely confounded by the fact that abatement requirements depend on the reference baseline, which itself is a predicted output of the models. Thus, if marginal abatement costs are low in a particular model because energy technologies are more easily substituted in production and consumption activities then, in the absence of a positive carbon price, inputs with relatively high carbon content might be used, thereby increasing baseline emissions.

ANNEX\_I: The use of emissions trading, holding total abatement constant across the included regions, would be expected to reduce average marginal abatement costs, since international abatement effort can be allocated more efficiently. However, Annex I trading reduces these costs across the board due to the availability of emissions permits from Russia. This so-called hot air reduces abatement requirements by an average of 15 percentage points for the four regions in our data set. Based on the regression coefficient on abatement, one would predict 64 percent lower marginal costs from the lesser requirements.<sup>16</sup> If the coefficient on the Annex I variable truly represents independent effects then, controlling for abatement levels, international emissions trading tends to reduce costs by nearly two thirds. The fact that trading may lower marginal costs as much as the lesser abatement requirement lends support to the Klepper and Peterson concern that domestic marginal abatement costs are highly dependent on other international linkages. Thus, it appears that cost curves drawn from a diverse set of international policy scenarios can be misleading. However, since it is clear that this variable is negatively correlated with ABATEMENT, it may be difficult to interpret these coefficients independently. Still, it is not unreasonable to think that parallel or collective actions by a group of nations might impose additional costs on any individual member of the group beyond the costs associated with unilateral action by a single nation.

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<sup>15</sup> Including the squared term improved the fit, although its close correlation with ABATEMENT may affect the interpretation of those coefficients. Overall, the set of independent variables identifying structural characteristics passes the Belsley-Kuh-Welsch test for multicollinearity with a condition number of 15.

<sup>16</sup> Compounding the reduction in abatement, the new costs would be  $(1.07)^{-15}$  or 36% of the average “no trade” marginal costs.

REGIONAL DUMMIES: Marginal abatement costs in Japan are estimated to exceed those in the United States by almost 50 percent, while EU costs are shown to be about one third above U.S. levels. At the same time, marginal abatement costs for the CANZ region do not differ significantly from those in the United States.

### ***Results from Variables Associated with Structural Characteristics***

HOUSEHOLDS: In theory, dynamic optimization by consumers over long periods of time should improve overall efficiency compared to myopic decision-making. Consistent with Manne and Richels' (1999) assertion, our results suggest that treating households as infinitely lived consumers appears to reduce marginal abatement costs. However, given the relatively large standard error on this variable, we do not have great confidence in this result.

BACKSTOP: By itself, making a backstop technology available should lower costs if the designated technology comes into play. Our results point in the opposite direction, as we find that the inclusion of a noncarbon backstop is strongly associated with higher marginal costs. Of course, all else is not equal in these models, and the incorporation of the backstop technology may be associated with different specifications of other aspects governing technology choices. For example, the decision to incorporate a backstop technology may reflect a concern that other underlying assumptions make marginal abatement costs high enough to warrant using a backstop. Unfortunately, we lack detailed information on these points, as well as whether backstops were predicted to be in use by 2010. Clearly, these design choices merit further investigation.

Another ongoing concern in climate policy modeling is the treatment of changes in technology over time. Although endogenizing technical change should lower costs since it would allow for greater opportunities for system-wide optimization, it is not a commonly used approach. MERGE 3.0 does allow for some learning-by-doing in the electricity sector, and later versions have incorporated additional elements of endogeneity. However, none of the models available to EMF-16 incorporated a comprehensive treatment of endogenous technical progress. Thus, we are unable to examine this issue explicitly in the meta-analysis.

REGIONS, NONENERGY, and ENERGY: All of our variables representing greater disaggregation in regions, goods, and energy supplies were found to be associated with higher marginal abatement costs. For nonenergy goods, this result is not statistically significant. *A priori*, one might expect greater opportunities for substitution and re-optimization, whether among countries, consumption goods, or energy inputs, to lower costs. Our results may indicate

that greater detail in model representations of the energy sector reflects a more realistic analysis of the rigidities inherent in many of these markets, such as supply constraints in the electricity or natural gas markets. Furthermore, this effect seems to dominate any increase in substitution opportunities that might occur with greater disaggregation.

**TECHNOLOGY:** Based on criteria developed by Weyant and Hill (1999), this variable reflects the incorporation of energy technology detail, as distinct from the sheer number of sectors. We find that more refined characterization of technology, such as including capital stock turnover and limitations to the introduction of new technologies, does not help explain the observed differentials in marginal abatement costs. The weakly negative coefficient aligns with the commonly held view that models with more “bottom-up” characteristics tend to generate lower costs than “top-down” models, but the relatively large standard error gives us little confidence in this finding. This weak association may indicate that the number of energy sources and sectors is a better predictor of cross-model differences in marginal abatement costs than the level of technological detail contained in the model. Since energy sector disaggregation is associated with higher cost estimates, these results run counter to the conventional wisdom and further strengthen the case for additional research in the modeling of energy technologies.

**PERFECTMOBILITY and ARMINGTON:** Both of these variables reflect international linkages embedded in the models. **PERFECTMOBILITY** distinguishes those models that assume capital is extremely mobile across the four regions in contrast to those that specify significant market imperfections, different regional rates of return, or zero-balance constraints on trade that do not allow for borrowing. **ARMINGTON** denotes the models that treat imports as imperfect substitutes for domestically produced goods in equilibrating trade flows. Interestingly, among the models examined, this variable is almost perfectly correlated with those incorporating a formal financial sector. In effect, **ARMINGTON** distinguishes an explicit treatment of trade and financial flows, which may include frictions, while **PERFECTMOBILITY** reflects the equalization of rates of return in the financial sector, which may or may not include a formal sector.

Empirically, we find that the assumption of perfectly mobile capital is associated with higher marginal costs. At the same time, Armington assumptions and the inclusion of more formal capital sectors are associated with lower cost estimates. At first glance, these findings may seem counterintuitive, since allowing for certain frictions in international markets tends to lower predicted marginal abatement costs, while the opposite applies for energy markets. One explanation may be that while perfect international arbitrage can allow for a more efficient allocation of capital and resources worldwide, individual countries can experience losses in

terms of trade, investment flows, and asset values (including permit assets).<sup>17</sup> A costly climate policy would tend to lower domestic rates of return, thereby increasing investment flows to non-Annex I countries or, possibly, to Annex I countries with less burdensome carbon abatement requirements. That is, the characterization of the international linkages can affect predicted costs since carbon policies, with or without permit trade, still operate in an international equilibrium and can have significant impacts on flows of goods and capital.

## Conclusion

Before adopting mandatory reductions in greenhouse gases, decision-makers need to have a good idea of the price tag. Toward that end, a better understanding is needed about why the estimated costs of complying with the Kyoto Protocol vary so widely. Policy differences—the focus of previous attention—are one source of variation. Measurement or performance indicators, such as GDP, welfare loss, or marginal abatement costs, are another source of variation. However, even holding constant the policy assumptions and adopting more uniform cost measures, the EMF-16 results suggest that major energy-economic models still produce a wide range of estimates of abatement costs, revealing the presence of important structural differences among the models.

Despite the limited data available for such an exercise, the value of meta-analysis is to identify in a systematic way which aspects of the models are the key cost drivers. Such knowledge can encourage model refinements that, over time, may serve to reduce the range of cost estimates. Of course, even with greater consensus on methodological approaches, variation in the specification of many parameter values will remain, reflecting a range of opinion and uncertainty about the appropriate representation of the world and its future path. But knowing which model variables and mechanisms most influence cost estimates can help us target empirical research toward reducing the uncertainties about these elements. Such research could include future EMF-style exercises in which modelers adopt more uniform structural or parameter assumptions to further investigate the sources of variation.

Our meta-analysis indicates that certain modeling choices can have important—and sometimes counterintuitive—effects on the estimated marginal abatement costs of reducing

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<sup>17</sup> Given the data limitations, we do not attempt to interact these variables, although in reality they are likely to have joint impacts.

carbon emissions. For example, despite the conventional wisdom that bottom-up models produce lower cost estimates, we find that greater detail in describing energy technologies in top-down models has no significant effect. Surprisingly, including a backstop technology tends to raise predicted costs. Variables indicating greater detail in regions, nonenergy sectors, and energy supplies also are associated with higher costs, as are those reflecting particular frameworks for modeling international linkages, such as perfect capital mobility. Meanwhile, Armington assumptions for modeling trade frictions generally are associated with lower predicted abatement costs. Since one might otherwise expect that greater substitution opportunities would lead to less costly abatement, the forces underlying these relationships seem an important direction of further study.

Collectively, large and small modeling choices form a black box that calculates abatement costs. The same black box calculates baseline emissions and, thereby, abatement requirements, making cross-model comparisons more difficult. In principle, one can open the box and seek detailed information across models about key modeling and parameterization choices: elasticities of substitution, resource depletion assumptions with respect to oil and gas, vintage approaches with respect to energy use, the availability of carbon sequestration, production functions, labor market dynamics, and tax regimes. Arguably, our ability to interpret the effects of broader structural choices in climate models is hampered by the lack of specific information about such choices.

Another approach to understanding differences in estimated abatement costs is to use the black box to ask different questions. There is a subtle but critical difference in asking, “what carbon price does a given policy require?” compared to “what level of emissions occurs at a given carbon price?” One can argue that the latter framework is a better way to estimate domestic abatement cost curves—in effect tracing out domestic carbon supplies from the world price, rather than calculating domestic prices from domestic supply targets. Due to the complex international linkages within these models, part of the variation in a country’s cost of meeting a fixed target hinges on the variations in each model’s estimates of the carbon price for the other regions of the world trying to meet their targets. Although it would be a major effort, we believe that the development of independently derived domestic marginal abatement supply curves would not only provide more consistent estimates of energy prices across models but also would help illuminate the importance of other underlying cost drivers.

Finally, we emphasize that the carbon price is an imperfect indicator of the economic impact of climate policies. Despite its appeal in policy circles, the reporting of more consistent aggregate measures of welfare loss should be an important goal of future model comparison



efforts, both to improve transparency and, possibly, to reduce the variability of aggregate cost estimates.

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