

REVIEW OF MITIGATION COST STUDIES AND TRAJECTORIES, AND ASSUMPTIONS THAT DRIVE THEM

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Introduction

What are the potential costs of cutting greenhouse gas (GHG) emissions? Can emission reductions be achieved without sacrificing economic growth? This debate is, to a large extent, played out through many economic analyses of climate change policy. These analyses all provide useful information, but their results are widely divergent. Some groups conclude that the United States can reduce its carbon emissions to significantly below its Kyoto target, with net economic savings, while others predict rather significant costs to the U.S. economy.

In preparing these economic analyses, modelers translate their expectations into assumptions about the future. Seven key assumptions are discussed in this memo. Two of the seven key assumptions – substitution and innovation – are structural features of the economic models used to make emissions projections. The other five – baseline emissions, policy objectives, policy regime, inclusion of benefits of emission reductions, and discount rate – are external factors or assumptions. Cost projections for a given set of assumptions can vary by a factor of two to four across models because of differences in the models' representation of substitution and innovation processes. However, for an individual model, differences in external assumptions – about the baseline, policy objectives, policy regime, emissions reduction benefits, and discount rates – can easily lead to cost

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estimates that differ by a factor of 10 or more. In understanding how these seven determinants influence cost projections, decision-makers will be better equipped to evaluate the likely economic impacts of climate change mitigation.

One rough measure of economic costs is the carbon price – the amount of money one would have to pay to reduce emissions by a metric ton of carbon. Model projections of the carbon price required for the U.S. to meet its Kyoto Protocol emissions target range from less than \$20 per ton to over \$400 per ton. GDP losses associated with these estimates range from about .2 percent of GDP to over three percent. These differences may result from using different models, as well as from using the same model with different input assumptions. The goal of this memo is to identify the factors driving these differences in model results, thereby enabling the reader to more knowledgeably interpret the results of the many studies that have been completed to date.

Seven Determinants of Climate Change Cost Estimates

Seven major determinants of GHG mitigation cost and benefit projections are discussed in this memo. Understanding how different forecasters deal with these determinants can go a long way toward understanding how individual estimates differ from one another. The seven major determinants are:

- A. Projections of base case GHG emissions and climate damages;
- B. The objectives for climate change policy considered;
- C. The climate policy regime considered (especially the degree of flexibility allowed);
- D. The representation of substitution possibilities by producers and consumers;
- E. How the rate and processes of technological change are incorporated in the analysis;
- F. The characterization of the benefits of GHG emissions reductions in the study; and
- G. The discount rate used to convert costs incurred in many years to a single year equivalent.

A. Projections of Base Case Emissions and Climate Damages

Projecting the costs associated with reducing GHG emissions starts with a projection of GHG emissions over time, assuming no new climate policies (often referred to as a business-as-usual scenario). This is often an important and under-appreciated determinant of the results. The higher the base case emission projection, the more GHG emissions must be reduced to achieve a specified emissions target. If a base case is higher, though, there may be more opportunities for cheap GHG mitigation due to a slow rate of technological progress assumed in the base case.

The base case emissions and climate impact scenarios, against which the costs and benefits of GHG mitigation policies are assessed, are largely the product of assumptions that are external to the analysis. Each GHG mitigation cost analysis relies on input assumptions in three areas:

- Population and economic activity.
- Energy resource availability and prices.
- Technology availability and costs.

Particularly important in the resource availability and price area are any current and possible future restrictions or fees placed on the combustion of fossil fuels because of the environmental impacts of the resulting emissions other than those resulting from greenhouse gas emissions. In the U.S. at present, sulfur dioxide, nitrogen oxide, particulate and volatile organic compound emissions are currently restricted and further restrictions are anticipated in the near future. The IPCC's Special Report on Emissions Scenarios shows how plausible assumptions about these factors can lead to global carbon emissions in 2100 that range from about half of 1990 levels to nearly five times that amount.

Projections of the benefits of reductions in GHG emissions are also highly dependent on the base case scenario employed. The greater the base case damages (i.e., the damages that would occur in the absence of any new climate policies), the greater the benefits of a specific emissions target. The magnitude of the benefits from emissions reductions depends not only on the base case level of impacts but also on where they occur, what sectors are being considered, and how well the affected populations can cope with any changes that occur. The task of

projecting base case climate change impacts is particularly challenging because: (1) most assessments project that serious impacts resulting from climate change will not begin for several decades; and (2) most of the impacts are projected to occur in developing countries where future conditions are highly uncertain. How well developing countries can cope with future climate change will depend largely on their rate of economic development.

B. The Objectives for Climate Policy

One can think of a climate policy analysis as proceeding from greenhouse gas emissions to the atmospheric loadings of greenhouse gases to radiative forcing to climate change to climate change impacts. Thus, we could simply calculate the climate change impacts resulting from a particular emissions trajectory. Alternatively one could work backwards from an acceptable set of climate impacts to find the emissions trajectories that are consistent with them. We could also set a target for the maximum emissions, concentration level, magnitude of climate change, or extent of climate impacts and compute the least-cost way to achieve that objective. This formulation is referred to as cost-effectiveness analysis, and, if there is a range of "acceptable impacts," as the tolerable windows approach. The tax required to reduce emissions by a pre-specified amount can also be computed. If one can value all the climate change impacts in a common unit of measurement they can be added together, and the net benefits (reduction in the cost of climate change less mitigation costs) of emissions reductions can be calculated. This approach is referred to as cost-benefit analysis. The result of the cost-benefit analysis is the optimal carbon equivalent tax and level of emissions reduction. Most analyses show that the discounted cost of a limit on carbon concentrations (above about 500 ppmv) or one that equates marginal costs of abatement with marginal costs of residual carbon emissions can be substantially less (from 1-2 percent of GDP discounted at 5% over the next hundred years to half that level or less) than one that places significant near term restrictions on carbon, because the emission reductions in the former can be timed to avoid premature retirement of existing plant and equipment. To a good approximation the adoption of a particular concentration target limits cumulative carbon emissions over the next century to a fixed amount and it is less expensive to make the required emission reductions later rather than sooner.

C. The Climate Policy Regime

The policy regime considered is a crucial source of differences in cost and benefit projections. Once one constructs a base case scenario and specifies a set of objectives for climate policy analysis, one must specify objectives for individual countries and the types of policies that nations may use to satisfy their GHG emissions obligations. The allocation of responsibilities for emission reductions (usually specified in terms of maximum allowable emissions) among nations is often referred to as “burden sharing” and is the most politically charged and crucial element of the current set of international negotiations on climate change policy.

The Kyoto Protocol explicitly includes flexibility in determining which GHGs can be reduced, where they can be reduced, and when they can be reduced. If the parties to the Protocol can employ these flexibility mechanisms, and can surmount definitional and other obstacles to their implementation, the mechanisms can reduce the economic impacts of achieving the Kyoto targets by a factor of ten or more.

An important flexibility mechanism in the Kyoto Protocol is that nations have agreed to consider six principal GHGs: CO₂, methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, and hydrofluorocarbons, and to allow inter-gas trading. These GHGs differ both in their heat-trapping capacity and in the length of time they remain in the atmosphere. CO₂ is the most significant contributor to global climate change among global GHG emissions. The Protocol also specifies that taking CO₂ out of the atmosphere (i.e., using CO₂ “sinks”) through afforestation and reforestation, as well as through avoiding deforestation, count towards each country’s emissions reduction commitment.

The Protocol also allows participants to average emissions over a five-year period (2008-2012, also known as the first budget period) in satisfying their emissions reduction requirements. Averaging allows corporations and households to shift their reductions in time to reduce the economic impact of the required emissions reduction. A number of studies indicate that this emissions averaging can be quite effective in cutting the cost of reducing cumulative emissions, and that an even longer averaging period could be very advantageous.

Another flexibility mechanism included in the Kyoto Protocol is international emissions trading. There are benefits from international emissions trading because the costs of reducing emissions vary greatly from country to country. If the cost of emissions reductions in any country is higher than it is in any other country, it is advantageous to both countries for the higher cost country to buy emissions “rights” from the lower cost country at a price that is between the two cost levels. If one aggregates all regions participating in the trading system together, one can compute the supply and demand for emissions rights at any price, as well as the equilibrium emissions rights price that balances the available supply with the amount demanded. The potential advantages of expanding the scope of the trading regime can be significant. Results from a recent model comparison study show that moving from a case where no international emissions trading is permitted to a case where all Annex I countries (generally, developed countries) can trade emissions rights lowers the carbon price required in Annex I regions by a factor of two. (This is because almost all of the models project that a significant amount of carbon emission rights will be available from Russia, an Annex I country). The advantages of full global emissions rights trading relative to Annex I trading are also significant primarily because non-Annex I countries can reduce emissions more inexpensively relative to their unconstrained allocation of emissions rights than can the Annex I countries relative to their much more tightly constrained Kyoto allocation.

International agreements like the Kyoto Protocol may also allow each national government to choose the policies it will use to comply with its obligations. Thus different governments may allow emitters different degrees of flexibility. For example, governments may establish mandatory standards for energy efficiency. Or governments may utilize price mechanisms, either directly or indirectly. Governments may impose emissions taxes to motivate GHG reductions; or they may cap the total amount of emissions, distribute or sell emissions “allowances”, and let the market determine the price and distribution of these allowances. In either case, fossil fuel combustion and other GHG-generating activities become more expensive. How producers and consumers respond to these price increases is described below.

Governments also have flexibility as to how they utilize any tax revenue or proceeds from allowance sales. The costs of carbon taxes can be significantly

reduced if tax revenues are used to finance cuts in other tax rates. Assumptions about such so-called “revenue-recycling” can also be important.

D. Representation of Substitution Possibilities by Producers and Consumers

It is important to understand that flexibility in the substitution of less GHG intensive activities for more GHG intensive ones is not a policy choice. It is a characteristic of the economy and depends ultimately on choices made by individual consumers and firms. Producers adjust to price increases – including policy-induced price increases – by substituting inputs (i.e., switching to inputs that generate fewer GHG emissions in manufacturing any particular product), and by substituting outputs (i.e., producing different products that require fewer GHG emissions to make). Different substitution responses are possible, depending on the time frame. In the short term, consumers and producers might turn their thermostats down; in the intermediate term, they might buy more efficient heating systems; and in the long term, they might take advantage of completely new technologies.

The extent to which inputs can be shifted depends on the availability and cost of appropriate technologies as well as the turnover rate of capital equipment and infrastructure. These two factors, as well as consumer preferences, determine an industry’s ability to produce and sell alternative mixes of products. Increases in the costs both of fossil fuels, and of products that depend on fossil fuel combustion, will reduce consumers’ real incomes. Consumers will simultaneously decide: (1) the extent to which they wish to adjust their mix of purchases towards less carbon-intensive products, and (2) how to adjust their mix of work and leisure time to compensate for the reduction in their real income.

There are two basic approaches to modeling substitution possibilities:

- Aggregate (longer-term models that characterize general, or aggregate, technological trends); and
- Technology-by-technology (short term models intended to shed light on precise technology choices by specifying many separate technologies).

The choice of approach depends, in part, on the time frame under consideration and the level of technological detail desired. Many models blend the two

approaches. Some models employ a technology-by-technology approach for the energy sector, but use an aggregate approach for the rest of the economy. Some models employ an aggregated approach for new capital investment, yet utilize a technology-by-technology approach for each vintage (i.e., all equipment of a particular age), once it has been installed. Similarly, a model may employ an aggregated approach for conventional fuels, yet stipulate discrete technologies for a particular non-carbon fuel.

The amount of effort required to reduce GHG emissions depends on the base case emissions projected by the model, the magnitude of the substitution and demand elasticities embedded in it, and the way capital stock turnover and energy demand adjustments are represented. Elasticities measure the responsiveness of the demand for a product to the price of the product. All three factors work together, so that models with higher base case emissions lead to higher adjustment costs. If the elasticities are high and the adjustment dynamics rapid, adjustment costs are lower.

E. Technological Change

New technologies and products can lower carbon emissions, thereby reducing the need for emissions reductions and/or making them less expensive. Such technologies might become available over time as a result of research and development (R&D) expenditures or cumulative experience. The emergence of these new technologies might be related to energy price increases, the base case trend of all other prices, or simply the passage of time.

Technological change is sure to be one of the dominant solutions to the problem of global climate change over the next century. However, there are large uncertainties about the most cost-effective way to accelerate the invention of brand new technologies, innovations in existing technologies, and the diffusion of new technologies. Each of these works on different time scales, and therefore different policies may be required to accelerate them.

There are opportunities for synergy between public support and private investment in new technology development. It would be worthwhile to find an appropriate combination of government interventions and private sector incentives that encourage innovation. Thus far, however, most of the policy debate on

the influence of technological change on climate change policy has focused not on technology policy options, but rather on how restrictions on GHG emissions affect the cost of GHG reductions over time. This effect has been labeled “induced technological change” (ITC).

In practice, many technological advances come from learning-by-doing (LBD) – the incremental improvement of processes through small modifications and adjustments. It is not until a technology is actually used that important lessons are learned that can be applied to its subsequent development. LBD is an integral part of the innovation process. Observation of past technological innovations show that initial installations are quite expensive, but that costs drop significantly the more the technology is used, and the more lessons are learned from using it. This type of learning may be the result of either exogenous or endogenous technological change.

How important is it for climate change modelers to include ITC? Put another way, does the assumption of exogenous technological change lead to significant or to small errors in policy recommendations? Two strong conclusions emerge from early studies. First, if innovation derives from R&D, then the larger the potential for innovation the more abatement should be pushed to the future. This is an intuitive result: the larger is the potential to improve technology, the better will be technology in the future and the cheaper will be future abatement. Second, the optimal timing is ambiguous under experience-based technological change. Two offsetting forces are at work. The lower are future abatement costs, the more abatement should be pushed into the future. This is offset by the fact that future abatement costs are a function of near-term abatement levels, i.e., more early abatement reduces future costs, which tends to favor near-term abatement.

F. Characterization of Benefits

The motivation for policies to reduce emissions of GHGs is the reduction in climate change impacts. Impacts on agriculture, forestry, coastal zones, ecosystems, human health, wildlife, biodiversity, fisheries and amenities are expected. Some analyses focus exclusively on mitigation costs, showing both the likely range of costs under different policy regimes and the sensitivity of the cost estimates to key model inputs and parameters. These studies often start with emissions targets proposed during the international negotiation process. These studies,

sometimes called “cost-effectiveness” analyses, do not estimate the benefits of the reduction in climate impacts, or any other accompanying benefits from the emissions reductions.

Other analysts, however, have projected base case climate impacts, and the change in those impacts resulting from climate policies. Those analyses that do address climate impacts vary widely in terms of what is included, and what is excluded. Aggregate impact/benefit studies differ as to whether they include only “market” impacts or both “market” and “non-market” impacts. It is much more difficult to place an economic value on non-market impacts.

The benefits of GHG emissions reductions, in terms of avoiding climate impacts for individual sectors, are difficult to assess. Valuation and aggregation across categories is difficult and controversial. In addition, climate change and impacts are more directly related to atmospheric concentrations of GHGs than to emissions, and GHGs can stay in the atmosphere for a hundred years or more. Thus, an assessment of the benefits of emissions reduction requires a long-run projection of the difference between climate impacts with and without controls. The difference must be aggregated over time with some sort of inter-temporal discounting. The assessment and the discounting also need to account for the risk that conditions could turn out to be much worse than expected in the future.

The current range of estimates for the direct benefits of reducing GHG emissions is from \$5 to \$125 per metric ton of carbon (1990 U.S. dollars). The wide range of estimates reflects variations in model assumptions, as well as a high sensitivity to the choice of a discount rate. Although simulations based on a social discount rate of 5 percent tend to be in the \$5 to \$12 range, assuming a rate of 2 percent or less can lead to estimates that are a factor of ten greater. There are three key points to keep in mind when interpreting these numbers:

- The range of benefits projections depends critically on assumptions about both base case impacts and the ability of people and institutions to adapt to these impacts;
- Many analysts and policy-makers believe that costs ought to be weighed against disaggregated impacts that are left in physical (and, therefore, more tangible) and not monetary form; and

- Most analysts now recognize the much greater relative importance of low-probability but high-consequence extreme events, as opposed to more gradual, linear changes, in our vulnerability to climate change. However, they have only just begun to study them.

Projections of ancillary (or co-) benefits range from \$0 to \$20 per metric ton of carbon (1990 U.S. dollars). These projections depend heavily on precisely where the emissions reductions occur. This is because: (1) most of the ancillary benefits are the result of incidental reductions in other air pollutants (e.g., SO₂, NO_x, volatile organic compounds, particulates, etc.) and (2) those air pollution benefits depend on both the prevailing meteorology and where people live relative to an emitting plant site or freeway system.

In summary, users of economic analyses should either: (1) focus on cost-effectiveness, taking emissions or concentration targets from other analysts or policy developers, or (2) factor in reductions in physical or monetary impacts and weigh them against mitigation costs. Above all, it is essential to keep the benefits of climate change policies transparent and separate from the costs, both in doing the analysis and in communicating the results.

G. The Discount Rate

Most GHG reduction strategies involve costs of reducing emissions and benefits from reducing climate change impacts in many years. To compute total costs and/or benefits it is, thus, necessary to convert the costs and benefits incurred in each year to a common year. A dollar expended in any one year is more valuable than one expended in a subsequent year primarily because it could be invested in the earlier year and that invested dollar would be worth more in the latter year. A constant annual discount rate is typically used to convert costs and benefits from one year to another. Not surprisingly, most analysts use a rate close to the pre-tax rate of return on capital (around 5-6 percent after accounting for inflation) as a discount rate, although some believe much lower rates (1-2 percent) are justified. These lower rates can have a large impact on discounted costs and benefits.

Conclusion

It is tempting to try to generalize about the relative importance of the seven factors in explaining differences in projections of the costs and benefits of policies designed to reduce GHG concentrations, but this is obviously not possible because of interdependencies among the factors. For example, we would expect a model with very little substitution and technological change and a very inflexible set of policy options to lead to a relatively high cost for achieving a 550 ppm CO₂ concentration target. If, however, the baseline GHG emissions trajectory being analyzed happens to be a very low one which self stabilizes the CO₂ concentration at less than 550 ppm the cost of stabilization would be zero. On the other hand, looking at what is being assumed in a particular analysis (including how extreme these assumptions are or are not) or what is implicit in the model being used (including how extreme its behavior is relative to other models) for the seven factors can usually help us understand exactly why the costs, benefits, optimal emission trajectories and optimal carbon taxes turn out the way they do.