Economic Modeling of Climate Change Policy

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Executive Summary

This paper focuses on the economic modeling of European policies to achieve the goals of the Kyoto treaty. The central question addressed is what sorts of models are best suited to analyze the costs of such policies when what is desired are effects on GDP, employment, labor productivity, savings and investment over a period of several years. I also examine the relative merits of bottoms-up and top-down approaches to energy market modeling. The following conclusions are reached:

- CO_2 emissions in most European countries in 2010 will be well above levels needed to meet their commitments. For that reason, a substantial carbon tax or tradable permit price would be needed for them to meet the goals of the Kyoto treaty. Estimates in the literature vary depending on assumptions, but given that action to curb emissions is slow to develop and trading probably will not be worldwide, the cost of tradable permits is likely to be substantial.

- A Kyoto-implementing carbon tax or tradable permit price would have a number of implications for European economies. These range from reduced energy use and substitution of non-fossil for fossil fuels to indirect effects in non-energy markets and changed trade relationships. Because shocks to an economy require realignment of resources among markets, a Kyoto-implementing policy would temporarily result in involuntarily unemployed resources. It also would result in longer run costs from decreased use of energy and a reduction in economically useful capital stock.

- Different types of economic models capture different impacts. Partial equilibrium models such as PRIMES or MARKAL capture effects in energy markets and the direct costs of reducing energy use, but do not capture indirect costs nor those associated with market adjustment. As shown in Table 3 herein, such models capture only a fraction of the full macroeconomic costs of adjusting to policies to reach climate change goals.

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- General equilibrium models capture both direct and indirect costs, but assume long run full adjustment of resources and hence fail to capture the costs of those adjustments. Nevertheless, they are useful for analyzing many longer-term issues and provide estimates of longer-term costs. Estimated European climate policy GDP impacts from several such models also are shown in Table 3.

- Macroeconomic models such as Oxford or DRI-WEFA are general equilibrium models that explicitly account for market disequilibria caused by economic shocks. In addition to identifying long term costs, these models provide the most complete near and intermediate-term analysis of the costs of Kyoto-implementing policy. Results in Table 3 indicate such models provide cost estimates for European compliance with Kyoto that are 50-100% higher than those from pure general equilibrium models.

- Bottoms-up energy models are constructed from engineering data applied to specific technologies whereas top-down energy models are based on statistical analysis of past data. Both can be useful in understanding the effects of policy on energy markets, but bottoms-up models often neglect certain costs that reduce returns on investment below what is predicted, resulting in unrealistic estimates of what will occur if energy markets are shocked. Top-down models are based on technology and institutions existing at the time their data applies to and hence may underestimate the ability of markets to adapt, but such models often incorporate technology parameters, induced technological change, or explicit changes in technology in order to avoid such bias, thus incorporating bottoms-up features within a top-down approach. Because these models are based on actual behavioral responses rather than simulation under somewhat idealized conditions, they appear to be the most realistic way to accurately estimate the consequences of climate change policy.

Introduction

It is widely recognized that country commitments made under the Kyoto climate change treaty and prospectively under follow-on agreements may have important implications for national economies. To analyze these implications, a variety of economic models have been constructed and utilized. Though there is agreement that such modeling can help to understand the economic consequences of implementing the Kyoto treaty, there is less agreement as to exactly which model provides the most accurate and reliable numbers. Indeed, there even is disagreement over what kind of model is needed for the task.

This paper investigates these issues. To do so, I review what policies are required to meet the goals of Kyoto and possible follow-on commitments, what sorts of impacts these are likely to have on an economy, and what sorts of models are needed to analyze such impacts. I argue that models of the energy market alone, while useful for understanding some of the effects of climate change policies, cannot reveal their full impacts. I argue further that economy-wide models can reveal such effects, but these should be capable of analyzing short and intermediate-term market adjustments necessitated by shocks and that not all economy-wide models are constructed for such purposes. Finally, I look more closely at energy market modeling, specifically at "bottoms up" and "top-down" approaches. While bottoms up information can aid the predictions of a top down model by identifying new cost-reducing technologies or barriers to the use of energy saving techniques, it also can mislead by suggesting lower costs than actually occur in energy supply or conservation activity. This is especially problematic if bottoms up information is used to establish normative standards to which energy markets are compelled to adhere. I conclude by summarizing my views on the best way to analyze the macroeconomic effects of climate policy.

Policies to Implement the Kyoto Climate Change Treaty

Country commitments to reduce greenhouse gases (GHGs) under the Kyoto treaty generally call for reductions by 2008-2012 relative to 1990 levels.[1] The European Union (EU), for example, has collectively agreed to an 8% reduction.[2] With some exceptions, country emissions have grown since 1990 and without policy intervention are likely to grow further between now and the 2008-2012 period. To simplify, the year 2010 often is taken as the endpoint for analysis of policies to constrain GHGs.

Since carbon dioxide (CO_2) accounts for 80% or more of most countries' GHGs, analytic efforts have focused on means to reduce this gas. These efforts reveal that the cheapest method is a carbon tax or its economic equivalent, tradable permits to emit carbon in a given year. The trading of permits is efficient because it enables lower cost sources of GHG reductions to sell some of their emission rights to higher cost sources, reducing costs overall. Capros and Mantzos estimate, for example, that a CO_2 tradable permit scheme within each EU country would reduce compliance costs by over 50% relative to a scheme in which countries assign to individual industry sectors their proportionate share of national reductions.[3]

How much would the cost of carbon have to rise to bring countries into compliance with their Kyoto commitments? That depends on a number of factors, such as:

- what would have happened in the base case (usually called Business As Usual or BAU)

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[1] Annex B of the Kyoto agreement identifies the 38 countries who have collectively agreed to reduce their GHG emissions by 5.2% below 1990 levels. For convenience of discussion, countries participating in Kyoto are termed Annex B countries.

[2] Some members already are proposing further future reductions. The German government, for example, has recently proposed that the EU cut its emissions by 30% relative to 1990 by 2020 (See BNA Environment Reporter, 33(2), October 25, 2002).

[3] E3M Lab, P. Capros and L. Mantzos, "The Economic Effects of EU-Wide Industry-Level Emission Trading to Reduce Greenhouse Gases," unpublished manuscript, May 2000.

- whether other GHGs (methane, nitrous oxide, HFCs, PFCs and SF_6) are constrained along with carbon dioxide
- the extent to which trading of carbon permits is allowed
- when action to constrain GHGs is begun
- the malleability of capital
- the extent to which sinks are counted, and
- the assumed rate of technological change.

If base case assumptions indicate a substantial rise in carbon emissions, perhaps because of rapid economic growth, then a large rise in the cost of carbon is needed to constrain emissions to their required level. Country situations differ, so that greater efforts will be required in some than in others to achieve Kyoto targets. Taking all EU countries together, however, considerable effort appears necessary. A recent analysis by the International Energy Agency estimates that EU carbon dioxide emissions will be 16% above target in 2010 in a BAU case, while a U.S. Department of Energy analysis projects that Western Europe taken as a whole will be 18% above.[4]

Inclusion of the five non-CO_2 GHGs could result in greater or lesser need to constrain carbon. The result in any given country depends on what growth is expected for these other gases and how expensive it is to reduce them. If for example they are expected to grow rapidly and to be expensive to reduce, then a higher increase in the cost of carbon than otherwise would be necessary to compensate.

The extent to which emission permits are traded has important implications for the cost of carbon among countries. Some have argued for limitations on countries' ability to purchase tradable permits, and on the extent to which permits should be granted countries whose economies have declined sharply since 1990. However, many objections to trading were dropped in the recent Marrakech COP-7 agreements on Kyoto implementation.[5] Generally speaking, the greater the extent of trading the lower the price of permits.

Earlier action provides more time for reducing a country's use of carbon, and hence the earlier a country acts to achieve its Kyoto goals the less it needs to raise the cost of carbon. To date, few countries have begun serious programs to achieve their targets, implying that rather substantial increases in the cost of carbon eventually will be necessary for them to do so.

The ease with which capital can move from one to another use within an economy affects the extent to which the price of carbon must rise. Researchers have shown via simulation

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[4] International Energy Agency, *Energy Policies of IEA Countries*, Paris, OECD/IEA, 2001.
and U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, *International Energy Outlook 2002*, Washington, DC, March 2002.

[5] COP-7 refers to the 7th Conference of the Parties to the original Rio De Janeiro agreements.

that highly malleable capital can reduce the cost of complying with Kyoto by over 50% relative to a substantially fixed capital stock.[6]

The recent COP-7 agreement suggests that sinks from forest management, agricultural activities and the Clean Development Mechanism may be counted to some extent in calculating country commitments under Kyoto. The counting of sinks reduces needed reductions in carbon, and hence decreases the amount by which the cost of carbon must rise.[7]

Technological change can reduce the cost of complying with the Kyoto agreements. What is assumed about the rate of change of energy technology thus affects the extent to which the carbon price must rise.[8]

The above considerations suggest there is a good deal of uncertainty concerning what the price of tradable carbon permits might be. Nevertheless, for purposes of policy analyses, relevant scenarios have been constructed.

For example, a recent analysis of the macroeconomic impact of Kyoto commitments and beyond on four individual European countries based on work by the consulting firm DRI-WEFA shows a permit price range between 85 and 180 Euros per metric ton of carbon.[9] In this case, countries trade internally but not with other countries. EU-wide trading might reduce the cost of permits somewhat, but the UK and Germany, two countries expected to be net sellers of permits within the EU, already are included in the analysis.

For present purposes it is not necessary to precisely specify the value of tradable permits or the equivalent carbon taxes for countries to achieve their Kyoto targets. What is necessary to understand is that projections of GHG emissions through 2010 relative to target levels suggest it will be necessary to substantially raise the cost of carbon within Europe and elsewhere to achieve the Kyoto targets.

Modeling the Economic Effects of Kyoto

What happens to an economy when it is subject to a carbon tax or its equivalent, the use of tradable permits to achieve the Kyoto goals? There are a number of effects, and it is

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[6] See Henry D. Jacoby and Ian Sue Wing, "Adjustment Time, Capital Malleability and Policy Cost," *The Energy Journal*, Special Issue, 1999.

[7] The effects of counting sinks are analyzed in Christoph Boehringer, "Climate Policies from Kyoto to Bonn: From Little to Nothing?" *The Energy Journal*, 23(2), 2002. A broader analysis of the effects of COP-7 is contained in Jean-Charles Hourcade and Frederic Ghersi, "The Economics of a Lost Deal: Kyoto -The Hague - Marrakesh," *The Energy Journal*, 23(3), 2002.

[8] Edmonds et al provide a useful discussion of how assumptions about technological change directly affect the results from climate change modeling. See Jae Edmonds, Joseph M. Roop and Michael J. Scott, "Technology and the Economics of Climate Change Policy," Report Prepared for the Pew Center on Global Climate Change, September 2000.

[9] See Margo Thorning, "Kyoto Protocol and Beyond: Economic Impacts on EU Countries," International Council for Capital Formation, October 2002. The DRI-WEFA analysis examines macroeconomic impacts from policy affecting all six GHG gases, not just carbon dioxide.

necessary to look at these individually to grasp what sort of model is most useful to estimate them.

Suppose that an economy is in equilibrium before such a tax is imposed. This means that capital, labor and energy resources are fully employed to produce goods and services, and that the economy grows as more of these inputs are added. The economy is open to trade with other countries, and so has export and import sectors.

Now the tax is imposed, in one form or another. The price of energy rises, and people economize on its use. Energy intensive industries contract, and energy using activities are curtailed. Some of the capital stock is rendered obsolete because it is no longer economic to employ it with the higher energy price. Since both energy and capital are inputs into the production of the economy's output, the reduction in energy use and the obsolescence of capital stock reduce GDP.[10]

Contractions by energy suppliers and by energy intensive industries have further effects. Such industries purchase goods and services from other industries, things like raw materials, transport and retailing services. These industries in turn purchase from others. Thus, the effects on the economy stretch well beyond energy use. A large number of industries are affected indirectly by the changed pattern of spending in the economy.

The trade sector imposes further effects. Exports of goods that are energy intensive to produce are less competitive. Over time, markets for such goods are largely or wholly lost to countries that are not party to the Kyoto protocol. Energy intensive-to-produce goods also flow in from such countries.

The government receives new revenues, either from a carbon tax or by the auctioning of tradable permits. These revenues reenter the economy via some form of government action. They could be used to reduce deficits, to cut other taxes, to develop new energy-saving technologies or simply redistributed to consumers. However the government uses the revenues, the real incomes of consumers of energy are reduced while those receiving the revenues are enhanced. This redistribution has economic effects of its own. Reduced spending by energy users is contractionary while increased spending by those receiving the revenues is expansionary.

The economy cannot adjust instantaneously. Resource owners must spend time and effort to find where they are best employed under the new circumstances. There is friction in the labor market as people laid off in some industries seek employment in others. Capital also must investigate where the best returns may be earned. Some capital may depart for abroad, to countries that are not participating in the Kyoto protocol. The process takes time, months and even years to complete, and if the institutions of the country impede the economic adjustment process (e.g., stringent restraints on worker layoffs), its duration is lengthened.

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[10] The impact on productivity and GDP of reducing energy available to workers is analyzed in W.W. Hogan and D.W. Jorgenson, "Productivity Trends and the Cost of Reducing CO_2 Emissions," *The Energy Journal* 12(1), 1991.

Finally, there is interaction between the real and financial sectors. These include effects of possible bankruptcies of companies unable to compete under the new price structure, which would adversely affect the lending sector. They also include the reaction of the monetary authorities, and possible fiscal policy initiatives. These could exacerbate or reduce the macroeconomic impacts of the Kyoto-based energy sector policies. Even if they are neutral, it is necessary to assess the effects of the energy policy on interest rates, investment and savings to fully understand the near and intermediate-term macro impacts.

Applying Economic Models to Greenhouse Gas Reduction Policies

For convenience, I divide the many economic models described in the literature into three classes; partial equilibrium models of energy markets, instantaneous adjustment general equilibrium models, and macroeconomic general equilibrium models, which do not assume instantaneous adjustment of resources. It is especially important to distinguish these last two classes of models, as many models that are described as macroeconomic models assume instantaneous adjustment of resources and therefore do not capture some of the costs of economic shocks over the near and intermediate term.

Table 1 shows the three types of models and some important attributes. These include key assumptions, what the models capture, and what they are best at doing. For example, partial equilibrium models of the energy market generally assume instantaneous adjustment and calculate the cost of a carbon tax to energy users and suppliers. Depending on the amount of detail, energy market models can provide estimates of such things as inter-fuel substitution, what happens in the separate energy markets, impacts on the power sector, and by how much energy prices will rise.

As shown in Table 2, the PRIMES model is an example of a partial equilibrium model that can be used to understand the impact of Kyoto policies in EU energy markets.[11] It develops costs of adjusting to higher energy prices for each sector in every EU country, and combines them into country-wide supply curves of CO_2 reduction. The country supply curves then can be combined into an EU-wide supply curve of such reduction, and estimates made of the total cost of CO_2 reduction under alternative assumptions. These assumptions can range from requiring each industrial sector to reduce CO_2 on its own to assuming EU-wide permit trading, in which case CO_2 reduction costs are minimized for that group of countries.

PRIMES provides a useful tool for understanding the effects of policy initiatives on energy users and producers. The costs it calculates are the direct costs of reduced CO_2 use. But it is not a macroeconomic model and cannot be used to assess overall country costs from a Kyoto-implementing policy that shocks the economy.

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[11] A description of the PRIMES model can be found in "The PRIMES Energy System Model: Summary Description," National Technical University of Athens, European Commission Joule-III Programme.

General equilibrium models assume long run adjustment to a Kyoto-implementing policy in all market sectors. The assumption is key because in the long run all resources are assumed to find their highest valued use, and therefore there is no resource unemployment. General equilibrium models examine economic impacts in energy markets and other markets that are indirectly affected by the policy change. They reveal the long run cost to the economy of substituting away from carbon-intensive energy and of reducing the stock of economically useful capital.[12]

MARKAL-MACRO is one of many general equilibrium models built to examine Kyoto-implementing policies (see Table 2). The MARKAL portion of MARKAL-MACRO originally was developed by the Brookhaven National Laboratory in the United States and is similar to the PRIMES model in that it models responses in the energy sector to changes in policy such as a carbon tax or tradable carbon permits.

MARKAL-MACRO represents the combination of MARKAL with MACRO, a general equilibrium model developed at Stanford University by Professor Alan Manne. With this combination, changes in the energy sector are communicated to the rest of the economy and resource movements among other markets are captured. The effects of capital obsolescence and of increased energy scarcity are captured. This then accounts for a larger set of costs than those experienced in energy markets alone, and hence provides a more complete picture of the consequences of shocking the economy through a change in energy prices. However, the model is a long run model which effectively assumes full resource adjustment. Thus, while it calculates economy-wide effects from changes in energy production and use, it does not model the adjustment process itself and therefore underestimates the full macroeconomic costs.

MARKAL-MACRO and other models of this type are useful for a variety of analyses that are less concerned with costs of adjustment. Very gradual changes in policy, for example, would lend themselves to analysis by this sort of model because actors in the economy would have long periods to anticipate and react to the policy changes, and adjustment costs could be small. Alternatively, such models can be used to analyze long run consequences of climate policy, after resources have had time to fully adjust.[13]

The chief question for most policy makers, however, is what are the impacts of climate change policy on national economies, particularly over the near and intermediate term, meaning the next several years. The impacts of most interest are on GDP, employment, labor productivity, investment and savings. Policy makers also are interested in what

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[12] Such models are useful for a variety of purposes, including analyses of alternative policies to achieve long-run stabilization of greenhouse gases in the atmosphere. For example, the Second Generation Model (SGM) of Battelle Pacific Northwest Laboratory and the MERGE3 model (Model for Evaluating Regional and Global Effects, version 3.0) of Stanford University and the Electric Power Research Institute have been used to address effects on stabilization costs of R&D policies, the timing of GHG constraints, learning behavior and numerous other variables.

[13] Yet another interesting application of such models is analysis of the effects of climate change policies in Annex B countries on other countries. Early versions of the Multi-Sector Multi-Regional Trade model (MS-MRT) were built for this purpose, linking economic effects among countries through trade and investment.

leverage they may have on these impacts, for example how to implement climate policy in ways that minimize economic costs.

For these purposes, a third class of models, macro-economic models, are more appropriate. Such models capture interactive effects between the energy and other sectors of the economy and in that sense are general equilibrium models. They also capture trade effects by accounting for an economy's relationship with other economies. However, unlike other general equilibrium models, macro models do not assume instantaneous full market adjustment but rather allow an economy to suffer involuntarily unemployed resources for a period as market participants adjust to a policy shock. In this way they capture near and intermediate-term as well as longer-term costs.

The DRI-WEFA and Oxford models are examples of macro models. They start by assuming an economy on a long run growth path, but then allow policy initiatives to shock it in such a way that it deviates from the path while adjustment takes place. In other words, resources become involuntarily unemployed while they seek their new most valuable uses, and the economy produces below its potential. As noted above, the length of adjustment depends on the magnitude of the shock and the flexibility of a country's internal markets, and can take several years to fully work itself out. DRI-WEFA and the Oxford model contain a financial sector as well a real sector and therefore allow for changes in monetary or fiscal policy, which can mitigate or exacerbate energy policy initiatives through changes in interest rates and their economy-wide effects on savings and investment.

For purposes of modeling economic shocks of the magnitude implied by Kyoto policies, macro models such as DRI-WEFA or Oxford provide the most complete analysis. Like pure general equilibrium models, they capture costs borne in energy markets and other markets, and international trade effects. But unlike these models, they also capture the costs associated with an economy having to adjust to policy over a period of time. Since economic shocks create adjustment costs, the ability of macro models to estimate near and intermediate-term resource unemployment and its consequences for GDP, investment, savings and productivity is an important contribution to understanding the full economic consequences of climate change policy initiatives. For policy makers interested in near and intermediate term costs of policy related shocks to an economy, such models provide the most complete analysis.

Table 3 illustrates the differences in estimated impacts of climate policy on European GDP. In the table, estimates of the macroeconomic costs to Europe of implementing the Kyoto agreement are shown for the year 2010. Each estimate is associated with a different model, and the models are classified into the three categories I have described. Partial equilibrium models such as PRIMES and MARKAL project quite small numbers, slightly over .1% of EU GDP for that year. General equilibrium models such as ABARE-GTEM and MERGE3 show numbers that are nearly an order of magnitude higher, around 1% of GDP. Macroeconomic models such as G-Cubed and Oxford show still higher numbers for the European economy, around 1.5-2.0% of GDP. And DRI-

WEFA, with results only for selected individual European countries, shows higher numbers still.[14]

The partial equilibrium estimates are capturing costs in energy markets, the general equilibrium models costs over the entire economy, and the macroeconomic models those plus the adjustment costs associated with policy implementation. If the purpose is to understand the full macroeconomic costs associated with implementing GHG policies, this last category of model provides the most comprehensive approach.

Bottoms-Up and Top-Down Approaches to Energy Modeling

I turn now to a second issue associated with analysis of Kyoto policies, namely the use of a bottoms-up and top-down approaches to energy modeling. The issue has been discussed by others,[15] but bears continuing attention because there has been evolution in modeling technique and because it remains important to understand how these approaches can best support climate change policy analysis.

Bottoms-up and top-down models aim at the same objective, namely identifying demand and supply side reactions to changes in energy market conditions. Bottoms-up models do so by conducting engineering analyses of the lifetime costs of various energy-producing or energy-using technologies and comparing these to what can be realized in revenues or savings. Top-down models, in contrast, analyze past behavior in energy markets using statistical techniques to estimate what supply or demand response might be expected with a change in price or some other variable.

Conceptually, the two approaches are complementary. Bottoms-up analysis can be helpful in identifying prospects for new energy technologies as well as possible barriers to market acceptance of otherwise attractive options. It also may be useful in demonstrating to entrepreneurs or other market participants the relative attractiveness of technologies that otherwise might have escaped notice. This identification of new technologies and revelation of the attractiveness of options may reduce the costs of complying with a Kyoto carbon constraint below what a top-down model might predict. Also, by identifying possible barriers to the use of energy-saving or energy-producing technologies, policies might be changed to facilitate such compliance.[16]

On the other hand, bottoms-up models by their nature are not based on actual behavior. Their reliance on engineering data can lead to omitting vital information that renders real-world behavior different from what the models predict. For example, such models often

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[14] The macroeconomic and general equilibrium models show somewhat different prices for tradable permits among themselves, but all are well over 100 Euros per ton of carbon. The partial equilibrium models provide marginal costs of carbon *dioxide* abatement, which when translated into Euros per metric ton of carbon are very similar to those of the other models.

[15] See for example Jonathan Fisher and Michael Grubb, "The Use of Economic Models in Climate Change Policy Analysis," Royal Institute of International Affairs, EEP Climate Change Briefing No. 5, October 1997.

[16] For example, removal of protective quotas or subsidies for fossil fuel production could facilitate the substitution of less carbon intensive technologies with overall economic gain.

fail to recognize transactions costs associated with using new energy technologies, e.g., costs associated with learning about the technologies, trying them out, training people to use them, financing them, and measuring the results. For that reason, bottoms-up models can over-project the extent to which new energy technologies will be adopted within an economy where an increased carbon constraint is imposed.[17]

Another problem sometimes associated with bottoms-up models is their use as normative instruments, i.e., to identify technologies that then are mandated via policy. For example, the U.S. Department of Energy has used engineering estimates of the lifetime costs of alternative versions of capital equipment such as washing machines and refrigerators to establish mandatory efficiency standards for them. Also, state public utility commissions have used engineering estimates of the returns to energy conservation investment to fund such investment using ratepayer monies. Reviews of these programs have revealed that their returns often are much less than calculated, however.[18] By implication, many of the resources diverted into the programs have been wasted. Thus, while resource allocation can be improved by using engineering analyses to inform market participants of opportunities or to seek removal of regulatory barriers, it likely is harmed if these analyses are used to compel resource expenditures that otherwise would not be made.

Top-down models avoid many of the problems associated with bottoms-up because the behavior they reflect incorporates all of the costs of employing energy producing or conserving technologies. They can anticipate introduction of new technologies by including a parameter which allows the costs of energy conservation and supply to decrease with time. In addition, they can allow technology to advance more rapidly with extra inducement to do so. In effect, this allows them to incorporate much of the information that a bottoms-up model provides. They are, however, are based on technology and institutions existing at the time their underlying data were gathered. Use of more recent data could change the market responses estimated by such models. Also, the underlying data generally covers only a limited range of experience, so that market shocks beyond such experience may yield inappropriate model estimates. Still, the advantage of incorporating behavioral responses to changed market conditions provides such models a means to validate their structure that bottoms-up models cannot readily duplicate.

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[17] An important example is the so-called “5-Labs Study” done by the U.S. Department of Energy in 1997, which assumed widespread adoption of a number of energy saving technologies. (“Scenarios of U.S. Carbon Reductions,” Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, Office of Efficiency and Renewable Energy). A number of parties including the U.S. General Accounting Office and various private scholars leveled criticisms that this study seriously overstated prospects for adoption of energy saving technologies (see for example Henry D. Jacoby, referenced in footnote 11, and Ronald J. Sutherland, “Commentary: Technology Policy to Reduce Carbon Emissions,” which comments and elaborates upon the Jacoby criticisms.

[18] See for example Gilbert E. Metcalf and Kevin A. Hassett, “Measuring the Returns to Energy Conservation Investment: Evidence from Monthly Billing Data,” *Review of Economics and Statistics*, August 1999. Also, see Paul L. Joskow and Donald B. Marron, “What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs,” *The Energy Journal* 14(4), 1992.

The partial equilibrium energy market models mentioned in this paper (PRIMES, MARKAL) are largely based on bottoms-up appraisals. As such, they likely understate the costs of complying with a carbon tax or CO_2 tradable permit scheme, even in energy markets alone. Thus, they should be viewed as useful tools to assess potential responses in such markets, not as predictors of aggregate costs.

The general equilibrium and macro-economic models reviewed here, by contrast, take a top-down approach. Past data has been used to estimate the relationships embodied within them, and to validate their predictions. Most also incorporate technology improvement parameters, induced technological change, or a backstop energy technology whose cost falls with time. Some also incorporate sectoral changes in technology, e.g., in the average fuel economy of automobiles. By so doing, they incorporate elements of a bottoms-up approach within their top-down structure. Overall, this appears to be the most realistic approach to accurate estimation of climate change policy impacts.

Conclusions

A great deal of scientific effort and international communication has gone into furthering understanding of climate change and developing means to deal with it. Economic modeling can contribute by analyzing the macroeconomic impacts of alternative policies such as the Kyoto agreement and possible follow-on commitments. The macroeconomic models reviewed in this paper suggest that attempts to constrain European GHG emissions at the rate required by Kyoto have large economic costs. The strength of such models is their ability to capture near and intermediate-term adjustment costs as well as longer term costs associated with Kyoto-implementing policy shocks. For decision makers concerned with European GDP, employment and other economic indices over the next several years, these models offer the most complete understanding of what to expect.

APPENDIX: Tables 1-3, Figure 1

Table 1

Table 1 - Analytic Tools to Examine GHG Policy Measures

	Type of Economic Model		
	Partial Equilibrium (Energy market only)	**General Equilibrium**	**Macroeconomic**
Key Assumption:	Instantaneous full adjustment in energy market.	Instantaneous full adjustment in all market sectors.	Markets adjust over time.
What it captures:	Cost of carbon permits to energy users.	Long run cost to the economy.	Short and intermediate term adjustment costs. Long run cost to the economy.
Bottom line:	Best for analyzing energy market response alone.	Relatively uncomplicated. Especially useful if market shocks are small or gradual.	More complex. Most accurate if economic shock requires substantial market adjustment.

Table 2

Table 2 - Classification of Economic Models Analyzing Climate Policy

Partial Equilibrium	General Equilibrium	Macroeconomic
PRIMES	MIT - EPPA	Oxford
MARKAL	WorldScan	G-Cubed
	MS-MRT	DRI-WEFA
	ABARE - GTEM	
	MERGE3	
	CETA	
	FUND	
	MARKAL-MACRO	
	SGM	

PRIMES - (National Technical University of Athens - Greece)

MARKAL (Brookhaven National Laboratory - USA)

MIT-EPPA - Emissions Projection and Policy Analysis Model (Massachusetts Institute of Technology - USA)

WorldScan (Central Planning Bureau - Netherlands)

MS-MRT - Multi-Sector - Multi-Regional Trade Model (Charles River Associates and University of Colorado - USA)

ABARE - GTEM - Global Trade and Environment Model (Australian Bureau of Agriculture and Resource Economics (ABARE) - Australia)

MERGE3 - Model for Evaluating Regional and Global Effects of GHG Reductions Policies (Stanford University and Electric Power Research Institute - USA)

CETA - Carbon Emissions Trajectory Assessment (Electric Power Research Institute and Teisberg Associates - USA)

FUND- Climate Framework for Uncertainty, Negotiation, and Distribution (Vrije Universiteit Amersterdam - Netherlands)

MARKAL-MACRO (Brookhaven National Laboratory and Stanford University - USA)

SGM - Second Generation Model (Battelle Pacific Northwest Laboratory - USA)

OXFORD - Oxford Model (Oxford Economic Forecasting - Great Britain)

G-Cubed - Global General Equilibrium Growth Model (Australian National University, University of Texas and U.S. EPA - Australia - USA)

DRI-WEFA - (DRI-WEFA Forecasting -

	USA)				

Table 3

Table 3 - Estimates of European Macroeconomic Costs in 2010 from Policies to Implement Kyoto*

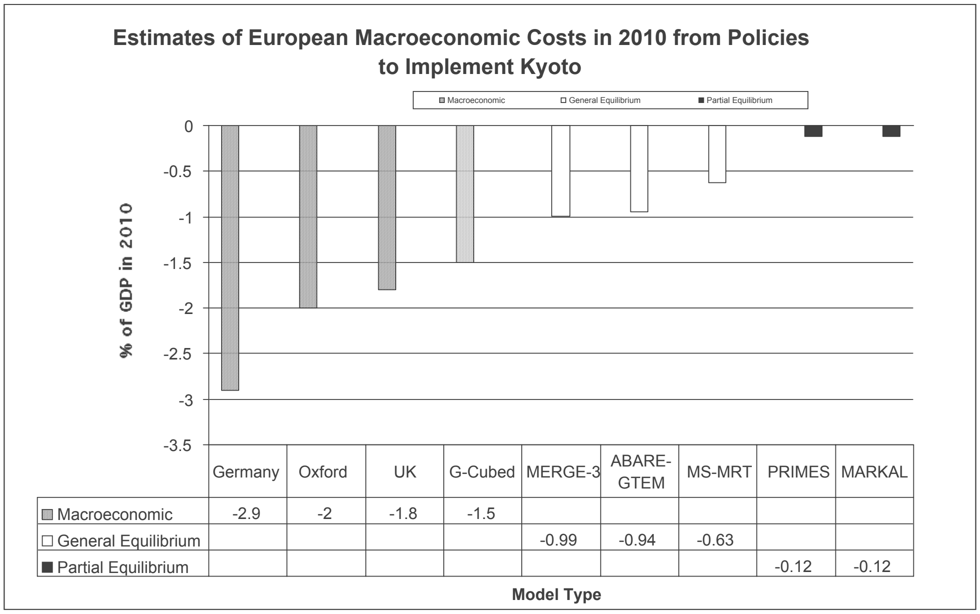
Model Type		% of GDP in 2010	
Macroeconomic			
	G-Cubed		1.50
	Oxford		2.00
	DRI-WEFA		
	Germany	2.90	
	Netherlands	1.90	
	UK	1.80	
	Spain	4.80	
General Equilibrium			
	ABARE-GTEM		0.94
	MERGE3		0.99
	MS-MRT		0.63
Partial Equilibrium			
	PRIMES		0.12
	MARKAL		0.12

*All of the numbers reflect scenarios in which there is internal carbon permit trading within countries but not between countries. Scenarios with trading among countries show lower absolute costs but the relative magnitudes among models remain as ranked in the table.

Sources: Macroeconomic and General Equilibrium estimates for OECD-Europe are from Energy Modelling Forum results shown in "Climate Change 2001: Mitigation," Chapter 8 of *Global, Regional and National Costs and Ancillary Benefits of Mitigation*, IPCC, Third Assessment Report, Working Group III. Individual European country macroeconomic results are from M. Thorning, "Kyoto Protocol and Beyond: Economic Impacts on EU Countries," Int'l Council for Capital Formation, Oct. 2002. Partial equilibrium estimates are derived for PRIMES from E3M Lab, P.Capros & L. Mantzos, "The Economic Effects of EU-Wide Industry-Level Emission Trading to Reduce Greenhouse Gases: Results from the PRIMES Model," May 2000, and for MARKAL from J.P.M. Sijm, K.E.L. Smekens, T. Kram and M.G. Boots, "Economic Effects of Grandfathering CO2 Emission Allowances," Energy Research Center of the Netherlands, April

	2002.							

Figure 1



	Germany	Oxford	UK	G-Cubed	MERGE-3	ABARE-GTEM	MS-MRT	PRIMES	MARKAL
▨ Macroeconomic	-2.9	-2	-1.8	-1.5					
☐ General Equilibrium					-0.99	-0.94	-0.63		
■ Partial Equilibrium								-0.12	-0.12