CUTTING CARBON EMISSIONS AT A PROFIT (PART I): OPPORTUNITIES FOR THE UNITED STATES

FLORENTIN KRAUSE, STEPHEN J. DECANIO, J. ANDREW HOERNER, and PAUL BAER*

This article identifies and corrects shortcomings in recent modeling studies on the economics of reducing greenhouse gas emissions in the United States. The major assessments of the Kyoto Protocol—by the U.S. Energy Information Administration, the Clinton White House Council of Economic Advisers, the U.S. Department of Energy Interlaboratory Working Group, and the Stanford Energy Modeling Forum—are found to be seriously incomplete. Each study omits one or several of four major cost-reducing policy options, resulting in cost estimates that are far too pessimistic.

In the present study, these shortcomings are overcome through the integrated evaluation of all major cost-cutting policy options within a coherent least-cost framework. Three domestic policies—a national carbon cap and permit trading program, productivity-enhancing market reforms and technology programs, and recycling of permit auction revenues into economically advantageous tax cuts—are combined with international emissions allowance trading.

This analysis shows that an integrated least-cost strategy for mitigating U.S. greenhouse gas emissions would produce an annual net output gain of roughly 0.4% of GDP in 2010 and about 0.9% of GDP in 2020. On a cumulative net present value basis, the United States would gain $250 billion by 2010 and $600 billion by 2020. International flexibility mechanisms (including emissions trading) are of only secondary significance in realizing these productivity, output, and welfare gains. (*JEL* Q43, Q48)

I. INTRODUCTION

This is the first of two articles that reexamine the economics of mitigating greenhouse gas emissions in the United States. The present article focuses on aggregate impacts on the U.S. economy. A subsequent publication will examine the sectoral distribution of employment and output effects.

*The preparation of this article was supported by the W. Alton Jones Foundation. Special thanks go to Erik Haites, who contributed modeling calculations of world carbon prices for various scenarios of domestic mitigation action and international flexibility rules. An extended version of this article with additional calculations and details is available online at www.ipsep.igc.org.

Krause: International Project for Sustainable Energy Paths, 7627 Leviston Ave., El Cerrito, CA 94530. Phone 1-510-525-7530, Fax 1-510-525-4446, E-mail ipsep@igc.org

DeCanio: Professor, Department of Economics, 3019 North Hall, University of California, Santa Barbara, CA 93106. Phone 1-805-893-3130, Fax 1-805-893-8830, E-mail decanio@econ.ucsb.edu

Hoerner: Director of Research, Center for a Sustainable Economy, 1731 Connecticut Ave. NW, Suite 500, Washington, DC 20009. Phone 1-202-234-9665, Fax 1-202-588-1297, E-mail ahoerner@wam.umd.edu

Baer: PhD candidate, Energy and Resources Group, University of California, Berkeley, CA 94720. Phone 1-510-642-1640, Fax 1-510-642-1085, E-mail pbaer@socrates.berkeley.edu

ABBREVIATIONS

AEEI: Autonomous Energy Efficiency Improvement
BAU: Business As Usual
CEA: Council of Economic Advisers
CEF: Clean Energy Futures
CGE: Computable General Equilibrium
COP: Conference of Parties
DRI: Data Resources, Inc.
EIA: U.S. Energy Information Administration
EMF: Energy Modeling Forum
EPA: U.S. Environmental Protection Agency
GDP: Gross Domestic Product
IPCC: Intergovernmental Panel on Climate Change
IPSEP: International Project for Sustainable Energy Paths
IWF: Interlaboratory Working Group
R&D: Research and Development
SGM: Second-Generation Model
UNFCCC: UN Framework Convention on Climate Change

Contemporary Economic Policy
(ISSN 1074-3529)
Vol. 20, No. 4, October 2002, 339–365

Our study is the first to integrate all major cost-cutting policy options into a coherent least-cost framework. Three domestic policies—a national carbon cap and permit trading program, productivity-enhancing market reforms and technology programs, and recycling of permit auction revenues into economically advantageous tax cuts—are combined with international emissions allowance trading.

This reassessment involves a number of analytic steps. We begin with a checklist of the major policy options that should be included in the analysis to make reliable economic assessments of U.S. mitigation costs. Our inventory is based on a whole-system perspective on the major cost-reducing policy options. Here, we include both options that can increase economic output relative to the baseline projections and options that reduce losses of output. We also specify important accounting boundaries that include non-CO_2 greenhouse gases, sinks, and cobenefits of greenhouse gas abatement in the areas of classical pollution control, public health, and other externalities.

Having established this checklist of input requirements for a sound assessment, we next investigate the adequacy of the major U.S. mitigation cost studies to date. This comparison provides a transparent review of the major methodological shortcomings of each study in our sample. This review is followed by the conceptual development of a methodology for correcting these shortcomings. The crucial issue is the proper integration of policies based on energy price signals with nonprice policies involving institutional and market reforms. The integration of these two types of policies into a least-cost framework requires the integrated consideration of gross domestic product (GDP) gains from market reforms and tax shift policies on the one hand, and GDP losses from increased energy prices on the other. We also discuss the impact of the combined application of both types of policies on the sign and relative magnitude of transitory macroeconomic adjustment costs.

Next, we quantify the scope of feasible emission reductions from non-price policies for the year 2010 to 2020 timeframe. Here, we draw on the recent in-depth Clean Energy Futures (CEF) study by the Interlaboratory Working Group of the U.S. Department of Energy. In that work, total emission reductions are partly based on a menu of more than 20 market reforms and technology programs and partly on a $50/t carbon price. The baseline GDP and emissions projections used in that study are also adopted as the baseline for the further elaboration and evaluation of an integrated policy approach.

We then proceed to a least-cost analysis of the Kyoto emission reduction targets for the United States. Here, the effects of price-based policies and their associated GDP losses from substitution effects are represented by the results of recent work reported by the Stanford Energy Modeling Forum (EMF). In our reanalysis, tax shift policies are assumed to offset (partially or fully) GDP losses from the substitution effects generated by higher energy prices.

We extend the CEF analysis to the full implementation of the U.S. Kyoto target, that is, emission reductions of roughly 520 million metric tons of carbon by 2010. To determine the required carbon prices (and the GDP losses associated with these carbon prices when tax shifts are not considered), we use an extrapolation of the EMF results. We again add tax shift policies to the market reforms and technology programs of the CEF work. Finally, we extend the timeframe for this policy assessment from 2010 to 2020.

Having established the economic fundamentals of an integrated policy approach, we next examine what economic benefits the United States would have realized if U.S. proposals on international emissions trading, flexibility mechanisms, and carbon sinks had been accepted in the U.N. negotiations. We perform separate marginal benefit analyses for restricted and unrestricted global allowance trading and for the incorporation of sinks, as well as sensitivity analyses that take account of the uncertainty range in the modeling work of the EMF.

II. BACKGROUND

At the Sixth Conference of Parties (COP-6) held in The Hague in November 2000, the UN climate negotiations suffered a major setback. Differences between the United States and the European Union on how to implement the 1997 Kyoto Protocol created a stalemate. Among the most contentious issues were constraints on international emission allowance trading and credits for carbon sinks. The United States maintained that to lower the economic costs of implementing the Kyoto treaty to acceptable levels, it needed unlimited access to the Kyoto Protocol's flexibility mechanisms—international emissions trading, joint implementation, and the clean development mechanism—as well as large credits for sinks.

The European Union and other countries argued that the wealthy industrialized nations should meet most of their commitments through cuts in emissions at home. They pointed to provisions in the Kyoto Protocol that restrict the use of the treaty's flexibility mechanisms to a supplementary level. The European Union and others also objected to the notion of large credits for enhancement of sinks during the first commitment period under the protocol, because uncertainties in quantifying sinks and issues of verification and permanence could undermine the environmental integrity of the treaty. Also, proposals by the United States and other countries to obtain credits for enhancements of sinks that would occur under business-as-usual conditions were seen as an attempt in effect to renegotiate the Kyoto targets.

The failure of negotiations in The Hague was followed by the withdrawal of the United States from the Kyoto treaty in early 2001. As justification, the Bush administration cited excessive negative economic impacts and issues of international fairness. Even though the nations still committed to the Kyoto process reached a tentative agreement regarding these issues at Bonn in July 2001 and at COP 7 in Marrakech in October–November 2001, the withdrawal of the United States decreases the effectiveness of the agreement and weakens ongoing international efforts to protect the climate.

These diplomatic developments have created new problems for the United States. First, delays or failure to initiate international abatement action exposes the United States to unmitigated risks of climate change. Second, the current U.S. posture of withdrawal from the COP process means that other nations will negotiate implementation rules for the Kyoto treaty without U.S. input. If enough countries ratify the treaty, such rules could include trade sanctions against noncomplying nations. The United States is home to many multinational corporations whose overseas operations would be affected by these rules. Third, the United States produces 25% of emissions with 5% of the world's population. Nonparticipation in climate change mitigation diminishes the ability of the United States to exert leadership in other international arenas.

Our analysis suggests that past U.S. assessments of the economic costs of the Kyoto treaty have been far too pessimistic. Both Democratic and Republican administrations failed to take significant information into account in formulating the U.S. negotiating position. Our reexamination of the economics of climate change mitigation is important beyond the recent history of the negotiations, however. Although the United States has indicated that it will not ratify the Kyoto Protocol, it has signaled a continuing commitment to the international negotiating process of the UN Framework Convention on Climate Change (UNFCCC). This process will involve repeated reviews of commitments to reduce emissions. At each of these points of the UNFCCC process, the United States will need to draw on accurate, comprehensive, and updated assessments of the economics of reducing greenhouse gas emissions, along with new information on the science of the global warming threat.

Our review shows that the economic assessments that shaped the U.S. discussion on the Kyoto treaty were seriously incomplete. Though each major cost-reducing policy option was examined in at least one study, no study examined the joint application of all the major domestic options for reducing costs or, for that matter, the joint application of the major domestic options and international trading. Thus, our review calls into question claims that the United States lacks affordable domestic mitigation options and needs to heavily rely on international mechanisms and credits for sinks to reduce costs. The validity of these claims can only be established through an analysis in which all the major cost-reducing policy options are implemented jointly. That is the purpose of this article.

III. A LEAST-COST STRATEGY: FLEXIBILITY WITH NO REGRETS

To be economically efficient, climate change mitigation needs to combine domestic policy options and international mechanisms in a cost-minimizing fashion. Our discussion therefore starts with an account and inventory of cost-reducing policy options. In examining costs and benefits, we follow the practice of most studies on the subject of mitigation costs by excluding the benefit of avoided climate change, which cannot be estimated reliably at this time. This means, of course, that the benefits we calculate will be underestimates of the true benefits of the policies.

A. Overview of Cost-Minimizing Policy Options

To minimize mitigation costs, governments need to combine the following four policy strategies: (1) taxes on greenhouse gas emissions or, alternatively, emission caps combined with a domestic permit auction and trading system; (2) cost-benefit tested market, structural, and organizational reforms and technology programs; (3) use of revenues from permit auctions or emissions taxes for growth-enhancing tax shifts; and (4) the international flexibility mechanisms of the Kyoto Protocol. The most widely analyzed policy scenario for examining the costs of implementing the Kyoto targets deals only with carbon emissions and consists of a domestic carbon tax or a cap-and-trade permit system in which the government auctions permits to domestic producers and international suppliers of energy. In this scenario, it is further assumed that the revenues generated by such permit auctions are rebated to consumers and firms in lump-sum fashion each year. By definition, lump-sum rebates do not affect consumers' or firms' incentives. (By contrast, recycling of the permit revenues in the form of reductions of the *marginal rates* of other taxes can induce new investment or job creation.) Thus, lump-sum rebates represent a worst-case scenario from a revenue recycling perspective. The permit price triggers economic substitution effects in the economy, which in turn reduce economic output (GDP), without offsetting effects from possible beneficial shifts in the structure of the tax system.

This simple domestic strategy is a convenient point of reference for quantifying the economic advantages of more sophisticated policy approaches to greenhouse gas mitigation. Among such policies, we distinguish between two types. The first type has the effect of reducing emissions while increasing productivity or otherwise enhancing economic efficiency, which leads to gains in GDP. These policies are often referred to as no-regrets options.[1] The second type of policy has the effect of substituting cheaper measures for more expensive measures. However, relative to the use of fossil fuels and other features of the baseline scenario, these measures result in a net loss of GDP—though that loss is smaller that it otherwise might be because the policies are designed to reduce marginal abatement costs.

In estimating the net economic impact of any emission abatement target, the inclusion and thorough treatment of no-regrets options is essential. If environmental targets are to be implemented at least cost, measures with negative net cost need to be implemented first. Total abatement costs are the sum of cost savings from negative cost measures and cost increases from positive cost measures. When this sum is negative, environmental policies can become a source of economic gains even though marginal abatement costs are positive. A widespread error in conventional assessments is to neglect no-regrets options and to treat positive and often high marginal abatement costs as the sole indicator of or proxy for net economic impacts. Given the potentially large but uncertain damage costs of global warming, policy makers should adopt targets that go beyond those emission reduction commitments that have a zero net effect on the economy.

There are two major categories of no-regrets options. The first category includes a range of domestic energy market reforms that stimulate cost-effective energy efficiency investments and thus lead to higher productivity. This market reform strategy includes financial incentives, standards, and voluntary agreements to remove organizational and institutional barriers to profitable energy efficiency improvements.[2] The strategy may

1. For a discussion of the theoretical and empirical basis of the no-regrets concept, and the deficiencies of conventional modeling input assumptions, see the companion report to this analysis (IPSEP, 2001a), and the discussions in Krause (1996) and IPCC (1996).

2. Policies designed to remove these barriers are generally referred to as market reforms, and we will use this terminology throughout. It should be kept in mind, however, that the barriers often are rooted in organizational decision-making practices, institutional structures, or informational deficiencies that exist outside the ordinary definition of markets. See DeCanio (1993) for a full discussion.

also include a variety of technology research and development (R&D) and commercialization programs that accelerate the introduction and diffusion of new technologies. The common feature of these policy measures is that they can reduce carbon emissions relative to the baseline projection at negative net cost (Interlaboratory Working Group [IWG], 2000; International Panel on Climate Change [IPCC], 1996).

A second domestic policy option with no-regrets potential is to use the revenues from carbon taxes or domestic cap-and-trade permit systems for tax reforms. Such fiscal reforms may lead to positive effects on GDP—the so-called strong double dividend. A strong double dividend can be achieved if revenues from carbon taxes or permit systems are used to offset other taxes that impede investment and employment more strongly than energy taxes do (Parry and Bento, 2000).

Other policies can reduce mitigation costs but do not produce net economic gains. In the context of the Kyoto Protocol, the major such option is to expand the supply of low-cost abatement opportunities beyond those available in the domestic economy. This is the flexibility component of the Kyoto mechanisms. It lowers total mitigation costs by reducing the marginal cost of carbon abatement for countries with Kyoto commitments. International emission allowance trading can also smooth differences in marginal costs among individual Annex I countries.

Tax shifts that only partially offset the GDP losses from price-induced economic substitution effects (weak double dividend) also fall into the category of cost-reducing policy options, as do certain types of market reforms and technology initiatives. Examples include programs that accelerate the learning curve effects for renewable energy technologies, such as minimum percentage targets for renewable power generation (portfolio standards) or other forms of market creation.

B. System and Accounting Boundaries

Mitigation cost assessments are also influenced by the system and accounting boundaries being used in the analysis. Three such factors are the most important: inclusion of non-CO_2 greenhouse gases, credits for carbon sink enhancement, and cobenefits of greenhouse gas mitigation.

The Kyoto Protocol specifies a percentage for reducing the sum of carbon-equivalent warming effects from a basket of six major greenhouse gases. If the Kyoto target is being approached through reductions in fossil carbon emissions alone, costs could be higher than when mitigation of carbon and non-CO_2 greenhouse gas emissions is pursued on a least-cost basis. However, abatement costs for non-CO_2 greenhouse gases are less well understood than those for mitigating carbon emissions from energy use.[3] Reductions in land-use emissions through afforestation or other measures to enhance carbon sinks may also reduce the costs of implementing the Kyoto targets. Indeed, a number of afforestation or reforestation measures may be no-regrets options.

During the first commitment period of the Kyoto Protocol, only certain afforestation or reforestation measures are eligible for emission reduction credits under Article 3.3. These restrictions reflect significant uncertainties regarding measurement, verification, and persistence over time. Additional land use changes might receive credits under Article 3.4, but these have been a source of conflict in the COP negotiations.

Finally, net mitigation costs will be lower if account is taken of the cobenefits of greenhouse gas abatement in the area of pollution, public health, and other externality costs. Though these cobenefits vary locally and are surrounded by significant uncertainties, ranges for their monetary value have by now been established in a voluminous research literature (IPCC, 2001). These can and ought to be incorporated into economic assessments.

C. How Economic Assessment Efforts Should Be Structured

Economic assessments of the Kyoto Protocol should be based on the integrated modeling of all of the above-mentioned factors, to the greatest extent possible. To provide sound guidance for policy making, studies should at a minimum incorporate the four most well-understood options,

3. Scenario runs for the United States reported by MacCracken et al. (1999) indicate a 16% reduction in costs from including non-CO_2 gases. In another analysis, Tol (1999) suggests that inclusion of methane abatement could reduce mitigation costs by the same order of magnitude as international trading.

that is, carbon taxes or permits, domestic market/institutional reforms, fiscal reforms, and international flexibility. We refer to this approach as a strategy of flexibility with no regrets.

Within this quartet of core policies, special attention should be given to those domestic market and fiscal reforms that cut carbon and other greenhouse gas emissions at a net economic gain. Without a thorough analysis of domestic no-regrets options, a realistic assessment of the benefits of international emission allowance trading is impossible. Failure to focus on domestic no-regrets options violates basic principles of marginal cost analysis, according to which the cheapest options should be pursued first. Translating conceptually flawed cost assessments into policy action can lead to bad decisions and the waste of large amounts of public and private funds.

IV. HOW ADEQUATE ARE THE U.S. COST ASSESSMENTS?

Given this checklist of the elements of a comprehensive economic analysis, we now examine recent government and academic assessments of U.S. mitigation costs and of the Kyoto treaty. Table 1 lists these studies, which include: (1) The study of the Kyoto Protocol by the U.S. Energy Information Administration (EIA, 1998a) that was performed in response to a request by the Science Committee of the House of Representatives of the U.S. Congress; (2) The results of the 16th EMF, an academic program at Stanford University in which a number of individual energy-economic models are tested side by side on the basis of normalized scenario assumptions (EMF, 1999); (3) the Clinton administration's economic analysis of the Kyoto Protocol, produced for the White House by the Council of Economic Advisers

TABLE 1
Policy Analysis Gaps in U.S. Assessments of the Kyoto Protocol

	Scope of Policy Analysis		
	Market Reforms, Technology Programs	**Tax Shift Reforms**	**International Allowance Trading**
1998 EIA			
Domestic w/o sinks	No	No	No
Domestic + sinks	No	No	No
Annex I trading + sinks	No	No	Limited
Global trading + sinks	No	No	Limited
Domestic + sinks + weak double dividend	No	Limited	No
Annex I trading + sinks + weak double dividend	No	Limited	Limited
Global trading + sinks + weak double dividend	No	Limited	Limited
1999 EMF 16			
No trading	No	No	No
Annex I trading	No	No	Yes
Global trading	No	No	Yes
1998 White House/CEA			
"Domestic only" policy case	No	No	No
Annex I trading	No	No	Yes
Best case trading	No	No	Yes
1997 IWG			
Nonprice policies, moderate	Yes	No	No
Nonprice policies, strong	Yes	No	No
Same plus $50/tC permit price	Yes	No	No
2000 CEF study (IWG)			
Moderate scenario, no C charge	Yes	No	No
Advanced scenario, no C charge	Yes	No	No
Advanced scenario including $50/tC permit price	Yes	No	No

TABLE 2
System Boundaries in Economic Assessments of the U.S. Kyoto Targets

	System Boundaries of Analysis			
	Realization of Kyoto Target (%)	**Enhancement of Carbon Sinks**	**Inclusion of Non-C Greenhouse Gases**	**Inclusion of Monetized Cobenefits**
1998 EIA				
Domestic w/o sinks	100	No	No	No
Domestic + sinks	100	Limited	No	No
Annex I trading + sinks	100	Limited	No	No
Global trading + sinks	100	Limited	No	No
Domestic + sinks + weak double dividend	100	Limited	No	No
Annex I trading + sinks + weak double dividend	100	Limited	No	No
Global trading + sinks + weak double dividend	100	Limited	No	No
1999 EMF 16				
No trading	100	Limited	No	No
Annex I trading	100	Limited	No	No
Global trading	100	No	No	No
1998 White House/CEA				
"Domestic only" policy case	100	No	Yes	No
Annex I trading	100	No	Yes	No
Best case trading	100	No	Yes	No
1997 IWG				
Nonprice policies, moderate	22	No	No	No
Nonprice policies, strong	45	No	No	No
Same plus $50/tC permit price	68	No	No	No
2000 CEF study (IWG)				
Moderate scenario, no C charge	16	No	No	No
Advanced scenario, no C charge	29	No	No	No
Advanced scenario including $50/tC permit price	58	No	No	No

(CEA, 1998); and (4) and (5) the two studies by the U.S. Department of Energy, produced jointly by five national laboratories through an IWG (IWG, 1997, 2000).

The first four studies were completed prior to the COP 6 conference. Although the second multilab study was essentially completed well before COP 6, it was withheld from publication until after the November 2000 election and was released only during COP 6. As a result, it did not have a chance to influence the public discourse surrounding the development of the U.S. negotiating position at COP 6.

A. Analysis of Input Assumptions

For each of these studies, we list in Tables 1 and 2 the scenario cases that are most relevant for the present review. We indicate what level of emission reductions were analyzed, what system boundaries were used, and whether key cost-reducing policy options and boundary choices were modeled or not. All the studies modeled a carbon tax or cap-and-trade system, so Table 1 tabulates the other three cost-reducing policies: market/institutional reforms, tax shifts, and international trading. Table 2 shows the inclusiveness of the system boundaries used in each analysis, based on three features: treatment of sinks, greenhouse gases other than carbon dioxide, and environmental cobenefits.

These tables show that none of the studies listed fully incorporates more than two of the six features that can improve on domestic carbon taxes or permit trading alone.[4]

In other words, the studies that have shaped U.S. perceptions on mitigation costs do not meet the minimum standards for integrated least-cost assessment outlined in the

4. The IWG (2000) report includes a qualitative review of tax shift studies for the United States but stops short of incorporating the findings of this review into the calculations of GDP impacts.

previous section. Furthermore, in the modeling exercises on which the U.S. government appears to have relied most heavily in developing its negotiating position regarding reduction commitments and flexibility mechanisms, the economically most attractive policy options—no-regrets market reforms and tax shifts—are simply absent when they should have been the center of attention.

All of the top-down modeling studies listed in Tables 1 and 2 (that is, the studies other than the two by the Department of Energy's IWG) are completely devoid of cost-saving market reform options. This is surprising, because the existence of no-regrets energy efficiency resources is by now well established through extensive empirical research on actual market reform and technology programs (IPCC, 1996, 2001). Moreover, market reforms and technology programs have been modeled with increasing detail and sophistication in a large body of studies including the authoritative work of the U.S. Department of Energy's IWG.

The first interlab study (IWG, 1997) analyzed which low-carbon technologies could be cost-effectively deployed with market reforms and R&D programs. It found that such programs could reduce U.S. carbon emissions by up to 205–258 MtC/year in 2010 (a median implementation of 45% of the U.S. Kyoto target) while producing net savings in energy bills of $28.5 billion/year (median value in 1995 dollars). In the absence of carbon charges, net savings in energy bills are a measure of positive GDP effects. When carbon charges are included in the policy mix, an offsetting GDP loss arises from price-induced economic substitution effects. The study further found that with a $50/tC charge, 68% of the Kyoto target would be reached domestically, again with net savings in energy bills.

The IWG (1997) report had certain modeling limitations. It did not track feedback effects on energy prices and the mix of energy carriers. However, subsequent work showed that these simplifications had only a small effect on the results (Koomey et al., 1998). The 1997 IWG qualitative finding of sizable emission reductions at a small net economic gain was not only confirmed but strengthened by the more recent *Scenarios for a Clean Energy Future* (IWG, 2000). This study not only calculated feedback effects on energy prices but also incorporated detailed specifications of market reforms and technology programs that had been lacking in the earlier IWG work.

It is noteworthy that energy sector technology programs and market reforms were systematically excluded from the EMF, EIA, and CEA studies, and other cost-reducing options were not. For example, in designing normalized modeling runs for its Kyoto Protocol evaluation, the EMF (1999) included carbon sinks as a subject of sensitivity tests but failed to give the same treatment to the much more widely embraced and thoroughly understood market reform options for achieving policy-induced energy efficiency gains. The same analytical bias is found in the White House report on the Kyoto Protocol (CEA, 1998). Here, the cost-reducing potential of nonprice policies—such as the Clinton administration's Climate Change Technology Initiative and other federal programs—was acknowledged, but all such programs were omitted from the computational runs. This omission was justified on the grounds of model limitations. It was claimed that the second-generation model (SGM) being used to illustrate the benefits of international trading was not suited for analysis of nonprice programs. However, the SGM modeling team had no such problems when it came to analyzing non-CO_2 greenhouse gases or carbon sinks even though these options pose modeling problems analogous to those connected with market reforms. In its 1998 work for the CEA, the SGM team incorporated a bottom-up abatement cost curve for these gases—precisely the kind of input that the interlaboratory studies provide for the energy efficiency options.

In the same vein, the SGM contribution to the 1999 EMF developed sensible bounds on the economic impact of carbon sink enhancement and the non-CO_2 gases despite a lack of reliable cost data (MacCracken et al., 1999). This same stylized zero net cost assumption for carbon sinks was used in the Kyoto assessment of the EIA (1998a), which adopted offsets from sinks of about 60 MtC. With this assumption for sinks, smaller emission reductions are needed from the energy sector, and a lower permit price is required to reach the Kyoto target. The cost-reducing effect of including sinks is simply measured by the lower GDP loss resulting from the reduced carbon permit price.

A similar approach could have been used in dealing with market reform and technology programs to accelerate cost-effective energy efficiency investments. Indeed, given the very detailed descriptions of these policy and resource options in the work of the IWG and in several other independent studies (e.g., Tellus, 1998; Tellus/SEI, 1999), much more specific estimates could have been developed. Findings from these studies could have been incorporated into the Kyoto policy cases of all the EMF-16 and CEA modeling runs in a straightforward if approximate manner by using a higher aggregate autonomous energy efficiency improvement parameter (AEEI coefficient) in the policy case, because this parameter is often used to represent technological change other than price-driven substitutions in top-down economic models. Indeed, the CEA (1998) report notes that the 1997 interlaboratory analysis would translate into a 30% increase in the AEEI—practically delivering the key model adjustment with which market reforms could be incorporated (CEA, 1998, p. 47).

A similar and equally serious analytic gap exists in the area of tax shifts. That economic impacts are strongly shaped by the manner in which carbon tax revenues are recycled has been recognized in both U.S. government–sponsored and the major academic and private modeling work. An early multimodel comparison of carbon tax recycling by Shackleton et al. (1992) for the U.S. Environmental Protection Agency (EPA) established that different revenue recycling approaches led to widely different impacts on GDP. All the tested models showed that relative to lump-sum recycling (in which the existing tax structure is left intact), GDP losses could be significantly reduced by a variety of tax shifts that also reduce emissions (weak double dividend). Furthermore, the analysis found that when tax shifts were designed to reduce taxes on capital or investment, three of the four models tested produced net GDP gains along with a reduction in emissions (strong double dividend). In these cases, efficiency gains in the tax structure produced gains that were one to three times as large as the losses in the lump-sum scenario. The fourth model produced a complete offset of GDP losses without adding GDP gains. Though tax shifts reducing the labor tax had a weaker effect on GDP, they are less regressive than capital-oriented tax cuts. Partly because of this income distribution effect, most of the eight countries that have now adopted fundamental environmental tax reform have used energy tax revenues to cut labor taxes (also called payroll or social insurance taxes).[5]

One might expect that these findings would have made tax shift analysis a major and ongoing area of mitigation cost analysis in the model comparisons of the EMF. Instead, EMF eliminated revenue recycling from its scenario runs and model comparisons. When this decision was first made in the early 1990s, it was argued that the goal of better understanding inherent structural differences among the various economic models required a simplified analysis excluding the complicating factor of tax shifts. If this reasoning had a semblance of plausibility during the early 1990s, it lacked any such justification by the time EMF-16 work was conducted in the late 1990s. By that time, differences between elementary model structures had been thoroughly examined. Omission of tax shift analysis also does not make sense in the context of assessing the economic impact of the Kyoto Protocol. Because the protocol is a specific treaty and because a central goal of EMF-16 was to help policy makers understand the economic implications of that treaty, adequately meeting this policy analysis objective certainly required the inclusion of revenue recycling in the modeling exercises.

A number of economic modelers have continued to investigate tax shift options on their own throughout the 1990s. This body of work has reconfirmed the possibility of a strong double dividend under U.S. conditions while leading to a more refined understanding of the conditions under which tax recycling produces weak and strong double dividends (Hammond et al., 1997; Parry, 1997; Parry et al., 1999; Parry and Bento, 2000; Sanstad et al., 2000; Repetto, 2000). Still more far-reaching energy tax recycling schemes have been investigated in the context of fundamental tax reform, such as replacing the current income tax system by a flat tax or a consumption tax (Norland et al., 1998).

5. These nations are Denmark, Finland, Italy, Germany, The Netherlands, Norway, Sweden, and the United Kingdom (Hoerner and Bosquet, 2001).

These developments are absent not only from the EMF studies but also from the cost estimates of the CEA (1998). Although the pre-Kyoto work of the Clinton Administration's Interagency Analytical Team had considered tax shifts as an integral part of its modeling investigations,[6] this element was no longer present in the report of the CEA. The assessment of the EIA (1998a), which is based on the Data Resources, Inc. (DRI), model, does include one form of tax shift based on reductions of payroll taxes. This scenario case produces a weak double dividend (a 55% offset of GDP losses estimated in the domestic-only, lump-sum rebate scenario).

The two bottom-up studies by the IWG (1997, 2000) suffer from drawbacks of their own. They provide only the most cursory discussion of international carbon allowance purchases and trading. This makes it difficult to use their reported results for quantifying the impact of market reforms on the economics of the U.S. Kyoto target. In fact, the IWG studies are limited to scenarios describing only the partial achievement of the U.S. target.

International allowance trading is part of the modeling analysis of the EIA (1998a) but with significant simplifications. Because the EIA model is national rather than global in scope, it assumed that the United States would purchase international permits at the marginal abatement cost determined for the United States in a purely domestic analysis. This assumption ignores the likelihood that marginal abatement costs in other Annex I and non–Annex I countries may differ widely from those in the United States. It also neglects the fact that hot air allowances from the former Soviet Union have no production cost and can shift international permit prices downward in ways that have no correlation with marginal abatement costs in the United States. As acknowledged in the EIA report itself (1998a, p. 120), the cost-reducing benefits of international allowance trading are likely to be underestimated in the EIA study. This pessimistic bias is further compounded by the omission of credits for sinks in other Annex I countries, which would further reduce the international carbon price.

6. See, e.g., the DRI-based modeling work of Probyn and Goetz (1996) for the EPA, which analyzed the combined reduction of both personal and business taxes.

These and other issues associated with the Kyoto Protocol are addressed in the global modeling analyses of EMF-16 and also in that of the CEA (1998). Unlike the EIA analysis, these studies take into account that the international allowance price is highly sensitive to the demand for allowances and the supply of hot air. However, they too fail to include the allowance price reducing effects of domestic market reforms and do not fully investigate the impacts of credits for sinks. As will be shown, such domestic action has a decisive effect on the role of low-cost hot air allowances and thus strongly affects the international price of carbon.

B. Quantitative Findings on Economic Impacts

Table 3 summarizes the GDP or energy bill impacts reported in the five studies under review. Results for the worst-case policy assumption range from a loss of 4.2% of GDP in the EIA analysis to 0.6% in the CEA report. With cost-reducing policies included, impacts range from a loss of 1.4% of GDP to a gain of 0.09% of GDP. In studies that analyze only market reforms, the best results indicate gains of as much as 0.5% of GDP.

In interpreting Table 3, two things need to be kept in mind. First, the positive economic impacts reported in the studies of the IWG apply only to scenarios for implementing 16–68% of the U.S. Kyoto target. The effect of the full implementation of the Kyoto Protocol is not calculated in these studies. Second, the significantly higher GDP losses in the EIA study reflect an important model difference. The EMF comparisons and the CEA analysis rely on economic models that were designed for the study of longer-term policy effects. These computable general equilibrium (CGE) models calculate effects on potential GDP. The EIA uses a model that was designed for short-term economic policy analysis and near-term transitional effects (the DRI neo-Keynesian macroeconomic model). It calculates both a potential GDP effect based on full employment and a transitory adjustment effect. The sum of both is reported as change in actual GDP. Although impacts on potential GDP in the EIA model are comparable to those in the CEA analysis and to the mean of the EMF-16 models, estimates of actual GDP

TABLE 3
Estimated Impacts of the U.S. Kyoto Target in 2010

	Realization of Kyoto Target (%)	GDP Impact in 2010 Incl. Cost of Intl. Allowances	
		$'97 Billion	**% of GDP**
1998 EIA			
Domestic w/o sinks	100	−443	−4.21
Domestic + sinks	100	−365	−3.47
Annex I trading + sinks	100	−210	−1.99
Global trading + sinks	100	−107	−1.02
Domestic + sinks + weak double dividend	100	−143	−1.36
Annex I trading + sinks + weak double dividend	100	−127	−1.21
Global trading + sinks + weak double dividend	100	−86	−0.82
1999 EMF 16			
No trading (mean)	100	−133	−1.26
Annex I trading (mean)	100	−63	−0.60
Global trading (mean)	100	−25	−0.24
1998 White House/CEA			
"Domestic only" policy case	100	−66	−0.55
Annex I trading	100	−39	−0.24
Best case trading	100	−8	−0.07
1997 IWG			
Non-price policies, moderate (mean)	22	17	0.17
Non-price policies, strong (mean)	45	30	0.30
Same plus $50/tC tax	68		NA
2000 CEF study (IWG)			
Moderate scenario, no C charge	16	40	0.36
Advanced scenario, no C charge	29	54	0.49
Advanced scenario including $50/tC charge	58	10	0.09

changes are significantly higher. The EIA study predicts GDP losses with tax shifts that are similar in magnitude or worse than the worst-case results of the EMF and CEA assessments without tax shifts.

The adjustment costs that drive these higher EIA estimates are based in part on the expectation that higher energy prices caused by permit auctions will trigger anti-inflationary monetary responses, which in turn will cause slower growth and investment during the economy's adjustment. Such adjustment costs are largest when the government does not take compensatory fiscal measures through tax shifts and when the Federal Reserve sets monetary policy on the basis of price inflation targets alone. As the EIA report itself acknowledges, its adjustment cost calculations are uncertain and controversial.[7]

With these factors in mind, the studies in Table 3 raise the possibility that the combined application of domestic market reforms, tax shifts, and flexibility mechanisms could move the economic impact of the Kyoto Protocol into positive territory: Flexibility could significantly reduce GDP losses, tax shifts could eliminate most or all remaining GDP losses, and market reforms could add productivity benefits and net GDP gains. Indeed, it is conceivable that the Kyoto target could be achieved at a positive net impact on the U.S. economy by just combining market reforms and international trading. Though market reforms and technology programs might not be sufficient to achieve the Kyoto target on their own, GDP gains from energy productivity investments might be more than enough to pay for the purchase of international permits to meet total Kyoto commitments.

7. See EIA (1998a), p. 127, and also the critique in Sanstad et al. (2000). The EIA's approach implicitly assumes that inflation is the sole concern of the Federal Reserve Board. It is possible to imagine that monetary policy could be adjusted to include other considerations, such as a desire to cushion the short-term impact of a carbon pricing policy adopted in pursuit of the legitimate national goal of reducing greenhouse gas emissions.

Alternatively, the Kyoto target might be achievable at a net economic gain through a completely domestic strategy: Market reforms and technology programs could generate productivity gains and GDP benefits while reducing the carbon charge needed to reach the Kyoto target. Tax shifts in turn could eliminate most or all GDP losses from economic substitution effects and could even add further GDP benefits. Indeed, this has been the finding of the handful of U.S. and European studies that combine market reforms with tax shifting (e.g., Barret and Hoerner, 2001; Hanson and Laitner, 2000; Laitner, 1999; see (Hoerner and Bosquet, 2001,) and Krause, 1996, for a survey of the European results).

V. METHODOLOGY AND SCOPE OF THIS STUDY

Our analysis builds on the results of the previous studies to develop improved estimates of the impacts of the Kyoto Protocol on the U.S. economy. We evaluate two versions of a least-cost strategy of flexibility with no regrets: (1) a domestic least-cost strategy that combines a domestic cap-and-trade system with tax shifts and energy market reforms, and (2) an international least cost strategy that also incorporates global trading of emission allowances. The starting point of our analysis is the CEF study of the U.S. Department of Energy (IWG, 2000). We integrate this study with results of the EMF (1999), findings from various tax shift studies, and recent analysis of global emission allowance markets (Haites, 2000).

We begin with the domestic strategy. We first reproduce the emission reductions achieved in the CEF study's advanced policy scenario for 2010. We then extend the analysis to the full implementation of the U.S. Kyoto target. Finally, we analyze the impact of maintaining the Kyoto reductions in 2020. We incorporate monetized estimates of the cobenefits of mitigating carbon emissions, but we do not include non-CO_2 greenhouse gases and we treat credits for the enhancement of carbon sinks only in a sensitivity analysis. Insofar as inclusion of these factors can lead to lower mitigation costs, our estimates will tend to overstate the costs or understate the net benefits of implementing the Kyoto Protocol. Omission of any of the benefits from mitigating the effects or risks of climate change reinforces the conservatism of our approach.

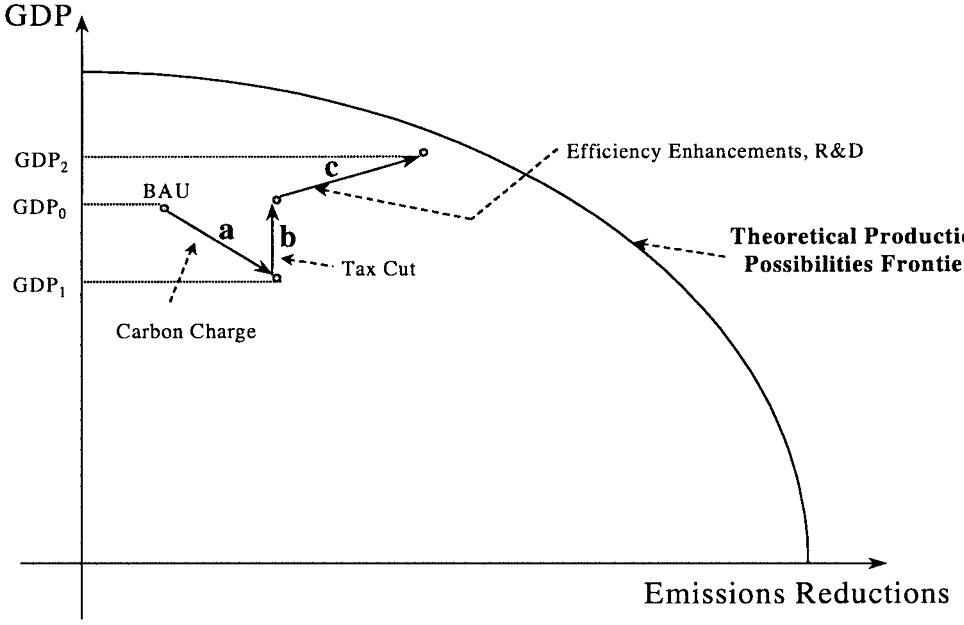
A. Conceptual Framework for Integrating Price and Nonprice Policies

A central task in the integrated analysis of market reforms and price-based instruments is to convert the impacts of market reforms, which are modeled in microeconomic terms, into macroeconomic impacts. This conversion step is done using a methodology originally developed by Sanstad et al. (2000; 2001) for the CEF study. In a fully efficient economy, larger reductions in carbon emissions mean a lower level of economic output or GDP. This trade-off between GDP and emission reductions is a version of the familiar production possibilities frontier. However, because energy and technology markets are characterized by many barriers to complete optimization (IPCC, 2001), the real economy works at less than optimal energy productivity or inside the frontier. The economy produces more carbon emissions than it would were it to function at full technological and economic efficiency—at the frontier.

The basic concept in the CEF methodology is to treat barrier-reducing market reforms as a move *toward* the production possibilities frontier. Economic gains are obtained by increasing energy productivity. As a result, the emission reductions produced by market reforms occur at a net gain in GDP. By contrast, the emission reductions produced by carbon charges are treated as a move *along* the frontier. Here, higher energy prices prompt substitution effects that lead to lower GDP. These substitution effects are measured by the top-down economic models.

Conceptualized this way, the net GDP impact of the combined application of market reforms together with carbon charges is the sum of the productivity gains produced by market reforms and the GDP losses produced by price-induced economic substitution effects. Figure 1 displays this combination of effects schematically. The economy initially is at the business as usual (BAU) point. The vector **a** shows the effect of a carbon charge alone, with the slope and magnitude of the trade-off between emissions reductions and GDP given by the estimates from the top-down models. The loss

FIGURE 1
Schematic Representation of Combined Policies to Reduce Emissions and Increase GDP



of GDP from the carbon charge ($GDP_0 - GDP_1$) is then offset (partially, fully, or more than fully) by the vector **b**, representing the tax shift effect. Vector **c** represents the efficiency enhancements brought about by market reforms and R&D. Provided that the sum of the GDP components of vectors **b** and **c** is greater than the GDP component of vector **a,** the net result (vector sum) of the three effects is a movement in the northeasterly direction from BAU toward the theoretical production-possibilities frontier. GDP increases from GDP_0 to GDP_2 and greenhouse gas emissions are reduced.

In the present analysis this basic approach is expanded to include a total of five components: (1) GDP gains from domestic market reforms, (2) GDP losses triggered by increased final energy prices, (3) GDP gains or offsets of GDP losses from tax shifts, (4) GDP losses from purchasing international emission allowances; and (5) co-control benefits in the area of air pollution and other recognized (and partly regulated) environmental impacts of energy use.

In the CEF methodology, the GDP benefits from market reforms are measured directly by the net savings in the total bill for energy services that these reforms bring about. The change in the total bill for energy services includes all marginal investments and program implementation costs, as well as the dynamic effects of mitigation programs on pretax energy prices and on energy demand. Calculation of substitution losses involves two steps. The first is to translate a given emission reduction requirement into a permit price. The second step is to translate the permit price into a GDP loss from substitution effects. In our analysis, a marginal cost (permit price) curve for emission reductions is constructed from the scenario cases reported in the CEF and EMF-16 studies. The methodology for calculating GDP losses from price-induced economic substitution effects is the same as in the CEF study. Following Sanstad et al. (2000; 2001), we use the EMF-16 simulations of the Kyoto Protocol to calculate a mean GDP response curve based on estimates from seven different models. Relying on the mean EMF results simultaneously addresses two modeling problems. One is the wide variation of results from individual economic models. The other is the paucity of formally integrated top-down/bottom-up models.[8] Given these limitations, the use of the mean EMF results for estimating economic substitution effects is a sensible approximation.

As already discussed, GDP losses from price-induced substitution effects can be categorized into long-term (equilibrium) effects and transient short-term (adjustment) effects. The CGE models compared in EMF-16 are designed to measure equilibrium effects. Neo-Keynesian models such as the one used in EIA (1998a) also estimate adjustment costs. However, the limitations of the neo-Keynesian models are compounded when analyzing market reforms, fiscal reforms, and international trading.

The 10- to 20-year time horizon of the present analysis suggests that the equilibrium computations of potential GDP in the EMF-16 models are a more reliable indicator of energy price impacts than estimates of "actual" GDP that are highly sensitive to uncertain and controversial assumptions about monetary policies and their transitory effects. Furthermore, the prediction of major adjustment costs rests on the assumption that the cost of carbon permits would unavoidably lead to significant inflation and would trigger a growth-reducing monetary policy. This view fails to take into account potential countervailing deflationary effects from no-regrets-oriented market reforms. These include reduced energy prices due to energy efficiency gains leading to lower final energy demand and reductions in the unit cost of energy services going beyond the fuel price effect. Also, modeling features that attempt to capture adjustment costs are relatively less informative when fiscal reforms are part of the analysis than when they are not. Within the wide range of available tax shift options, several can substantially reduce transitory adjustment costs or even turn them into net benefits (strong double dividend). For these reasons, short-term adjustment costs are excluded from our analysis.

Although the CEF study includes an extensive discussion of the cost-reducing benefits of various tax recycling options, its quantitative scenario analysis excludes tax shifts. Instead, GDP losses from price-induced substitution effects are based on a worst-case assumption, that is, lump-sum recycling of revenues. In the present analysis, this assumption is compared to tax shift policies that represent more plausible and economically efficient uses of revenues. We examine a range of assumptions that stretches from a weak double dividend all the way to a strong double dividend but falls far short of fundamental tax code reform.

The CEF analysis covers only domestic abatement of U.S. carbon emissions. The study does not investigate the integration of domestic policies with the international flexibility mechanisms of the Kyoto Protocol. This results in two limitations. First, the level of emissions abatement being achieved in 2010 falls significantly short of the U.S. Kyoto target. Second, the price of carbon assumed in the analysis—$50/tC in the advanced scenario, and $25/tC in a sensitivity case—does not reflect the feedback effects of domestic market reforms on the international price of carbon. In our analysis, emission reductions are extended to the Kyoto level either by raising the domestic carbon charge (domestic least cost strategy) or by purchases of international allowances (international strategy) or both. In either case, tax shifts are also introduced.

The international carbon price is determined using a regionalized model of the global allowance market assuming unrestricted or constrained use of international emissions trading, joint implementation, and clean development mechanisms. As part of this analysis, we estimate the impact of market reforms in Annex II countries on the demand for international allowances.[9] In calculating the GDP effect of U.S. allowance purchases, we also introduce a conservative simplification. Following the practice adopted in the EIA, CEA, and EMF studies, we

8. An early attempt at such formal integration is the Markal-Macro model developed for the Energy Technology Systems Analysis Programme of the International Energy Agency. An integrated least-cost analysis using this model is found in Laitner (1999). An example of a second-generation integrated modeling system is the All Modular Industry Growth Assessment model of Argonne National Laboratory (Hanson and Laitner, 2000).

9. The Annex II group refers to the countries having a financial obligation (including funding of technology transfer) to assist developing countries in meeting the objectives of the UNFCCC. The Annex II group is basically the same as the Annex I group of countries under the UNFCCC minus the countries of Eastern Europe and the former Soviet Union (UNFCCC, 2002).

TABLE 4
Key Results of the CEF Study for 2010

Scenario Case	Total C Emissions U.S. (MtC)	Permit price ($'97/tC)	Emissions Reductions in 2010 All Policies (MtC)	Market Reforms (MtC)	Permit Auction (MtC)	Net Energy Bill Savings ($'97 billion)
BAU	1769	0	0		0	0.0
BAU25	1720	25	49		49	1.8
BAU50	1663	50	106		106	−2.6
BAU100	1551	100	218		218	−11.8
Advanced 0	1620	0	149	149	0	54.4
ADV25	1540	25	229	149	80	53.6
ADV50	1467	50	302	149	154	48.1

treat the entire expenditure for allowances as a GDP loss. In reality, some of this cost will flow back to the national economy through increased exports to the sellers of allowances. This partial offset from secondary trade effects is omitted in both the mentioned studies and in our calculations.

The CEF study (IWG, 2000) includes a qualitative discussion of a variety of cobenefits of emission reduction measures. It also provides physical quantity estimates for reductions in emissions of sulfur dioxide and nitrogen oxides. However, no monetized value of these emission reductions is provided. Estimates of the monetized cobenefits of carbon mitigation are available from a large body of literature (IPCC, 2001). The reported figures reflect considerable ranges of uncertainty, but they all support the notion that the least accurate assumption is to neglect these benefits. The estimate that will be used here is the midpoint of the $8–$67/tC ranges developed for the specific conditions of the United States by Abt and Pechan-Avanti (1999) and by Boyd et al. (1995). This estimate of $37.5/tC (in 1997 dollars) excludes monetized estimates of the benefits of mitigating climate change. Monetized externalities other than classical environmental impacts, such as those related to oil dependence and energy security, are also excluded. The inclusion of monetized externality benefits requires an expanded definition of the metric of our economic analysis because reduced externalities may not register as changes in GDP per se. We therefore refer to the combined GDP and monetized externality changes as the economic welfare impact, or simply as the net economic impact, of the scenarios.

B. *Point of Departure: The CEF Study*

At this time, the CEF study is the most comprehensive government-sponsored assessment of domestic opportunities for cutting U.S. carbon emissions through market reforms and technology programs (IWG, 2000). This study incorporates the accumulated experience, high technical competence, and professional standards of the U.S. national laboratories.

A summary of modeling results for several key scenario cases of the CEF study is given in Table 4. More detailed discussions of the CEF scenarios and their implications for U.S. energy policy challenges are found in International Project for Sustainable Energy Paths (IPSEP, 2001a, 2001b). Our analysis starts with the advanced scenario of the CEF study. In this scenario, reductions in U.S. carbon emissions are pursued through a combination of market reforms and technology programs (nonprice policies) and a domestic permit trading scheme in which permits are auctioned off by the U.S. government. The permit auction price is capped at $50/tC.

In Table 4, we also show two sensitivity cases of the advanced scenario. One assumes only nonprice policies (zero carbon charge), the other examines a lower carbon charge of $25/tC. These cases are the basis for calculating how net energy bill savings vary with the level of the carbon charge. Also, Table 4 shows sensitivity runs in which no market reforms and technology programs are assumed while the permit price is $25, $50, and $100/tC, respectively.[10] These data points show not only that market reforms generate major emission reductions but also that price signals are more effective and produce larger emission reductions when applied in conjunction with no-regrets energy efficiency policies and technology programs.

The market reform and technology programs of the advanced scenario are discussed in detail in IWG (2000). The assumptions on policy effectiveness in the CEF study are conservative when compared to other analyses. Only a fraction of annual investments in end-use technologies is shifted to best cost-effective levels of energy efficiency. This conservatism is reflected in the fact that market reforms in the CEF advanced scenario contribute less than a third of the Kyoto emission reduction commitments. Other studies using the same modeling approach find that market reforms and technology programs could achieve most or all of the U.S. Kyoto commitments while still following normal capital stock turnover cycles (Tellus, 1998; Tellus/SEI, 1999).

The baseline scenario for the CEF study is the Annual Energy Outlook 1999 Reference case of the U.S. EIA (1998b). Projections of energy use and carbon emissions account only for policies in effect as of mid-1998. In the CEF study, this baseline was amended to reflect scheduled updates of energy efficiency standards and steady funding levels for energy technology programs.

The CEF market reform policies lead to reductions in emissions due to increased energy productivity and greater use of low-carbon and carbon-free energy sources. The reduction in demand for fossil fuels, in turn, leads to lower energy prices than in the BAU baseline. This feedback effect is captured by the energy sector model and is incorporated into the net energy bill savings. However, energy price reductions from reduced demand are more than offset by the carbon charge arising from the $50/tC permit price. After-tax energy prices are somewhat more expensive (heating oil and gas) or significantly more expensive (coal) than in the base case. Motor gasoline prices increase by 30%, chiefly on account of pay-as-you-drive insurance.

Relative to official baseline projections of rising primary energy consumption, total fossil fuel use declines by 14% in 2010 and by 25% in 2020. Coal use declines the most, due to a shift to gas and other energy carriers especially in the power sector. The contribution of renewable energy sources grows significantly. The United States realizes 58% of its Kyoto target in 2010 and 84% by 2020.[11] Relative to the BAU case, carbon emissions decline by 17% in 2010. These reductions bring with them significant side benefits for clean air. BAU emissions of nitrogen oxides are cut by 27% in 2010, and sulfur dioxide emissions are reduced significantly below projections in subsequent years.

VI. LEAST-COST DOMESTIC IMPLEMENTATION OF THE U.S. KYOTO TARGET

To arrive at a least-cost assessment of the U.S. Kyoto target, we first replicate the emission reduction level achieved in the CEF advanced scenario while incorporating tax shifts. We then extend the CEF analysis to the full implementation of the U.S. Kyoto target.

A. Partial Domestic Implementation of the Kyoto Target

Table 5 shows a step-by-step transformation of the CEF analysis into a domestic least-cost scenario that includes several levels of tax shifts. The upper portion of the table shows the evolution of carbon emissions, beginning with the BAU growth of emissions between 1990 and 2010. The policy variants shown in each column all match 2010 emission reductions being achieved in the CEF advanced scenario. Reductions are disaggregated into those resulting from non-price policies, and those resulting from the $50/tC charge.

10. These sensitivity runs are not presented in the CEF technical report but are available online at http://enduse.lbl.gov/projects/cef.html (with slight differences from Table 4 due to updating).

11. The implementation fraction of the Kyoto target rises from 58% to 63% in 2010 when including additional reductions from cogeneration that are identified in the CEF report (IWG 2000). These were not included in the tabulated scenario runs and are also excluded from our analysis.

TABLE 5
GDP and Welfare Impacts of Implementing 58% of the U.S. Kyoto Target in 2010: Domestic Action

		BAU	**EMF Mean**	**CEF Scenario**	**Least-Cost CEF Scenario**		
Market reforms			No	Yes	Yes	Yes	Yes
Carbon price ('97$)	$/tC	No C tax	134	50	50	50	50
Revenue recycling			Lump sum	Lump sum	Tax shifts	Tax shifts	Tax shifts
Offset of GDP losses caused by C charge	fraction				0.50	1.00	1.5
Emissions							
Baseline U.S. emissions in 2010	MtC/yr	1769					
Emission reductions from market reforms	MtC/yr			−149	−149	−149	−149
Emission reductions from C charge	MtC/yr		−302	−153	−153	−153	−153
Intl. allowance purchases to match CEF baseline	MtC/yr						
Remaining domestic C emissions in 2010	MtC/yr		1467	1467	1467	1467	1467
GDP and welfare							
Net energy service bill savings in 2010	$ billion/yr			48	48	48	48
GDP losses from substitution effects of C charge	$ billion/yr		−88	−36	−36	−36	−36
GDP benefits from C tax shift reforms	$ billion/yr				18	36	54
Domestic co-control benefits	$ billion/yr		11	11	11	11	11
Purchase of international allowances	$ billion/yr						
Net economic impact in 2010	$ billion/yr		−76	24	41	59	77

The bottom half of the table shows the net economic impact of alternative domestic policy packages. In the first column, based on the EMF-16 studies, a carbon charge is applied alone, and neither market reforms nor tax shifts are included. The permit price needed to cut emissions by the same amount as in the advanced scenario (302 MtC) is $134/tC.[12]

We next translate this carbon charge into a price-induced economic substitution effect. For this calculation, we use the mean GDP response from the EMF-16 multimodel comparison. This yields a GDP loss of $88 billion/year in 2010, equivalent to about 0.8% of projected GDP. After accounting for the $11 billion clean air benefits of domestic carbon mitigation, the net welfare impact is a loss of $(-88+11) = -\$76$ billion (including rounding effect).

The next column shows the CEF advanced scenario without tax shifts, as analyzed in the interlaboratory study. Here, market reforms create a GDP gain of $48 billion from savings in energy service bills (net savings after accounting for investment and program costs and changes in energy costs excluding costs for permits). In the CEF study, this gain is diminished by the substitution effects of the $50/tC charge, which result in a GDP loss of $36 billion/year. Because tax shift policies are not included in the CEF scenario, this economic substitution effect is not offset. After accounting for environmental cobenefits, the net economic impact is $(48 - 36 + 11) =$ $24 billion/year in 2010 (including rounding effect). This economic gain is about twice the figure reported in the CEF study, which did not include monetized clean air cobenefits.

The next three columns show the effect of including tax shift reforms. At the low end, tax shifts offset 50% of the GDP losses from economic substitution effects (offset ratio 0.5). This weak double dividend is similar to that assumed in the Kyoto analysis of the U.S. EIA (1998a). At the high end, tax shifts generate a positive effect that is 150% of the

12. This calculation is based on the mean carbon price response curve of the EMF-16 models for the "no trading" scenario.

GDP losses in the lump-sum case (offset ratio 1.5). This strong double dividend is assumed to be achieved by emphasizing reductions of taxes on capital and investments.[13] In an intermediate case, the offset ratio is 1.0.

Table 5 thus illustrates the central significance of tax shift reforms in assessing domestic mitigation strategies. On a net basis, the domestic least-cost policy package of tax shifts plus market reforms creates an economic welfare benefit of about $40–80 billion/year, with a midpoint of about $60 billion/year. Although energy-productivity–oriented market reforms can overcompensate GDP losses from substitution effects and create positive net impacts by themselves, tax restructuring tips the balance decisively toward significant net economic benefits.

In the further representations of GDP impacts, we assume that the GDP benefits of tax shifts just offset the GDP losses from energy price effects (offset ratio 1.0). This corresponds to a midpoint between a weak double dividend and a strong double dividend. For this midpoint, which leaves significant flexibility in the design of tax shifts, the net GDP impact is equal to the energy bill savings produced by market reform programs plus the air pollution control cobenefits.

B. Full Domestic Implementation of the Kyoto Target

Table 6 shows the effect of extending the CEF scenario to the full implementation of the U.S. Kyoto target. The reference point is again a purely domestic strategy consisting of a carbon tax or cap-and-trade permit auction system with lump-sum recycling and no market reforms. To generate the required carbon emission reductions in 2010 using the EMF-16 mean results, a permit price of $230/tC is required (1997 dollars). The GDP impact in 2010 for this permit price is a loss of $133 billion/year. After accounting for clean air cobenefits of $19 billion/year, the total economic loss is $(-133+19) = -\$113$ billion/year (including rounding effect).

Now we introduce the domestic market reforms of the CEF scenario. These programs yield emission reductions of 149 MtC. The additional reductions of 153 MtC brought about by the $50/tC permit price are insufficient to reach the Kyoto target. To close the gap, the permit price must rise to $136/tC (Table 4).[14] The higher price reduces net energy bill savings, which are now only $29 billion/year.[15] At the same time, the higher permit price results in larger GDP losses from substitution effects. Again making use of the EMF-16 mean results, GDP losses rise to $88 billion/year. After accounting for environmental cobenefits, the net economic impact is $\$(29-88+19) = -\$40$ billion/year.

When tax shifts are added to this extended CEF policy case, the economic substitution effect is compensated (offset ratio 1.0). The economic losses shown in the previous column are converted into a $48 billion/year gain, equivalent to +0.4% of GDP.

The total benefit of moving from a domestic tax with lump-sum recycling (which produces a loss of $113 billion/year in 2010) to a least-cost mix of domestic market and fiscal reforms (which produces a gain of $48 billion/year) thus is $\$(48+113) =$ $162 billion/year (including rounding effect). International trading schemes must be measured against this figure.

C. Extension of the Kyoto Target to 2020

To capture the dynamics of capital stock turnover, the CEF study examines emission reductions all the way to 2020. During the second decade of the century, BAU projections of carbon emissions continue to grow, albeit at a slower pace. Emissions are 1922 MtC in 2020, compared with 1767 MtC in 2010 and 1346 MtC in 1997. Maintaining the Kyoto limit in 2020 requires emission

13. An offset ratio of 1.5 is based on a conservative application of findings from various analyses of strong double dividend tax recycling (Shackleton et al., 1992; Jorgenson and Wilcoxen, 1993; Hammond et al., 1997; Norland et al., 1998; Parry and Bento, 2000; Sanstad et al., 2000).

14. This figure is calculated from the emission reduction response curve of the CEF model as defined by the CEF sensitivity cases involving only a $25, $50, and $100/tC permit price (no market reforms). For the high range, the quadratic fit makes use of the zero point and the Annex I trading and no trading cases of the EMF-16 study. For low values, the global trading and Annex I trading cases are used.

15. This figure is derived using a quadratic fit of three data points provided by the net energy bill savings of the $Adv+0$, $Adv+\$25$, and $Adv+\$50$ cases of the CEF advanced scenario.

TABLE 6
Economics of Fully Implementing the U.S. Kyoto Target in 2010: Domestic Action

			Domestic Mitigation Strategies		
		BAU	**EMF Mean**	**CEF Extended Scenario**	
Market reforms			No	Yes	Yes
Carbon price ('97$)	$/tC		230	136	136
Revenue recycling			Lump sum	Lump sum	Tax shifts
Offset of GDP losses caused by C charge	fraction				1.00
Emissions					
Baseline U.S. emissions in 2010	MtC/yr	1769			
Emission reductions from market reforms	MtC/yr			−149	−149
Domestic permit auction	MtC/yr		−517	−369	−369
Remaining domestic C emissions in 2010	MtC/yr		1252	1252	1252
GDP and welfare					
Net energy service bill savings in 2010	$ billion/yr			29	29
GDP losses from substitution effects of C charge	$ billion/yr		−133	−88	−88
GDP benefits from C tax shift reforms	$ billion/yr				88
Domestic co-control benefits	$ billion/yr		19	19	19
Purchase of international allowances	$ billion/yr				
Net economic impact in 2010	$ billion/yr		−113	−40	48

reductions of 670 MtC relative to the BAU projection.

The continued application of market reforms together with the $50/tC charge from permit auctions result in emission reductions of 565 MtC. Despite continued growth in the economy, absolute emissions decline significantly below the 2010 level, ending up within 1% of their 1990 level. Clean air benefits also grow. BAU projections of emission levels in 2020 are cut in half for sulfur dioxide and by 43% for nitrogen oxides.

In the CEF advanced scenario, net energy bill savings grow from $48 billion/year in 2010 to $108 billion in 2020. This more than doubling of savings substantially outpaces the rate of growth in GDP, which rises by 18% in real terms, from $11,123 billion in 2010 to $13,128 billion in 2020. By 2020, the carbon/GDP ratio of the U.S. economy is a third lower than in 2010 and less than half the value in the 1990 base year.[16] These figures indicate that the penetration of cost-saving low-carbon technologies is far from complete in 2010. The ramp-up times for policy programs and the limits of capital stock turnover up to 2010 delay most policy effects to the 2010–2020 period. As in 2010, the response of emissions to higher carbon prices is significantly more elastic when accompanied by market reforms than when applied alone.

If EMF modeling results for 2020 were available, it would be possible to compute GDP response curves, and the CEF results on net energy bill savings in 2020 could be translated into aggregate economic impacts using the same techniques as in the analysis for 2010. Even without EMF estimates for 2020, a good indication can be obtained on the basis of qualitative considerations and simplified limiting cases.

Several qualitative relationships indicate that even within a purely domestic mitigation strategy, the GDP losses to the U.S. economy from substitution effects will be significantly lower in 2020 than in 2010. First, the results of the CEF study show that any given carbon price produces larger emission reductions in 2020 than in 2010, both in relative and absolute terms. Second, the CEF modeling analysis shows that in a domestic strategy that combines permit auctions and market reforms, a much smaller carbon price is needed to reach the full Kyoto target in 2020 than in 2010: $65/tC in 2020 (Table 7) versus $136/tC in 2010 (Table 6). At the same time, top-down modeling research suggests that a given carbon price has a relatively smaller impact on GDP in 2020 than in 2010 (Wigley et al., 1996). In combination, these

16. Indeed, while GDP continues to grow, net energy bills (in real 1997 dollars) peak in 2007 at $637 billion and then decline continuously until 2020 (IWG, 2000).

TABLE 7
Economic Impacts of the CEF Advanced Scenario for 2020: Domestic Least-Cost Strategies

		BAU	CEF 2020	CEF Extended 2020	
Level of emission reductions			1990 + 1%	1990 − 7%	1990 − 20%
Market reforms			Yes	Yes	Yes
Carbon price ('97$)	$/tC		50	65	77
Revenue recycling			Tax shifts	Tax shifts	Tax shifts
Offset of GDP losses caused by C charge	fraction		1.00	1.00	1.00
Emissions					
Baseline U.S. emissions in 2020	MtC/yr	1922			
Emission reductions from market reforms	MtC/yr		−350	−350	−350
Emission reductions from C charge	MtC/yr		−215	−320	−495
International allowance purchases	MtC/yr				
Remaining domestic C emissions in 2020	MtC/yr	1922	1357	1252	1077
GDP and welfare					
Net energy service bill savings in 2020	$ billion/yr		108	98	92
GDP losses from substitution effects of C charge	$ billion/yr		$-x$	$-x$	$-x$
GDP benefits from C tax shift reforms	$ billion/yr		x	x	x
Domestic cocontrol benefits	$ billion/yr		21	25	28
Purchase of international allowances	$ billion/yr				
Net economic impact in 2020	$ billion/yr		129	123	120

two factors mean that percentage GDP losses from substitution effects are likely to be less than half as large as those in 2010. Substitution losses in 2020 can be expected to remain substantially lower in absolute terms, even after taking into account the roughly 20% growth in projected GDP over the course of the decade. Finally, if the Kyoto target is maintained after 2010, revenues from permit auctions or carbon taxes will be lower by more than half in 2020 than in 2010. The magnitude of revenues relative to (growing) GDP will decline even more, by 60%.[17] This means that all else being equal, any given level of offsets from tax shifts should be relatively more easily achievable in 2020 than in 2010.

These qualitative considerations are translated into a quantitative analysis in Table 7. The table shows three versions of a domestic least-cost mitigation strategy. In each of them, the CEF market reforms and the domestic permit auction are supplemented by tax shifts with an offset ratio of 1.0. With this assumption, exact data on the GDP response to permit prices are not needed because economic substitution effects ($-x$) are just canceled by tax shift gains (x). Because the two terms cancel, it is not necessary to calculate the substitution effect. The net GDP effect is equal to the net energy bill savings plus the air pollution cocontrol benefits.

We examine three levels of emission reductions. In the first case, we replicate the CEF advanced scenario, which is equivalent to 1990 levels plus 1%. In this case, the carbon charge is $50/tC. In the second case, we extend the CEF results to the Kyoto target level (1990 minus 7%). In the third case, we explore a more progressive target of 1990 minus 20% in acknowledgment of the fact that climate stabilization will require much larger fossil carbon emissions in coming decades (IPCC, 1996, 2001).

Ancillary benefits of mitigation up to 517 MtC (implied by the Kyoto target in 2010) are assumed to have the same monetized value in 2020 as in 2010. This approximation is plausible insofar as both BAU sulfur dioxide and nitrogen oxide emissions remain flat between 2010 and 2020 (IWG, 2000). Second, tighter clean air standards that extend to mercury and to particulate matter are under way and are assumed in the CEF advanced scenario, and these will increase the value of ancillary reductions in classical

17. For any given carbon price, the permit revenue is determined by remaining emissions after mitigation measures have been implemented. This emission level would be constant at about 1,250 MtC/yr (1990 minus 7%) for both 2010 and 2020. Tables 6 and 7 indicate a 54% decline in the needed carbon price between 2010 and 2020. After accounting for the 18% growth in GDP, the relative magnitude of revenues is lower by about 60%.

emissions relative to the estimates used in the present analysis. However, we account for the diminishing value of marginal emission reductions at higher levels of carbon mitigation in stylized fashion: We assume that ancillary benefits for emission reductions beyond the 517 MtC level will decline in proportion to the ratio of 2010 and 2020 reductions.

The CEF scenario for 2020 then yields net energy bill savings of $108 billion/year, plus clean air cobenefits of $21 billion, for a total net benefit of $\$(108 - x + x + 21) = \$129$ billion/year. When this scenario is extended to the Kyoto target level, a 30% higher carbon charge of $65/tC is needed. This reduces net energy bill savings to $98 billion, more than ancillary benefits are increased due to greater emission reductions. The net result is an economic benefit of $(\$98 + 25) = \$123$ billion/year. When emissions are further reduced to the 1990 minus 20% level, economic gains are reduced to $120 billion. As the carbon charge rises another 18% to $77/tC, reductions in net energy bill savings again somewhat exceed gains in ancillary benefits.

These bottom-line results are equivalent to a gain of 0.9% of projected 2020 GDP. This benefit is significantly larger than the gains realized with the same strategy in 2010. The more than doubling of net benefits is explained by the fact that money-saving productivity investments are continuing to penetrate the capital stock in the period between 2010 and 2020. In cumulative terms, the net present value of economic benefits between 2013 and 2020 is more than $350 billion. Despite the effect of discounting, this gain is larger in net present value terms than the cumulative gains in the 2005–2012 period. Total cumulative net present value benefits between 2005 and 2020 are more than $600 billion.[18]

VII. NEGOTIATING ISSUES: FLEXIBILITY, SINKS, AND SUPPLEMENTARITY

During the negotiations at The Hague and earlier, the United States justified its insistence on including sinks and its opposition to supplementarity constraints on the basis of claims that these approaches would bring large reductions in mitigation costs for the United States and other parties. Wigley et al. (1996) argued that mitigation costs for the United States and other Annex II countries could be significantly lowered by postponing major emission reductions and by making use of extensive international allowance trading. The studies of the EMF (1999) and of the CEA (1998) strongly echoed this conclusion. On the basis of these and other studies, many policy makers believe that flexibility would result both in large percentage reductions of mitigation costs—of the order of 50–85%—and in large absolute cost savings, measured in tens or hundreds of billions of dollars per year for the United States alone.

However, these beliefs are based on comparisons with suboptimal domestic policies that exclude market and fiscal reforms. As a result, the benefits of international trading and the other flexibility mechanisms are grossly overstated. The true marginal benefit of global trading must be calculated in a least-cost context, that is, when trading and market and fiscal reforms are applied in combination. In calculating the incremental cost reduction impact of global trading, domestic market and fiscal reform policies need to be applied first because they yield the larger cost reductions and realize some emission reductions at negative net cost. As the marginal policy, international trading merely enhances the net economic gains obtainable from a purely domestic no-regrets strategy.

A. *The Marginal Benefits of International Allowance Trading*

The role of international trading in fully implementing the Kyoto Protocol in 2010 is shown in Table 8. These calculations involve two new steps: the derivation of an international allowance price (which, in the absence of constraints on flexibility, also determines the domestic permit price), and the apportionment of emission reductions between price-induced domestic action and international allowance purchases.

In the absence of market reforms, the international allowance price can be directly obtained from the EMF-16 analysis, which includes modeling of the global allowance markets. The level of domestic emission

18. Based on a real discount rate of 5%. Cumulative economic impacts are calculated by scaling the relationship of annual net energy bill savings and cumulative net energy bill savings.

TABLE 8
Economic Impacts in 2010 of Fully Implementing the U.S. Kyoto Target: International Strategies

				International Mitigation Strategies		
		BAU	Domestic EMF Mean	EMF Mean w Trading		CEF Extended Scenario
Market reforms			No	No	No	Yes
International carbon price ('97$)	$/tC			41	41	11
Domestic permit price ('97$)	$/tC		230	41	41	11
Revenue recycling			Lump sum	Lump sum	Tax shifts	Tax Shifts
Offset of GDP losses caused by C charge	fraction				1.00	1.00
Emissions						
Baseline U.S. emissions in 2010	MtC/yr	1769				
Emission reductions from market reforms	MtC/yr					−149
Total reductions from permit purchases	MtC/yr			−517	−517	−369
Domestic permit auction	MtC/yr		−517	−91	−91	−36
International allowance purchases	MtC/yr			−426	−426	−332
Remaining domestic C emissions in 2010	MtC/yr		1252	1678	1678	1584
GDP and welfare						
Net energy service bill savings in 2010	$ billion/yr					54
GDP losses from substitution effects of C charge	$ billion/yr		−133	−25	−25	−6
GDP benefits from C tax shift reforms	$ billion/yr				25	6
Domestic cocontrol benefits	$ billion/yr		19	3	3	7
Purchase of international allowances	$ billion/yr			−17	−17	−4
Net economic impact in 2010	$ billion/yr		−113	−39	−14	57

reductions induced by this international carbon price can be calculated from the same data. When domestic market reforms are included, the EMF-16 calculations can no longer be used. Domestic no regrets action in the United States would in all likelihood be accompanied by similar action in other Annex II countries. Such action would have the effect of removing a portion of total international demand for allowances: The economics of domestically profitable emission reductions cannot be improved through international trading.

To complete the analysis, we estimate the total no-regrets emission reductions in the Annex II region. We then calculate the corresponding world price of carbon using a simplified version of one of the EMF-16 models (see later discussion for further details). To simulate the effective removal of no-regrets emission reductions from the international allowance market, we add these reductions to the Kyoto Protocol's assigned amounts for the Annex II region. For purposes of easy reference, the first column in Table 8 repeats the impact of a purely tax-based domestic strategy without tax shifts as developed in Table 6, that is, a permit price of $230/tC and a net GDP change (loss) of −$113 billion/year in 2010.

The second column shows the results for unrestricted global allowance trading, excluding domestic market reforms or tax shifts. For this scenario, the EMF-16 models yield a mean permit price of $41/tC (in 1997 dollars). At this permit price, 91 MtC are abated domestically, and $(517 - 91) = 426$ MtC are supplied through international allowances, an 82% contribution. The greatly reduced permit price under global trading leads to a much smaller GDP change from economic substitution effects (−$25 billion/year). The price-induced economic substitution effect is diminished by $\$(133 - 25) = \$108$ billion/year (that is, the GDP loss due to the substitution effect is $108 smaller than in the no-trading case). At the same time, however, new costs arise for purchases of international allowances (−$17 billion) and in the form of forgone environmental cobenefits of domestic emission abatement (−$16 billion), leaving only a small clean air cobenefit of $3 billion. The net result is an economic loss of $\$(-25 - 17 + 3) = -\$39$ billion/year in 2010. When tax shifts are added in the next column, these losses are at least cut in half (offset fraction 0.5) and may be more than compensated (offset fraction 1.5). For our midpoint estimate (offset fraction 1.0), the net economic impact becomes a loss of −$14 billion/year in 2010.[19]

The last column in Table 8 shows the joint application of market reforms, tax shifts, and unrestricted international allowance trading. The market reforms and technology programs have the effect of reducing U.S. carbon emissions by 149 MtC in 2010. As a result, the amount of emission reductions that could potentially be supplied through international allowance purchases shrinks to $(517 - 149) =$ 369 MtC (including rounding effect). For the European Union, our estimate of the reduction in emissions from market reforms is based on a recent detailed analysis similar to the CEF study (IPSEP, 2000; see also IPSEP, 2001a). We estimate that on a weighted average basis, about 44% of the combined U.S. and EU targets can be supplied by profitable nonprice policies. This percentage is then extrapolated to Japan and the other countries in the rest of the Annex II group. In total, we estimate that about 500 MtC of demand will be removed from the international allowance market.

To calculate the international allowance price at this reduced level of demand, we use a version of the MIT Emissions Prediction and Policy Analysis model developed by Haites (2000). This model is one of seven used in the Kyoto assessment of EMF-16, and it produces midrange estimates for international carbon prices.[20] The MIT/Haites model is a geographically aggregated version specially designed for the broad analysis of sinks, supplementarity constraints, and other issues related to the flexibility mechanisms of the Kyoto Protocol.

Application of the MIT/Haites model shows that with domestic no regrets action in Annex II countries as estimated above, the global demand for allowances sinks to a level where most of it can be met by hot air allowances from the former Soviet Union, with only a secondary role for the clean development mechanism or joint implementation. Because hot air allowances have effectively a zero net cost, their dominance in the supply of allowances dramatically lowers the international permit price from $41/tC in the EMF-16 global trading scenario to $5/tC for the CEF/Kyoto scenario.

With an allowance price of $5/tC, price-induced domestic carbon reductions in the United States become very small. Only 17 MtC are supplied domestically, and 352 MtC are delivered through international purchases. This contribution from international trading amounts to 68% of the U.S. Kyoto target. Net energy bill savings for this case are $54 billion/year. Economic substitution effects, at $6 billion/year, are minimal, and are again assumed to be offset by tax shifts. Clean air cobenefits are only $7 billion, due to the lesser contribution of domestic emission reductions. However, the cost of international allowance purchases is reduced to $4 billion. Here, our analysis shows that the larger financial outflows from such purchases found using the EMF-16 results and in the Kyoto Protocol assessment of the U.S. EIA (1998a) are an artifact produced by the omission of market reforms. The net result is an economic gain of $\$(54 - 6 + 6 + 7 - 4) =$ $57 billion/year.

These calculations show that the incremental contribution of international trading is small. Table 9 collects results from our calculations for 2010 in Tables 6 and 8. The reference point is the cost impact of a purely domestic carbon tax or cap-and-trade permit auction strategy that excludes fiscal and market reforms. This approach would require a

19. In these calculations, the multiplication of the substitution losses with fixed offset fractions for both domestic and international trading scenarios is an approximation of two countervailing effects. On the one hand, international trading reduces the auction revenues collected by the U.S. government in proportion to the significant decline in allowance prices. GDP offsets from tax shifts would reasonably decline the same way, that is, they would be limited to 50%, 100%, or 150% of the declining flow of auction revenues. A side calculation shows that this approach to calculating available GDP offsets would produce somewhat (20–30%) lower values than those shown in Table 5. On the other hand, when the total volume of revenue available for tax shifts is dramatically lower, relatively larger offsets can be produced for each recycling strategy, because a greater fraction of the existing taxes being displaced will stem from taxes with the highest relative deadweight losses. Our simplified method of analysis in a later table assumes that these two effects will approximately cancel or that tax shifts will be adjusted somewhat to produce the indicated net offset.

20. In the standardized global trading case of EMF-16, this model produced international allowance prices that are close to the mean of the EMF-16 models: $36/tC for unconstrained global trading (Haites, 2000), compared to $41/tC for the average model (Weyant and Hill, 1999; see also Table 7).

TABLE 9
The Marginal Benefit of Global Allowance Trading for the U.S. Economy

		EMF-16	CEF/Kyoto Scenarios	
		Mean	**Domestic**	**International**
Market reforms		No	Yes	Yes
Carbon price in 2010 ('97$)	$/tC	230	136	11
Revenue recycling		Lump sum	Tax shift	Tax shift
Offset of GDP losses caused by C charge	fraction		1.0	1.0
Global allowance trading		No	No	Yes
Net economic impact 2010	$ billion/yr	−113	48	57
Savings from domestic least cost strategy	$ billion/yr		162	
Marginal savings from global trading	$ billion/yr			9
Percent (domestic least cost savings = 100%)				5.5

carbon tax of $230/tC and would result in economic losses of $113 billion/year in 2010.

When domestic market reforms are added to this scenario, the required carbon charge to reach the Kyoto target is lowered to $136/tC. The shift to this domestic least-cost policy mix results in a net economic gain of $48 billion/year. Global trading brings only a small marginal gain: benefits of $48 billion/year from a purely domestic least-cost strategy are increased to $57 billion/year. Total savings relative to the EMF no-trading case are $(48 + 113) = $162 billion/year (including rounding effect). The marginal gain from international emissions trading is $9 billion/year. This is only 5.5% of the gain already obtained by moving from the domestic tax without fiscal and market reforms to the domestic strategy including such reforms. The claim of large percentage savings from global emissions trading thus turns out to be an illusion produced by the neglect of domestic market and fiscal reforms in conventional modeling studies.

The results so far rely on the mean of the EMF-16 modeling results for the economic substitution effect, and they assume midpoint estimates for cobenefits and for offsets from tax shifts. Because the sensitivity of GDP losses to carbon prices varies by a factor of four among the seven EMF-16 models, it is worthwhile to examine the uncertainty range when using worst-case and best-case models. We also vary assumptions on carbon reductions and energy bill savings from market reforms, using the CEF analysis as a midpoint. We develop these ranges for both a domestic and an international least cost strategy.

For the worst case, we adopt the EMF-16 model that realizes the U.S. Kyoto target with the highest GDP losses per dollar of carbon tax in the no-trading case. We also use an offset ratio of only 0.5 for tax shifts. Emission reductions from market reforms are reduced by a third, to only 100 MtC, with a proportional decline in net energy bill savings. The lower contribution from no-regrets options also increases the domestic and international permit price. In the domestic case, it rises from $136/tC to $158/tC. In the international case, it increases from $11/tC to $18/tC. These higher permit prices further reduce net energy bill savings while increasing economic substitution losses. For cobenefits, we assume the low end of the range of estimates (i.e., $8/tC instead of $37.5/tC).

For the best case, we adopt the EMF model that realizes the U.S. Kyoto target with the lowest GDP losses per dollar of carbon tax in the no-trading case. We also use an offset ratio of 1.5 for tax shifts, and the higher end of the range of cobenefit estimates (i.e., $67/tC instead of $37.5/tC). Market reforms contribute a third more, with a proportional increase in net energy bill savings.[21] The higher contribution from

21. In the CEF scenarios, significant further increases in the penetration of energy efficiency technologies are feasible. In many applications, less than a third of annual replacements and expansions of energy-using equipment are shifted to higher energy efficiency levels. As this fraction is increased, some program administration costs may rise, but because these are only a minor fraction of the levelized cost of saved energy, and because larger energy savings generate favorable energy price effects, total net

TABLE 10
Sensitivity Analysis: Worst-Case and Best-Case Impacts on the U.S. Economy in 2010

		CEF/Kyoto Scenarios for 2010			
		Domestic strategy		International strategy	
		Worst	Best	Worst	Best
Market reforms	$/tC	Yes	Yes	Yes	Yes
Permit price ('97$)	$/tC	158	114	18	5
Revenue recycling		Tax shifts	Tax shifts	Tax shifts	Tax shifts
Offset of GDP losses caused by C charge	fraction	0.5	1.5	0.5	1.5
GDP and welfare					
Net energy service bill savings in 2010	$ billion/yr	16	46	36	73
GDP losses from substitution effects of C charge	$ billion/yr	−172	−39	−28	−3
GDP benefits from C tax shift reforms	$ billion/yr	86	59	14	4
Domestic cocontrol benefits	$ billion/yr	4	35	1	15
Purchase of international allowances	$ billion/yr			−6	−2
Net economic impact in 2010	$ billion/yr	−66	100	17	87

no-regrets options also decreases the domestic permit price from $136/tC to $114/tC. In the international strategy, the global allowance price is reduced to $5/tC. These lower permit prices further increase net energy bill savings while decreasing economic substitution losses.

The sensitivity ranges for the domestic and international strategies in Table 10 lead to two important observations. First, international trading narrows the uncertainty range by more than half, from $(100+66)=$ $166 billion in the domestic strategy to $(87-17)=$ $70 billion in the international trading case. Second, although the domestic uncertainty band stretches from significantly negative to significantly positive results, international trading shifts the range of economic outcomes entirely into positive territory. Thus, although international allowance trading offers only a small gain relative to domestic market and fiscal reforms of midpoint effectiveness, trading does provide a certain amount of insurance against domestic policy problems. It makes the impact of the Kyoto treaty robustly positive for the U.S. economy, for a wide range of outcomes from domestic policy reforms.

energy bill savings are assumed to increase proportionately. Further no-regrets increases in emission reductions can be obtained by including some or all of the additional cogeneration resources analyzed in the CEF study but not included in the formal scenario runs. These are estimated to reduce year 2010 emissions by 26 MtC.

B. The Marginal Value of Credits for Sinks and Supplementarity Constraints

The same kind of result carries through when the marginal value of credits for sinks or the benefits of relaxing the supplementarity constraints of the protocol are calculated. Once the full domestic implementation of efficiency enhancement, a carbon price signal, and intelligent revenue recycling is accounted for, the additional cost reductions that can be achieved by enhancing sinks or relaxing supplementarity constraints are small or nonexistent. The details of these calculations are available elsewhere (IPSEP, 2001c) and are not reported here because of space limitations. What differences exist are in the +1% to −2% range relative to the overall savings that are realized in the flexibility with no regrets scenarios. The deal-breaking insistence by U.S. negotiators on the importance of the flexibility mechanisms was misplaced; it rested on modeling analyses that omitted key domestic policy options for generating net economic gains.

VIII. CONCLUSIONS

Successive U.S. administrations have labored under the misconception that greenhouse gas emission reductions would unavoidably result in significant economic losses for the United States. During the Clinton administration, U.S. negotiators sought to reduce these perceived costs by focusing on the Kyoto flexibility mechanisms and on credits for sinks. The Bush administration used the perception of significant costs to justify its outright rejection of the Kyoto treaty.

In support of their policy actions, both administrations cited certain key economic modeling studies. An in-depth review of these studies shows them to be analytically deficient and incomplete. Each of them omitted one or several major cost-reducing policy options, in particular those based on domestic market, institutional, and fiscal reforms.

When these shortcomings are corrected, the conventional perception of U.S. mitigation costs and climate policy options is turned upside down. Instead of harming the economy, the U.S. could meet the emission reduction targets set forth in the Kyoto Protocol by 2010—and exceed them by 2020—while increasing economic output from baseline growth projections. In 2010, an integrated least-cost strategy would produce an annual net output gain of about $50–60 billion/year or roughly 0.4% of GDP. By 2020, this gain grows to $120 billion/year or about 0.9% of GDP. On a cumulative net present value basis, the United States would gain $250 billion by 2010 and $600 billion by 2020. Most of these economic gains could be achieved through a purely domestic no-regrets strategy. International trading adds some further benefits, but these are not decisive for a positive economic outcome. In the context of an integrated least-cost strategy, savings from credits for carbon sinks and the use of the Kyoto flexibility mechanisms are of only minor economic significance.

Some level of international flexibility could be significant as a backup against domestic policy failures. However, given the positive net economic impacts over a wide range of assumptions, a sensible approach would give greater weight to competing considerations. These include the integrity of the Kyoto mechanisms, the stimulation of no-regrets technology innovation from domestic mitigation in the most highly industrialized countries, and the threat of global climate change to U.S. welfare and to global stability. Our analysis indicates that U.S. economic and environmental interests would have been better served by a much more accommodating posture in the COP negotiations.

In summary, the perception that emission reduction targets, such as those of the Kyoto Protocol, are unavoidably costly for the U.S. economy is the result of incomplete and outdated modeling assessments. An integrated economic analysis reveals that U.S. emissions could be reduced at a net gain in economic output. The benefit of this higher output would be accompanied by gains in welfare due to avoided climate damages and other cobenefits of greenhouse gas mitigation.

A question that remains unanswered in the present analysis is the impact of greenhouse gas mitigation on output and employment in particular industries, notably energy-intensive basic materials industries. The analysis of industry-by-industry impacts, based again on an integrated policy approach that includes tax shifts and accelerated energy productivity investments, will be presented in a subsequent publication.

REFERENCES

Abt Associates and Pechan-Avanti Group. "Co-Control Benefits of Greenhouse Gas Control Policies." Prepared for Office of Policy, U.S. EPA, Washington, DC, 1999.

Boyd, R., K. Krutilla, and W. K. Viscusi. "Energy Taxation as a Policy Instrument to Reduce CO_2 Emissions: A Net Benefit Analysis." *Journal of Environmental Economics and Management*, 29(1), 1995, 1–25.

CEA. "The Kyoto Protocol and the President's Policies to Address Climate Change: Administration Economic Analysis." Council of Economic Advisors, Washington, DC, 1998.

DeCanio, S. J. "Barriers within Firms to Energy-Efficient Investments." *Energy Policy*, 21(9), 1993, 906–14.

EIA. "Impacts of the Kyoto Protocol on U.S. Energy Use and Economic Activity." EIA SR/OIAF/98-03, Washington, DC, 1998a.

———. "Annual Energy Outlook 1999." DOE/EIA-0383 (99), Washington, DC, 1998b.

EMF. "The Costs of the Kyoto Protocol: A Multi-Model Evaluation." 16th Energy Modeling Forum, *Energy Journal*, special issue, 1999.

Haites, E. Institutional Features of the Kyoto Mechanisms and the COP-6 Decisions. Toronto: Margaree Consultants, 2000.

Hammond, J., S. J. DeCanio, P. Duxbury, A. H. Sanstad, and C. H. Stinson. *Tax Waste, Not Work*. San Francisco: Redefining Progress, 1997.

Hanson, D. A., and J. A. Laitner. "An Economic Growth Model with Investment, Energy Savings, and CO_2 Reductions." Presented to Salt Lake City meetings of the Air & Waste Management Association, June 18–22, 2000.

Hoerner, J. A., and B. Bosquet. *Environmental Tax Reform: The European Experience.* Washington, DC: Center for a Sustainable Economy, 2001.

IPCC. *Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of*

Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge/New York: IPCC, 1996.

———. *Climate Change 2000: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge/New York: IPCC, 2001.

IPSEP. *Cutting Carbon Emissions while Making Money: Climate Saving Energy Strategies for the European Union*. El Cerrito, CA: IPSEP, 2000. Available online at www.ipsep.org/Carbon.pdf.

———. *Solving the Kyoto Quandary: Flexibility with No Regrets*. El Cerrito, CA: IPSEP, 2001a.

———. *Regulating Global Warming Pollution while Reducing U.S. Gas and Electricity Bills: A Least-Cost Analysis*. El Cerrito, CA: IPSEP, 2001b.

———. *Cutting Carbon Emissions at a Profit: Opportunities for the U.S. (Technical Report)*. El Cerrito, CA: IPSEP, 2001c.

IWG. "Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond." Lawrence Berkeley National Laboratory (Berkeley, CA), and Oak Ridge National Laboratory (Oak Ridge, TN), 1997. Available online at www.ornl.gov/ORNL/Energy_Eff/labweb.html.

———. "Scenarios for a Clean Energy Future." IWG on Energy-Efficient and Clean-Energy Technologies, Oak Ridge National Laboratory, and Lawrence Berkeley National Laboratory. ORNL/CON-476 and LBNL-44029, Oak Ridge, TN and Berkeley, CA, 2000.

Jorgenson, D. W., and P. J. Wilcoxen. "Reducing U.S. Carbon Emissions: An Econometric General Equilibrium Assessment." *Resource and Energy Economics*, 15(1), 1993, 7–25.

Koomey, J. G., R. C. Richey, J. A. Laitner, R. J. Markel, and C. Marnay. "Technology and Greenhouse Gas Emissions: An Integrated Analysis Using the LBNL-NEMS model." Lawrence Berkeley National Laboratory, LBNL-42054, 1998. Available online at http://enduse.lbl.gov/Projects/GHGcosts.html.

Krause, F. "The Costs of Mitigating Carbon Emissions: A Review of Methods and Findings from European Studies." *Energy Policy* (special issue on the Second UN IPCC Assessment Report, Working Group III), 24(10/11), 1996, 899–915.

Laitner, J. A. "Modeling the Influences of Technology Policy, Organizational Structure, and Market Characteristics on the Economic Evaluation of Climate Change Policies." in Proceedings, ACEEE Industrial Summer Study. Saratoga Springs, NY, 1999.

MacCracken, C., J. Edmonds, S. Kim, and R. Sands. "Economics of the Kyoto Protocol." *Energy Journal* (Special issue, The Costs of the Kyoto Protocol: A Multi-Model Evaluation), 1999, 25–72.

Norland, D., K. Y. Ninassi, and D. W. Jorgenson. *Price It Right. Energy Pricing and Fundamental Tax Reform*. Washington, DC: Alliance to Save Energy, 1998.

Parry, I. W. H. "Environmental Taxes and Quotas in the Presence of Distorting Taxes in Factor Markets." *Resource and Energy Economics*, 19(3), 1997, 203–20.

Parry, I. W. H., and A. Bento. "Tax Deductions, Environmental Policy, and the 'Double Dividend' Hypothesis." *Journal of Environmental Economics and Management*, 39(1), 2000, 67–96.

Parry, I. W. H., R. C. Williams III, and L. H. Goulder. "When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets." *Journal of Environmental Economics and Management*, 37(1), 1999, 52–84.

Probyn, C., and W. Goetz. "Macroeconomic Impacts of Greenhouse Gas Control Policies." *Proceedings of the Interagency Climate Change Analysis Workshop*, Springfield, VA, June 6–7, 1996.

Repetto, R. "Yes, Virginia, There Is a Double Dividend." Working Paper, University of Colorado, Denver, 2000.

Sanstad, A. H., S. J. DeCanio, and G. A. Boyd. "Estimating Bounds on the Macroeconomic Effects of the CEF Policy Scenarios." Appendix E-4 in *Scenarios for a Clean Energy Future*. IWG on Energy-Efficient and Clean-Energy Technologies, Oak Ridge National Laboratory, and Lawrence Berkeley National Laboratory. ORNL/CON-476 and LBNL-44029, Oak Ridge, TN and Berkeley, CA, 2000.

Sanstad, A. H., S. J. DeCanio, G. A. Boyd, and J. G. Koomey. "Estimating Bounds on the Economy-Wide Effects of the CEF Policy Scenarios." *Energy Policy*, 29(14), 2001, 1299–311.

Shackleton, R., M. Shelby, A. Cristofaro, R. Brinner, J. Yanchar, L. Goulder, D. Jorgenson, P. Wilcoxen, P. Pauly, and R. Kaufman. "The Efficiency Value of Carbon Tax Revenues." U.S. EPA, November 1992.

Tellus, *Policies and Measures to Reduce CO_2 Emissions in the United States*. Boston: Tellus Institute, 1998.

Tellus/SEI. *America's Global Warming Solutions*. Boston: Tellus Institute and Stockholm Environment Institute, 1999.

Tol, R. S. "Kyoto, Efficiency, and Cost-Effectiveness: Applications of FUND." *Energy Journal* (special issue, Costs of the Kyoto Protocol: A Multi-Model Evaluation), 1999, 131–52.

UNFCCC. "Full Text of the Convention." 2002. Available online at http://unfccc.int/resource/conv/index.html.

Weyant, J. P., and J. Hill. "Introduction and Overview." *Energy Journal* (special issue, Costs of the Kyoto Protocol: A Multi-Model Evaluation), 1999, vii–xliv.

Wigley, T., R. Richels, and J. Edmonds. "Economic and Environmental Choices in the Stabilization of Atmospheric CO_2 Concentrations." *Nature*, 379, 1996, 240–43.