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The Costs of Kyoto for the US Economy

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Abstract

The high costs for the US economy of mitigating climate change have been cited by the Bush administration as one of the reasons for rejecting US ratification of the Kyoto Protocol. A range of cost estimates are assessed in the IPCC's third report (2001), but they are hedged with so many qualifications that it is not easy to reach useful conclusions. This paper organises some of the quantitative information on costs of greenhouse gas mitigation for the US published before the US rejection of Kyoto. The aim is to put them in a wider context, e.g. allowing for non-climate benefits, and to draw conclusions that are robust in the face of the uncertainties. Important lessons can be drawn for how costs can be reduced in any future international commitment by the US to reduce emissions. Provided policies are expected, gradual and well designed (e.g. through auctioned Annex I tradable permits with revenues used to reduce burdensome tax rates) the net costs for the US of mitigation are likely to be insignificant, that is within the range + or – 1% of GDP.

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1. INTRODUCTION

The high costs for the US economy of mitigating climate change have been cited by the Bush administration as one of the reasons for rejecting US ratification of the Kyoto Protocol (US White House, 2001). This view of the costs is also held by many economists: e.g. “The contention of most economists – and conclusion of most economic assessments – is that reducing carbon emissions, according to the terms of Kyoto, is highly costly.” (Sutherland, 2000). This paper examines the basis for this view and concludes that it is not well founded: the literature, available in 1999 and 2000 and reviewed here, shows that early, well-planned action could have made the costs insignificant, as defined below, or even provided benefits to the economy.

The IPCC in its Third Assessment Report has assessed this literature and has found that the macroeconomic costs depend on a range of factors (Watson et al., 2001, p.144, 300-2, 343-4, 349). The costs depend on the approach adopted, whether top-down or bottom-up modelling, and on the structure of the model and the assumptions about parameter values. They depend on the factors included in the modelling, namely which fiscal instruments are used for mitigation, what happens to any tax or emission permit revenues, whether the permits are traded, which greenhouse gases (GHGs) are included, and whether the environmental benefits of mitigation (averted climate change and ancillary benefits) are included. Finally, the costs depend on the baseline chosen. These conclusions are supported by a meta-analysis of the estimates in the literature of the global costs of mitigation to 2100 (Barker et al., 2002), in which stabilisation of greenhouse gas concentrations in the atmosphere is achieved.

With all these qualifications to the cost estimates, it is difficult to come to useful conclusions on the scale of the costs that are robust to the inevitable uncertainties in modelling economies and policies and in projecting the future. This paper builds on the IPCC assessment as regards the costs of mitigation for the US economy with the aim of reaching some such robust conclusions. It does so by focusing on results from those approaches and assumptions yielding the higher-cost estimates, to see just how high these costs are and whether they may be reduced by more appropriate assumptions relating to policy design and implementation.

The top-down, economic models tend to give higher costs than the bottom-up energy-engineering models (Watson et al., 2001, p. 349; Sutherland, 2000). And within the group of top-down models, the macroeconometric models tend to give higher costs than the general equilibrium models. This paper, therefore, sets aside the bottom-up literature, which often finds that there are significant net benefits from GHG mitigation policies[1], and examines the quantitative results from top-down modelling studies, particularly the macroeconometric results. It focuses on three studies covering a wide range of models and results:

1. The WRI meta-analysis of 162 results from 16 models on the GDP costs of CO2 mitigation for the US economy (Repetto and Austin, 1997)
2. The US Energy Information Administration’s (EIA, 1998) study of the costs of Kyoto for the US economy under various scenarios and
3. The EMF study using 16 models looking at the costs of Kyoto for OECD regions (including the US) under various scenarios concerning the emission trading regime (Weyant and Hill, 1999).

Section 2 discusses what is meant by “costs” in the literature. Section 3 summarises the three studies and explains where the high-cost estimates come from. Section 4 assesses how costs could be reduced by allowing a longer period of adjustment and by using the flexibilities that are part of the Kyoto Protocol, that relate to non-CO_2 GHGs, sinks and emission trading. Sections 5 and 6 review the treatment of ancillary benefits and revenue recycling, respectively. Section 7 brings the estimates together and concludes with an assessment of the likely costs of mitigation for the US economy and how robust they are under uncertainty.

2. COSTS OF GHG MITIGATION

Before proceeding, it is worth a brief exploration of what constitutes “costs” in the context of mitigating climate change (see UNEP, 1998 for a discussion). The costs are not observable from market prices, since they involve assessment of (1) complex energy-environment-economy (E3) systems responding to price signals and regulations influenced by government and (2) changes in

[1] Sutherland (2000) contrasts the high-cost estimates in the macroeconomic literature, reviewed here, with the “no cost” estimates from the bottom-up energy conservation literature, arguing that the “no cost” conclusion is not supported by the basic principles of economics. However, when the underlying assumptions and omissions of the high-cost estimates are explored, the macroeconomic costs also turn out to be much less than they first appear.

environmental and other outputs of the system that have no market valuations. The costs estimated for a proposed mitigation policy, such as the USA being part of the Kyoto process, are always hypothetical because they involve a comparison of two different states of the E3 system over future years. How these costs are summarised is important if an unbiased view is to be conveyed.

The literature usually uses differences in GDP in constant prices between two scenario outcomes as a summary measure of macroeconomic costs because it is comprehensive of all changes in marketed output and it is a standard concept in national accounting, and so comparable across different countries' accounts. The main shortcomings of the concept are well known: it does not include environmental effects and partly for this reason it can be a poor indication of welfare; and it can conceal important changes in distribution of income and wealth. The changes in GDP can be expressed (1) in absolute terms, (2) as % of the reference case GDP or (3) as differences in growth rates. The absolute amounts are misleading if quoted out of context and they depend on the price base chosen. If quoted in present values, they also depend on the choice of discount rate, and there is little agreement as to what an appropriate rate for this purpose should be. The change as a % of GDP in the reference case shows the scale of the costs, avoids the discount rate problem (since the costs and the level of GDP are contemporaneous) and allows easier comparison across years and countries. This measure is adopted in this paper to compare the costs of mitigation. The third measure, differences in growth rates, is appropriate for comparing long-term mitigation costs e.g. over the years to 2100.

There is also the question of whether a particular change in costs as measured by % of GDP is statistically significant. This depends on the properties of the assumed underlying distribution of observations. Here the observations are of changes in forecast real GDP for the US economy compared to a business-as-usual base. One measure of the general reliability of forecasts of GDP can be estimated from *ex post* model projections. The Fair model has a long track record of such forecasts (http://fairmodel.econ.yale.edu/). The average mean absolute error from this model of the next 4 quarters of real US GDP annual growth is 1.18 percentage points, taken from 20 years of forecasts 1983-2002. This implies that even a change in GDP of 4% over 10 years to 2010 would be very difficult to detect in any *ex post* forecast exercise. The rule of thumb, adopted below as a guide, is that a change in GDP is insignificant if it implies a difference from base of less than 1% over the 10-year forecast period.

The level of carbon tax or estimated permit price for CO_2 emissions is sometimes taken as the summary measure of mitigation costs. For example, Sutherland (2000, p. 94) in a paper on the GHG mitigation costs for the USA quotes $348 per tonne (EIA, 1998) as the top-down modelling estimate of the costs of Kyoto[2] by US domestic actions. This may be adequate in limited comparisons of costs, e.g. for different emission-trading regimes, but it is inadequate as a general measure of costs for several reasons. First, there are many mitigation policies available (e.g. taxation, regulation, fiscal incentives for low-carbon technologies) and the carbon tax is only one particular tax so its level cannot be used to compare costs between policies. Second, the use of carbon prices as a measure of costs from top-down models implies that mitigation policies are always costly, whereas macroeconomic effects as measured by GDP in such models and reported in the literature can be negative or positive, i.e. costs or benefits. Mitigation policies based on carbon taxes can lead to increases in GDP, depending on modelling approach, assumptions about revenue recycling and treatment of technical change. Third, the use of the carbon tax rates as a measure of overall costs of mitigation is more partial than the use of GDP effects, since the carbon tax relates to prices, especially those of fossil fuels, whereas GDP effects relate to the incomes and output of the whole economy. Fourth, positing a carbon tax as a measure of cost misrepresents its role as a response to an environmental externality. In fact, provided that it is at or below the optimal level, a carbon tax will, by definition, lead to social benefit rather than cost, so its use at all as a proxy for costs seems in principle misleading.

3. THREE TOP-DOWN STUDIES OF THE COSTS OF KYOTO FOR THE US ECONOMY

The World Resources Institute Study

The literature up to 1997 on costs to the US economy in terms of losses in GDP when the Kyoto Protocol was negotiated has been summarised in a comparative study by World Resources Institute

[2] This is however a misinterpretation of the EIA report result, which is for US domestic action reducing CO_2 (not GHG) emissions 7% below 1990 levels by 2010. The Kyoto Protocol allows for non-CO_2 GHGs and GHG sinks as well as international trading.

(WRI) (Repetto and Austin 1997). This study is a quantitative meta-analysis of the GDP costs of mitigation. Econometric regression techniques are used to assess the role of assumptions in 162 results from 16 models used to project GDP costs of CO_2 mitigation. Most of the studies used a carbon tax explicitly or as an implicit addition to the price of carbon needed to restrict its use. The regression equation explains the % change in US GDP in terms of the CO_2 reduction target, the number of years to meet the target, the assumed use of carbon tax revenues (how the revenues are 'recycled' through the economy) and 7 model attributes. It estimates that, as a summary of the results of these models, in the worst case combining these assumptions and attributes, a 30% reduction in US baseline emissions by 2020 would cost about 3% of GDP. The corresponding best case implies an increase of about 2.5% in GDP above the baseline. The total difference of 5.5 percentage points (pp) (i.e. 3pp plus 2.5pp) of GDP in lower costs can be attributed to the recycling assumption (1.2pp) and across the attributes (4.3pp as follows):

- general equilibrium models gave lower costs than macroeconometric models (1.7pp)
- the inclusion of averted non-climate change damages, e.g. air pollution effects (1.1pp)
- the inclusion of Joint Implementation and/or international emission permit trading (0.7pp)
- the availability of a constant cost backstop technology (0.5pp)
- the inclusion of averted climate change damages in the model (0.2pp)
- the degree of product substitution in the model (the more the better) (0.1pp)
- the degree of inter-fuel substitution in the model (0.0pp).

Over 70%[3] of the variations in the GDP impacts in the models are explained by these factors and size of the CO_2 target reductions.

The Energy Information Administration (EIA) 1998 Study

The EIA in 1998, at the request of the US House of Representatives' Committee on Science, analyzed the impacts of the Kyoto Protocol on U.S. energy use, prices, and the general economy by 2008-2012, with actions to achieve the target beginning in 2005. The EIA used Data Resources Incorporated (DRI)'s annual macroeconometric model to assess the general economic effects. The study projects the

[3] Repetto and Austin (1997) report goodness of fit of 0.8, but this value can only be reproduced by omission of the constant term in the regression. See (Barker, Koehler and Villena, 2002).

US economy to 2020 and considers a reference case and 6 carbon emission reduction cases, ranging from 7% below to 24% above 1990 levels by 2010.

This study appears to be the source of the "huge costs" given by the White House Press Secretary when explaining why the United States was withdrawing from the Kyoto negotiations (US White House, March 2001). President Bush later put numbers to this cost: "The approach taken under the Kyoto protocol would have required the United States to make deep and immediate cuts in our economy to meet an arbitrary target. It would have cost our economy up to $400 billion and we would have lost 4.9 million jobs." (White House, February 2002). The highest costs in the EIA study come from the worst-case assumption of a 7% cut in CO_2 emissions below 1990 levels by 2010. Such a cut, implemented over the 4 years 2005 to 2008, implies a reduction of 4.2% in GDP below projected levels for 2010, or some $400bn out of a total $9,429bn (1992 prices) and a carbon permit price in 2010 of $348 per ton carbon (1996 dollars).

Note that this result was not intended by the authors of the EIA report to be seen as the outcome of the proposed legal commitment of the Kyoto Protocol, which allows for multiple gases and flexible mechanisms, including international permit trading. It was intended to be a standardised scenario to be compared with the results of other modelling exercises, such as those by the EMF-16 considered below. In such scenarios, a reduction in carbon used is assumed to be achieved by an domestic auctioned permit scheme, with revenues from the auctions recycled as lump-sum rebates to income-tax payers (lump-sum recycling scenarios). This is a high-cost result as can be seen by comparing the other scenarios given in the EIA report. It is the result of the assumption forcing short-term adjustment and the choice of how the auction revenues are spent (see below).

The other carbon reduction cases given by the EIA study are intended to show the assumed impacts of the various flexibilities in the form of sinks, multiple GHGs, emission permit trading and other mechanisms that are part of the Kyoto Protocol. As these are introduced by successive assumptions about the extent to which CO_2 emissions need to be reduced, the estimated costs fall further and further, becoming some 1% of GDP in 2010 for the best-case scenario (EIA, 1998, Table ES5). The results of the study are in line with official estimates[4] that accounting for sinks and the flexibility to use 1995 as the base year for the synthetic GHGs would mean that the US could comply with the Kyoto Protocol with a 3% (rather than the nominal 7%) reduction in CO_2 emissions below 1990 levels[5]. Since the allowances for sinks were eventually negotiated at more generous levels than expected at the Marrakesh meeting in November 2001, and since there may be opportunities for profitable reductions in methane emissions, the 4% allowance for non-CO_2 GHGs and sinks seems on the low side.

The Energy Modeling Forum 16 Studies on the Costs of Kyoto

A series of studies assessing the costs of adopting elements of the Kyoto Protocol was undertaken in a consistent framework of assumptions and reported in a Special Issue of *The Energy Journal* in 1999, following an Energy Modeling Forum (EMF) exercise. This report and the exercise are both substantial and influential; the report dominates the literature on the global costs of adopting the Kyoto Protocol (Watson et al., 2001, pp 114-7).

Weyant & Hill (1999) summarise the EMF-16 studies and the results. In order to make the studies comparable, they all use carbon emission permits as the instrument for mitigation and therefore yield implicit carbon tax rates to achieve the targets; all assume lump-sum recycling of revenues; and all set aside the environmental benefits. The emphasis is on how emission-permit trading may reduce costs; the teams were not asked to consider how alternative ways of recycling revenues, or how consideration of ancillary environmental benefits might have reduced net costs even further.

[4] See the fact sheet published by the U.S. Department of State on January 15, 1998.
[5] Similar estimates were cited by Dr. Janet Yellen, Chair, Council of Economic Advisers, in her testimony before the House Committee on Commerce, Energy and Power Subcommittee, on March 4, 1998.

Table 1: EMF-16 results for carbon-permit prices and GDP effects for Kyoto[1] targets, US, 2010

Model[2]	Carbon permit price US$$_{90}$ per tC			GDP change %		
	No trading	Annex I trading	Global trading	No trading	Annex I trading	Global trading
ABARE-GTEM	322	106	23	-1.96	-0.47	-0.09
AIM	153	65	38	-0.45	-0.31	-0.20
CETA	168	46	26	-1.93	-0.67	-0.43
G-Cubed	76	53	20	-0.42	-0.24	-0.06
MERGE3	264	135	86	-1.06	-0.57	-0.20
MS-MRT	236	77	27	-1.88	-0.91	-0.29
RICE	188	62	18	-0.94	-0.56	-0.19
Median	188	62	26	-1.06	-0.56	-0.20

Source: Watson (2001, pp. 116, 340, 341)

Note to Table 1:

[1] The Kyoto target for the US was a 7% reduction in GHG emissions below 1990/1995 levels. Although the results in the table relate to the Kyoto target they do not allow for various allowances and flexibilities (apart from emission permit trading) in the Kyoto Protocol that are likely to reduce costs further such as non-CO2 GHGs, sinks, Joint Implementation, and the Clean Development Mechanism.

[2] The model results quoted here are derived from those reviewed in (Weyant and Hill, 1999) and included in the IPCC assessment. They do not include the results from the Oxford model, which gave some of the highest GDP losses, because these were excluded from the IPCC assessment: "The results of the Oxford model are not included in the ranges cited in the Technical Summary or the Summary for Policymakers because this model has not been subject to substantive academic review (and hence is inappropriate for IPCC assessment), and relies on data from the early 1980s for a key parametrization that determines the model's results." Watson, 2001, p. 340. For a separate assessment of the Oxford model, see Barker & Ekins, 2001.

Table 1 summarises the main EMF-16 results appearing in the IPCC Third Assessment Report (IPCC, 2001). Two features stand out in the results: the wide range of carbon-permit prices and the substantial reduction in costs when trading is introduced. Carbon permit prices range from $76 to $322 in 1990 US$/tC with no trading and $46 to $135 with Annex I trading. Although many key assumptions are consistent across the studies, there is an extra feature (excluded from the WRI study) that gives rise to differences. The Kyoto target is assumed to be an absolute one in relation to a 1990 base. This means that the range in the EMF results, where the carbon emission reductions are all fixed by the 1990 base, is partly due to the different rates of growth of CO_2 emissions in the different baselines. The studies reviewed by the WRI consider various CO_2 emission reductions relative to different baselines over the projection period, and not to a fixed base.

Comparison between the carbon tax rates and the range of GDP costs from the EMF-16 lump-sum recycling studies for 2010 in Table 1 (for example, for the CETA and RICE models) confirms that, as explained above, carbon tax rates are not a good general indicator of costs of mitigation. A high carbon tax does not necessarily imply high GDP costs across the models. All the GDP effects are negative, but it may be noted that with trading of any kind all the costs are insignificant, as defined above.

4. COSTS OF SHORT-TERM ADJUSTMENT

One important factor affecting costs is the period allowed for the adjustment of the energy system and the economy to the mitigation policies and their effects on energy prices. Rapid, unplanned and unexpected adjustment is likely to be much more costly than slow, planned and expected change (Watson et al., 2001, p. 145). For example, if adjustment is too rapid, some capital stock such as coal-fired power stations will become uneconomic before the end of its working life (the stranded assets problem). This effect is included to a greater and lesser extent in the model results cited above and it is important for policy in that costs of mitigation may be substantially reduced if short-term adjustment costs are minimized. This may be done by announcing the change in policy in advance and by introducing any tax changes gradually.

The WRI study does introduce the length of the period of adjustment as a factor affecting costs, but it is estimated to be very small, with an extra 10 years of adjustment reducing the costs of a 30% reduction in CO2 emissions by 0.015pp. Since short-term adjustment is widely expected to be much more costly, it is worth speculating why the WRI study does not give more prominence to this factor. There seem to be two reasons for the result. First, it is only macroeconometric models that are able to measure the short-term dynamic costs of adjustment directly and a dummy variable for such models is already included in the equation explaining costs (there is in addition a dummy variable for the time given for adjustment). This suggests that those extra costs associated with macro-econometric models in the analysis (1.7pp) already include some costs of adjustment following the shock of the new mitigation policies. This point is important, and one that is not mentioned in the literature. The WRI study may therefore not be correct in attributing the 1.7pp effect to the greater 'efficiency' assumptions in CGE, compared to macroeconometric, modelling. The second reason for regarding the low-cost WRI result as suspect is that it is unreliable because there are so few observations on different lengths of periods of adjustment in the macro-econometric modelling studies.

The EIA study uses a macro-econometric model that does make allowance for short-term adjustment costs and the different time periods allowed for adjustment give an indication of the size of such costs. To meet the target of 7% below 1990 levels of CO_2, a reduction in total US CO_2 emissions of over 30% is required over the 4-year period 2005-2008 because of two factors:

1. the high baseline growth of CO_2 emissions from 1990 to 2005 and
2. the assumed delay in taking action until 2005.

A 30% cut requires a massive adjustment in energy structures over a short period, which will incur some avoidable costs, such as premature scrapping of coal mines and coal-fired electricity plants. If the adjustment period had been chosen as 2002-2010 (the mid-point of the Kyoto commitment period), more than twice as long as the 2005-2008 in the EIA study, it seems likely that the estimated costs would have been much lower. Had the US begun planning for the Kyoto targets in 1998, immediately after it signed the protocol, the likely costs would have been lower still. In fact, evidence for the scale of such a reduction in costs is given in the study itself: the EIA report that if the economy is allowed a longer time to adjust, the costs with lump-sum recycling fall from 4.2% of GDP in 2010 to 0.8% in 2020. The longer period allows production and consumption extra time to respond to changes in relative prices and to move to a more efficient utilisation of resources. This well illustrates the dependence of cost figures on imposed assumptions about adjustment times.

In contrast, the EMF studies in general assume a long period of adjustment, usually starting from the year 2000. In addition, two of the EMF-16 studies address the issue of short-term adjustment costs.

The Oxford model is the main study in the EMF-16 to consider adjustment costs by combining a global estimated macroeconomic model with an energy model. Weyant and Hill remark that the Oxford model deals “with very important issues not addressed elsewhere in the [Energy Journal] volume”, i.e. “macroeconomic adjustment costs” (1999, p.xiii). However the explanation of long-term growth of the US economy in the Oxford model is not convincing[6], so the size of the short-term adjustment costs cannot be judged. The other EMF-16 models are CGE, although some have macroeconometric components. The CGE models include short-term costs by changing parameters and assumptions, but this requires special treatment that is not necessarily part of the studies reviewed. However, Jacoby and Sue Wing (1999) look explicitly at the effects of changing the assumptions for the proportion of the capital stock in the MIT-EPPA model[7] which is malleable, i.e. responding to long-term changes in factor prices so allowing substitution away from energy inputs. They find that the effect on the USA carbon price to achieve the Kyoto target is significant. They then measure the effect of the reference value of 70% of the capital stock being malleable on the costs of ratifying. They explore the effect on carbon prices in 2010 of varying the date of US ratification and action. With ratification in 2000 the price is \$193/tC, but with ratification in 2005 the price is \$241/tC (both in 1990 prices). This result implies that, taking just one aspect of longer-term flexibility, costs are reduced by 25%.

5. ANCILLARY BENEFITS OF GHG MITIGATION

One of the effects of GHG mitigation is a reduction in other environmental effects and emissions associated with burning fossil fuels, such as emissions of sulfur dioxide and particulate matter. Since such emissions are damaging, this reduction is a potential benefit that can be offset against any direct costs of GHG mitigation. This is a benefit even although such emissions may be capped by other environmental regulation, because the GHG mitigation policies by reducing the emissions will then reduce the requirement for expensive abatement equipment, such as flue-gas-desulfurisation equipment for coal-fired electricity.

[6] In the Oxford results (Cooper et al. 1999), the long-term costs of Kyoto for the US economy continue to grow after 2010. This appears to be due to the fact that the long-term total factor productivity growth of economies is derived from a short-run equation that is not valid for long-run growth when labour and capital can vary. The equation imposes high costs of carbon taxation on potential output growth simply by assuming a value for a substitution elasticity from the literature. See (Barker and Ekins, 2001) for details.

The literature generally acknowledges that such ancillary benefits exist and that in some cases they may be comparable to the costs of the mitigating measures (Watson et al., IPCC, 2001, p. 117). The WRI study includes model treatment of the benefits as a factor explaining the differences between cost estimates and finds it to be large and significant, giving a 1.1% GDP reduction in costs for a 30% reduction in CO_2 below baseline by 2010 (see above).

However, the EIA and EMF-16 studies do not give any estimates of ancillary benefits or costs and do not explain why they have been ignored. The potential for such benefits is evident from the huge reductions in coal production and consumption given or implied by the studies. The EIA estimate for the effect of a 31% reduction in CO_2 is a 77% reduction in coal consumption below reference case by 2010 and for a 36% reduction in CO_2 it is a 92% reduction by 2020, mainly from electricity use. Coal production is reduced by similarly large amounts. There are also significant reductions in consumption of petroleum products of 13% below reference case by 2010 and 11% by 2020. These reductions imply reductions in both emissions of pollutants and abatement costs. The report states that the reduction in SO_2 is so large that the prices for the SO_2 allowances will be driven to zero[8]. This implies that there will be a reduction in SO_2 as well as all other pollutants from coal burning and mining such as particulate matter, soot and methane but it is not clear how much. There will also be significant reductions of at least 10% in all air pollution from cars, trucks, aircraft and all fixed equipment burning oil products. This is very likely to lead to reductions in concentrations of low-level ozone across North America and indeed across the Northern Hemisphere.

The measurement and valuation of these ancillary benefits is complex and uncertain, which is perhaps why they are not included, but they are not likely to be insignificant for 2 reasons. First, the costly and stringent air quality controls in many US states shows that air quality is highly valued. And second, the increase in incomes expected over the next 20 years implies that the value of clean air may well continue to rise.

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[7] Results from this model are not included in Table 1 because no GDP effects are reported.

[8] "In the electricity generation sector, each reduction in overall coal generation will make it easier to achieve the Clean Air Act Amendments sulfur dioxide (SO2) target of 9 million tons of SO2, and in the more severe carbon reduction cases, prices for the SO2 allowances will be driven to zero." (EIA, 1998, p. 111)

Burtraw and Toman (2000) review the estimation problems and the estimated ancillary benefits of GHG mitigation for the US. The main problems are (1) that the emissions accumulate and interact in the atmosphere and their effects (e.g. creation of ozone) depend on prevailing winds and temperatures and (2) that the damages are time and site specific, with respect to both the source and the receptor. Aggregation across all pollutants for different scenarios is difficult and may be misleading. They argue that the more recent specific studies may be more appropriate for marginal reductions in GHGs[9], when emissions of SO_2 are contained within the cap, but that the three economy-wide studies (Goulder, 1993 and Scheraga and Leary, 1993; Boyd et al., 1995; and Viscusi et al., 1994) "may be better suited for examining the effect of more substantial and broad scale GHG mitigation policies." (Burtraw and Toman, 2000, p. 504). These three studies give average ancillary benefits per ton of carbon reduction (1996 dollars) of $32, $39 and $86 respectively (p. 498). A more recent study (McCubbin et al., 1999) allows for the SO_2 cap and gives estimates of $8 to $68 (1996 dollars) for the average ancillary benefit per ton of carbon for carbon taxes of $30 and $67/ton carbon respectively. The EIA high-cost estimate has a carbon price above $300/ton carbon (1996 dollars) and the lowest estimated carbon price in the EMF no-trade results is $76/ton carbon (1990 dollars). Since both are well above the carbon tax rates considered in the McCubbin et al. study, it is conservative to take the higher value from the study as the estimate of ancillary benefits to be added to the EIA and EMF results in the no-trade case. Taking the estimated ancillary benefits of $68/ton carbon reduced (1996 dollars), the EIA study's estimates of the reduction in CO_2 of 31% by 2010 and 35% by 2020, and their projections of GDP for those years, gives estimates of economy-wide ancillary benefits of 0.4% of GDP for each year. This value is much lower than the WRI study estimate of 1.1% of GDP, for similar reductions in CO_2. It will be reduced when trading in permits is allowed because domestic CO_2 (and other fossil fuel) emissions will be reduced by a lower amount.

[9] They quote Burtraw et al. (2000) as best practice. This study considers the effects of a carbon tax at rates of $23 and $83/tC (1996 prices) and finds ancillary benefits per ton carbon between $7 and $9 by 2010, but the study is limited in scope to the effects of emissions of NOx from electricity generation on human health (Burtraw and Toman, 2000, p.497).

6. THE EFFECTS OF RECYCLING REVENUES

A further potential benefit to the US economy from using auctioned permits for mitigation is to be found in the use of the revenues from the permit auction to reduce distortions in the economy, the so-called "double dividend"[10]. This benefit is estimated in both the WRI and EIA studies, but it is not considered in the EMF-16 results. The WRI study finds that the benefit of such recycling is about 1.2% of GDP, and that the inclusion of the benefit is one of the main reasons for differences between the model results. The EIA study finds that if the recycling assumption is changed from lump-sum so that revenues are used to reduce social security payments by employees and businesses, the costs fall to 1.9% of GDP in 2010 and then to a negligible 0.2% in 2020 (EIA, 1998, Table ES6)[11]. The size of the double dividend has been investigated by other researchers, and they have found that the costs of mitigation have been reduced substantially. Jorgenson and Wilcoxen state: "(Lump-sum recycling) is probably not the most likely use of the revenue. ... Using the revenue to reduce a distortionary tax would lower the net cost of a carbon tax by removing inefficiency elsewhere in the economy." (Jorgenson & Wilcoxen 1993, p.20). This is precisely the effect that they find when they reduce distortionary taxes to offset a carbon tax; a 1.7% GDP loss under lump-sum redistribution is converted to a 0.7% loss by reducing labour taxes or to a 1.1% *gain* by reducing capital taxes (1993, Table 5 p.22). Goulder (1995) has also examined the effects of changing the recycling assumption. The GDP cost as a result of a carbon tax of $25/tC is reduced by 40-55% over the long run when the revenues are recycled via reductions in marginal rates of personal income tax rather than lump sum. Support for the potential benefits of recycling the revenues is given by other researchers (Hammond et al., 1997; Norland et al., 1998, Sanstad et al. 2000; Parry and Bento, 2001).

If the recycling of revenues is so important in the cost estimates, why has it not been included in the EMF-16 results? In the context of general equilibrium modelling, lump-sum recycling is a neutral means of recycling tax revenues because in theory and by assumption it has no behavioural

[10] There has been a considerable debate on the meaning and existence of the double dividend. See Ekins and Barker (2001) for a recent review.

[11] It is clear from the detailed macroeconomic results of the EIA study that the increase in costs is associated with a large increase in overall consumer prices, as a result of the increases in costs of energy. This suggests that an alternative way of recycling revenues may be even less costly. For example, the revenues could be used to reduce sales taxes, thereby reducing consumer prices and offsetting the energy-price increases.

implications in the model, although it can have substantial effects on the distribution of income. The assumption provides a benchmark to compare effects for different countries and other forms of recycling. The emphasis in the EMF-16 study is on comparing models and this is why this benchmark assumption has been chosen.

However when the lump-sum recycling assumption is combined with the usual treatment of the production structure in the EMF-16 modelling, it has the *inevitable outcome* that any carbon tax will entail GDP costs. In general equilibrium theory, if the economy is represented as being in an optimum position, any tax or permit scheme that causes prices to change will inevitably lead to a shift away from the initial equilibrium and be costly. If the revenues raised from the tax or permits are recycled in a neutral manner, i.e. lump-sum, then the cost will remain[12]. If, however, the initial position is distorted by pre-existing taxes and subsidies, or factor markets out of equilibrium, then the outcome can be costs or benefits.

It is worth emphasising that if recycling revenues is to prove beneficial, they must be used to reduce existing distortionary taxes[13]. If the revenues are not used as such, then they may become an opportunity for wasteful government expenditure. The controversies surrounding the attribution of the recycling benefit (is it due to reform of the tax system or to efficient mitigation policy?) show that it is best to identify any such benefits separately, as done below.

7. CONCLUSIONS: A COMPARISON OF COST ESTIMATES

The estimates of the costs of Kyoto for the US economy are summarised in Table 2. The table is divided into 2 parts for 2010 and 2020, with estimates from the 3 sources reviewed above. However, since the modelling approach is so important for the results, they are presented for the macroeconometric models and the CGE models separately.

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[12] There is a paradox in this procedure, because, as noted above, in theory an externality is being corrected by the carbon tax/permit scheme. In this view the initial position is not optimal, and the introduction of the tax/permit scheme is a benefit, bringing the economy towards the optimum. The paradox is resolved if it is understood that in the EMF-16 studies the carbon tax or permit schemes are regarded not as correcting an externality but as implicitly introducing a distortion into the economy.

[13] It has been argued that if these taxes are distortionary, they should be reduced anyway, but then the government will lose revenues and the problem becomes how should the lost revenues be recovered. The issue becomes one of general tax reform. In this light a revenue-raising mitigation policy becomes an opportunity for a wider reform of the tax system.

Table 2: Summary of estimated effects for the US to reach Kyoto-style targets, 2010 and 2020

	% difference from base for real GDP			
	2010 WRI Macro	EIA macro	WRI CGE	EMF-16 7 CGEs
No trading: % change CO_2	[-29.1]	-30.6	[-29.1]	-29.1
Lump-sum recycling effect	-2.8	-4.2	-1.2	-1.1
Non-CO_2 GHGs & sinks	0.5	0.7	0.2	
Ancillary benefits	1.1	[0.4]	1.1	
Revenue recycling benefit	1.3	1.9	1.3	
Total effect	0.1	[-1.2]	1.5	
Annex I trading: % change CO_2	[-20.9]	-18.4	[-20.9]	-20.9
Lump-sum recycling effect	-1.9	-2.0	-0.7	-0.6
Non-CO_2 GHGs & sinks	0.4	0.3	0.2	
Ancillary benefits	0.8	[0.3]	0.8	
Revenue recycling benefit	0.9	0.7	0.9	
Total effect	0.3	[-0.7]	1.2	
Global trading: % change CO_2	[-7.4]	-6.9	[-7.4]	-7.4
Lump-sum recycling effect	-0.4	-1.0	0.0	-0.2
Non-CO_2 GHGs & sinks	0.2	0.3	0.0	
Ancillary benefits	0.3	[0.1]	0.3	
Revenue recycling benefit	0.3	0.4	0.3	
Total effect	0.4	[-0.2]	0.6	
	2020 WRI Macro	EIA Macro	WRI CGE	EMF-16 3 CGEs
No trading: % change CO_2	[-35.1]	-35.1	[-35.1]	-35.1
Lump-sum recycling effect	-3.5	-0.8	-1.6	-1.0
Non-CO_2 GHGs & sinks	0.5	0.1	0.3	
Ancillary benefits	1.3	[0.4]	1.3	
Revenue recycling benefit	1.6	0.4	1.6	
Total effect	-0.1	[0.1]	1.6	
Annex I trading: % change CO_2	[-33.3]	-23.9	[-33.3]	-33.3
Lump-sum recycling effect	-3.3	-0.6	-1.4	-0.7
Non-CO_2 GHGs & sinks	0.5	0.1	0.3	
Ancillary benefits	1.3	[0.3]	1.3	
Revenue recycling benefit	1.5	0.2	1.5	
Total effect	-0.1	[0.0]	1.6	
Global trading: % change CO_2	[-11.4]	-13.5	[-11.4]	-11.4
lump-sum recycling effect	-0.7	-0.5	0.0	-0.4
non-CO_2 GHGs & sinks	0.3	0.1	0.0	
ancillary benefits	0.4	[0.1]	0.4	
revenue recycling benefit	0.5	0.2	0.5	
total effect	0.5	[-0.1]	0.9	

Notes: (1) Unless otherwise stated (i.e. in the rows for % change in CO_2), the effects are shown as differences from base for the year in question for real US GDP. Costs are shown as negative changes in GDP.
(2) The numbers in brackets are included for completeness. The CO_2 reductions for the WRI results have to be imposed for the WRI regression to yield GDP costs; they are taken from those assumed for the EMF-16 study. The estimated ancillary benefits for the EIA study come from the literature survey reported above.

Each block of figures in the table shows the estimates under assumptions of (1) no emission permit trading, i.e. the US undertakes all mitigation actions domestically, (2) Annex I trading as allowed under the Kyoto Protocol and (3) global trading as interpreted by the EMF-16 modellers. The first row in each block gives the required CO_2 reduction under the relevant assumption (of course, in general, trading allows domestic CO_2 reductions to be lower). The first indented row in each block gives the models' estimates of GDP costs of the CO_2 reduction, with lump-sum recycling of revenues and ignoring the effects given in the rows below. Subsequent rows show, each on a separate line, the effects on GDP of incorporating consideration of a number of the issues discussed earlier in this paper: non-CO_2 GHGs and sinks, ancillary benefits and recycling revenues. The final line of each block gives the sum of all the effects on GDP detailed in the lines above.

The reported results for the EMF-16 are only partial, because the study omits or does not report the overall effects on costs of non-CO_2 GHG mitigation, sinks, ancillary benefits and recycling revenues to reduce tax distortions. However, some idea of these potentially offsetting effects can be made from the other studies, and if included in the models they suggest that the EMF results would also show insignificant levels of costs. Ancillary benefits were also not measured in the EIA study and the numbers quoted in the table are included for completeness, being derived from the literature survey as described above. These can be added to the model results because the extra effects are environmental and outside the scope of the economic models. However, this is not the case for the effects of revenue recycling for the EMF-16 model results, because the models' treatment of labor and other markets and the precise assumptions about recycling will affect the results. Without any recycling effect (i.e. setting it to zero) the estimated effect of Kyoto under Annex I trading in 2010 from the EMF study is a reduction in GDP of 0.1%. Note that the effects of ancillary benefits and revenue recycling are the same for the WRI-macro and WRI-CGE results as a consequence of the regression chosen – in effect there are no interaction terms between the modelling approach and the inclusion of these benefits.

Several common results to the studies emerge from the table.

1) All the modellers agree that a substantial reduction of about 30% would be needed by 2010 for the US were to reach the Kyoto target, and an even larger reduction by 2020 for emissions to be maintained at that level.
2) Taking the assumption of lump-sum recycling and ignoring non-CO_2 GHGs, sinks and any ancillary benefits, there are always costs, between 0% and 4% of GDP, whatever the approach adopted by the model builders.
3) The costs for 2010 are approximately halved with Annex I trading and halved again with global trading. The costs for 2020 are also reduced by trading, but there are only 3 sets of results for 2020 in the EMF-16 study and the reduction in CO_2 for Annex I trading is very close to that needed without trading.
4) The EIA cost estimates fall dramatically for 2020, suggesting that indeed a large component of the 2010 costs are short-term adjustment costs as argued above.
5) The allowance for non-CO_2 GHGs and for land-use sinks has the effect of reducing the required CO_2 reduction and so reduces the costs under all conditions.
6) The various costs and benefits tend to be reduced together as the overall requirement for the reduction in CO_2 is diminished through trading. More trading, and hence less domestic action to reduce emissions, means that there will be fewer ancillary benefits and lower revenues from sales of emission permits for recycling.
7) The total effect on GDP from taking all these issues into account differs strikingly from the simple lump-sum recycling effect. For the WRI study, the total effect of carbon reduction is to *increase* GDP in all cases, except for macromodels in 2020 with restricted trading, for which the net costs, at 0.1% GDP, are very small. For the 7 estimates from the EMF-16 study for 2010, net benefits would appear likely to emerge after allowance for other factors. This is true even for the study with the highest costs for Annex I trading (costs of 0.9% of GDP from the MS-MRT model – see Table 1 above) making conservative assumptions for the other factors. The EIA study shows net costs ranging from 0.2-1.2% GDP for all 2010 trading scenarios, but very small effects by 2020.

The overall conclusion is that the high-cost estimates drawn from this literature are either misleading or they demonstrate

(1) the costs of making policy mistakes (e.g. by too hasty, unexpected action, or sub-optimal use of the revenues[14])

(2) the costs of policies that do not include the use of the Kyoto flexible mechanisms and/or

(3) how a selection of worst-case assumptions and parameters can accumulate to give high costs.

These estimates and the models on which they are based are now some five or more years old and many of the models have been further developed and improved. However, there has been no suggestion in the literature that these developments have led to any substantial upward revisions to the estimated costs of mitigation. Taking all the literature into account the macroeconomic costs of greenhouse gas mitigation of the kind envisaged by the Kyoto commitments is likely to be insignificant in the US, provided that the policies are expected, long-term and well-designed. In this context, insignificant means effects giving small overall benefits to the economy or costs of less than 1% below base in GDP and well-designed means that market-based instruments are used, such as auctions of internationally tradable emissions permits, and revenues earned by the government are recycled via reductions in burdensome taxes. At the same time there are very likely to be relatively large costs for a few sectors, such as coal, and for reasons of equity and political acceptance, compensation of some form in any policy package may be justified.

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[14] It is worth noting that the proposed EU Emission Trading Scheme to be implemented in 2005 is restricted to large combustion units (mainly in the electricity sector) and has only limited provision for the auctioning of permits, so severely reducing any benefit from revenue recycling.

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