THE COSTS OF INTERNATIONAL AGREEMENTS TO REDUCE CO₂ EMISSIONS: EVIDENCE FROM GREEN

John P. Martin, Jean-Marc Burniaux, Giuseppe Nicoletti and Joaquim Oliveira-Martins

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INTRODUCTION

There is widespread concern that climate change leading to global warming may be occurring and that this could involve costs that would warrant an internationally negotiated response to deal with it effectively. This concern was the main impetus behind the recent signing in Rio de Janeiro of a Framework Convention on Climate Change. While the signing of the Rio agreement is an important step forward, detailed and lengthy international negotiations lie ahead on the difficult issues of implementation, monitoring and enforcement. Economic issues, with a strong focus on the likely costs and benefits of international agreements, will loom large in this process and it is important that the negotiators and other interested parties have this information at their disposal.

To date, much more progress has been made on quantifying the costs of possible measures to curb greenhouse gas emissions, most notably carbon dioxide (CO₂) emissions, than the benefits of averting climate change. This paper also focuses on the cost side of the equation. It reports the results of several simulations with the OECD's GREEN model designed to quantify the economy-wide and global costs of a range of international agreements to curb CO₂ emissions – see the paper by Burniaux et al. in this volume for a full description of the model. Two particular aspects of international agreements are highlighted, with the aim of providing useful information for the negotiating process. The first is the issue of country coverage of the international agreement. This is examined by simulating the costs of an agreement among the OECD countries alone and comparing this with a simulation where the agreement is extended to embrace the non-OECD regions too.

Second, the paper seeks to quantify the potential gains to individual countries and the world economy as a whole from implementing international agreements that take account of the principle that the emission reductions should be secured at minimum cost, i.e. cost-effective agreements. A necessary condition for such an agreement is that the marginal costs of cutting emissions are equalised across countries. This condition can be achieved if all countries participating in the agreement either impose a common tax on emissions or trade emission permits on a world market.

The structure of the paper is as follows. The first section reviews the so-called Business-as-Usual (BaU) scenario, i.e. the path CO₂ emissions would be expected to take in the absence of policy actions to restrain their growth. Section II considers an international agreement under which emission curbs are only applied by the OECD countries and no actions are taken by the non-OECD regions. Section III extends the coverage of the international agreement to embrace the non-OECD countries and quantifies the gains from a cost-effective version of the agreement. Section IV dis-
cusses some other considerations governing the choice of policy instrument to ensure a cost-effective agreement. The final section draws some conclusions for policy.

I. BUSINESS-AS-USUAL (B. AS) PATH OF CO₂ EMISSIONS

The first important step in quantifying the costs of any policy intervention to curb CO₂ emissions is to derive a plausible BaU scenario for future emissions. The BaU path determines the required magnitudes of the cuts in emissions needed to achieve any given target. The assumptions about GDP and population growth rates underlying the GREEN BaU scenario are taken from the guidelines laid down for the Energy Modelling Forum No. 12 (EMF12) exercise at Stanford University and the OECD’s Model Comparisons Project (see Table 1). Further details on the latter, as well as a comparison of the GREEN BaU emissions path with the BaU paths in other global models, are provided in the paper by Dean and Hoeller in this volume.²

<table>
<thead>
<tr>
<th>GDP and population projections underlying the BaU scenario in GREEN</th>
<th>1990-2000</th>
<th>2000-2020</th>
<th>2020-2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real GDP</td>
<td>Population</td>
<td>Real GDP</td>
</tr>
<tr>
<td>United States</td>
<td>2.6</td>
<td>0.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Japan</td>
<td>3.7</td>
<td>0.3</td>
<td>2.7</td>
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<tr>
<td>EC</td>
<td>2.2</td>
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<tr>
<td>Energy exporting LDCs</td>
<td>3.6</td>
<td>2.3</td>
<td>3.5</td>
</tr>
<tr>
<td>China</td>
<td>4.6</td>
<td>1.3</td>
<td>4.4</td>
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<tr>
<td>India</td>
<td>4.6</td>
<td>1.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Dynamic Asian Economies (DAEs)</td>
<td>4.4</td>
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<tr>
<td>Brazil</td>
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<td>1.7</td>
<td>4.2</td>
</tr>
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<td>Rest of the World (RoW)</td>
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<tr>
<td>Total OECD</td>
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<tr>
<td>Total non-OECD</td>
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<td>1.8</td>
<td>3.4</td>
</tr>
<tr>
<td>World</td>
<td>2.9</td>
<td>1.6</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Source: Study design for EMF12. Since the number of regions in GREEN is significantly larger than the five region breakdown adopted for EMF12, the GDP and population growth projections had to be adapted to the needs of GREEN. It was assumed that relative growth differentials between groups of regions, projected by the World Bank for the period 1986-95, will persist until 2050, while remaining consistent with the aggregate projections made over the long term by EMF12.
Two important assumptions about policies underlie the BaU path in GREEN. First, no allowance is made for the commitments to reduce CO₂ emissions which have been announced by OECD countries. Second, the existing levels of energy taxes and subsidies across regions in the benchmark year – which is taken to be 1985 in GREEN – do not change over time even though the countries of Central and Eastern Europe (CEECs) have reduced their subsidies sharply in recent years and some of the countries which made up the former Soviet Union have announced their intention to do likewise.

The motivation for these existing energy taxes and subsidies has important implications for the welfare analysis of policies to restrict CO₂ emissions. The implicit assumption throughout this paper is that the energy tax system, as it existed in 1985, is optimal in all regions – abstracting from considerations of global warming and treating the objectives of existing taxation as being independent of global warming. All other models which address the CO₂ issue either make the same assumption or ignore the issue of existing energy taxes and subsidies. The assumption of optimal energy taxation implies that the observed differences in energy prices across countries reflect the marginal social costs of using energy in each country – ignoring the externality arising from the release of carbon into the atmosphere.³ This assumption may not be too unreasonable for the OECD countries once allowance is made for the role of energy taxes in offsetting the negative externalities from road use and congestion; it may be less satisfactory for some non-OECD regions which subsidise energy heavily in order to promote industrial development and/or to achieve domestic distributional objectives.⁴

The alternative extreme assumption would be that all existing energy taxes and subsidies are distortionary, thereby driving a wedge between the marginal private and social costs of using energy. This is the approach adopted in the paper in this volume on energy taxation by Burniaux et al. That paper shows that the efficiency costs from imposing a carbon tax are larger in countries which already tax energy use and they are reduced in countries which subsidise energy use.

A. Composition of energy demand

The world oil price is endogenous in GREEN from 1990 on; its time path is related to the depletion of oil reserves in the Energy-exporting LDCs, a region which includes OPEC.⁵ The potential oil supply constraint in this region becomes binding around 2030, oil output declining thereafter by over 2 per cent per annum until 2050. From 1990 to 2030, the world oil price rises steadily in real terms, at an average annual rate of 1.7 per cent. From 2030 to 2050, the rate of price increase slows (to 1.1 per cent per year) as oil competes with the carbon-based synthetic fuel whose price acts as a cap on the oil price.

Figure 1 shows the shares of primary energy demands in the OECD and the non-OECD regions accounted for by the three fossil fuels and the three back-stop options – carbon-based synthetic fuels, carbon-free liquid fuels and a carbon-free electric option – which it is assumed can replace them in the production of energy from the year 2010 on. The most striking trend is the steep rise in the share of coal: up from 27 per cent in the OECD area in 1985 to 39 per cent in 2050 and from 36 to 63 per cent in the non-OECD regions. The rising importance of coal as an energy source comes at the expense of oil, especially in the OECD area.
All three back-stop energy sources are assumed to become available in all regions in virtually infinite supply from 2010 on. From 2030 on, oil use in the OECD area is rapidly replaced by the carbon-based synthetic fuel which accounts for 18 per cent of total energy demand by 2050. The carbon-free electric option, the most costly back-stop, only makes important inroads as an energy source in Japan, where it replaces all conventional electricity by 2030.
In sharp contrast to the OECD regions, the non-OECD regions make almost no use of the back-stop options: by 2050, the carbon-based synthetic fuel only accounts for 3 per cent of their total energy demands. Total energy demand also increases much faster in the non-OECD regions than in the OECD area: the annual growth rate is 2.6 per cent over the period 1985-2050 compared with 0.8 per cent in the latter. As a result, total energy demand in the non-OECD area in 2050 is projected to be three times the OECD level.

The main explanation of why back-stop technologies are not used by the non-OECD regions lies in the existence in 1985 of large subsidies on the use of primary fossil fuels in some major countries/regions such as China, India, the former Soviet Union and the CEECs. Table 2 shows that fossil-fuel prices, particularly for coal, were very low (relative to U.S. levels) in these regions. Since it is assumed in the BaU scenario that these subsidies are not eliminated, fossil-fuel prices in most non-OECD regions do not increase enough to reach the break-even levels at which back-stop options would become profitable and begin to penetrate the market.

B. CO₂ emissions

Emissions growth over the period to 2050 depends on several factors. First, there is the direct link to projected GDP growth; on the basis of this factor alone emissions growth would be expected to slow down in the next century and such deceleration does indeed occur after 2010 in the non-OECD regions (see Table 3). Second, the rise in real oil and gas prices encourages substitution from oil and gas towards coal; since coal is a “dirtier” fuel than oil or gas – in terms of releasing CO₂ into the atmosphere per unit of energy produced, this inter-fuel substitution tends to raise emissions growth. Third, the phasing-in of back-stop options also affects emissions growth, depending upon whether the back-stop is “clean” or “dirty”. For example, the phasing-in of the carbon-free electricity option in Japan contributes to a sharp fall in emissions growth in the OECD area in the first decade of the next century. But after 2010 this downward pressure on OECD emissions growth is more than offset by the growing penetration of the “dirty” synthetic fuel in the OECD countries – synthetic fuel emits even more CO₂ than coal.

The net outcome of these opposing trends is a stable 2 per cent per annum growth rate of global emissions (Table 3), yielding almost 19 billion tons of carbon annually by 2050 (Figure 2). The regional distribution of emissions changes sharply over this period. The OECD countries, which accounted for 49 per cent of global emissions in 1985, only account for 26 per cent in 2050. China becomes the single most important CO₂-emitter: its share of world emissions rises from 9.5 per cent in 1985 to 29 per cent in 2050. Rapid growth of emissions in China reflects its above-average growth rate and a switch towards coal. This latter factor is exacerbated by the low domestic price of coal.
Table 2. Fossil-fuel emission shares and prices in the benchmark data sets by country/region, 1985

(a) Share of fossil fuels in total C02 emissions (percentage)

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Japan</th>
<th>EC</th>
<th>Other OECD</th>
<th>Energy-exporting LDCs</th>
<th>China</th>
<th>Former Soviet Union</th>
<th>India</th>
<th>CEECs</th>
<th>DAEs</th>
<th>Brazil</th>
<th>RoW</th>
<th>WORLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>34.7</td>
<td>30.5</td>
<td>32.9</td>
<td>32.8</td>
<td>20.0</td>
<td>86.2</td>
<td>38.1</td>
<td>74.1</td>
<td>66.9</td>
<td>37.5</td>
<td>21.0</td>
<td>45.3</td>
<td>42.0</td>
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<tr>
<td>Crude oil</td>
<td>46.7</td>
<td>61.4</td>
<td>51.8</td>
<td>51.1</td>
<td>61.6</td>
<td>12.5</td>
<td>33.4</td>
<td>24.4</td>
<td>20.1</td>
<td>60.2</td>
<td>76.1</td>
<td>46.7</td>
<td>42.2</td>
</tr>
<tr>
<td>Gas</td>
<td>18.6</td>
<td>8.1</td>
<td>15.3</td>
<td>16.1</td>
<td>18.4</td>
<td>1.4</td>
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<td>13.0</td>
<td>2.3</td>
<td>2.9</td>
<td>8.0</td>
<td>15.8</td>
</tr>
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</table>

(b) Relative fossil-fuel prices \(^1\)
1985 prices and exchange rates; average U.S. price = 100

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Japan</th>
<th>EC</th>
<th>Other OECD</th>
<th>Energy-exporting LDCs</th>
<th>China</th>
<th>Former Soviet Union</th>
<th>India</th>
<th>CEECs</th>
<th>DAEs</th>
<th>Brazil</th>
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<th>WORLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>35.4</td>
<td>126.4</td>
<td>63.9</td>
<td>27.0</td>
<td>30.8</td>
<td>20.5</td>
<td>24.8</td>
<td>25.6</td>
<td>26.2</td>
<td>68.5</td>
<td>110.6</td>
<td>25.7</td>
<td>35.8</td>
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<tr>
<td>Crude oil</td>
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<td>178.3</td>
<td>166.7</td>
<td>136.8</td>
<td>99.4</td>
<td>155.0</td>
<td>24.1</td>
<td>95.4</td>
<td>100.1</td>
<td>135.2</td>
<td>123.8</td>
<td>142.5</td>
<td>119.9</td>
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<tr>
<td>Gas</td>
<td>92.5</td>
<td>167.1</td>
<td>140.6</td>
<td>81.9</td>
<td>84.4</td>
<td>106.7</td>
<td>17.0</td>
<td>61.3</td>
<td>44.9</td>
<td>166.1</td>
<td>71.9</td>
<td>198.6</td>
<td>76.4</td>
</tr>
<tr>
<td>Average</td>
<td>100.0</td>
<td>162.6</td>
<td>131.2</td>
<td>92.4</td>
<td>87.8</td>
<td>46.9</td>
<td>21.8</td>
<td>47.8</td>
<td>48.4</td>
<td>118.5</td>
<td>120.1</td>
<td>106.7</td>
<td>81.6</td>
</tr>
</tbody>
</table>

1. Defined as the unit value of one terajoule relative to the average unit value of fossil fuels in the United States. Fossil-fuel demands are converted into a common energy unit (1 terajoule = 10 E 12 joules). This facilitates the conversion into tons of carbon emitted with the help of widely-used conversion factors: 1 terajoule of coal = 23.3 tons of carbon, 1 terajoule of oil = 19.2 tons of carbon, 1 terajoule of gas = 13.7 tons of carbon.
Table 3. **Carbon emissions by region in the BaU scenario**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>United States</td>
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<td>1.2</td>
<td>0.9</td>
<td>0.7</td>
<td>0.9</td>
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<tr>
<td>Japan</td>
<td>2.8</td>
<td>-0.4</td>
<td>1.2</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>EC</td>
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<td>0.7</td>
<td>0.7</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Other OECD</td>
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<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
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<td>2.6</td>
<td>2.6</td>
<td>2.1</td>
<td>2.5</td>
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<tr>
<td>China</td>
<td>2.0</td>
<td>4.5</td>
<td>3.9</td>
<td>3.2</td>
<td>3.7</td>
</tr>
<tr>
<td>Former Soviet Union</td>
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<td>1.2</td>
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<td>India</td>
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<td>4.3</td>
<td>4.0</td>
<td>3.6</td>
<td>3.9</td>
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<td>CEECs</td>
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<tr>
<td>DAEs</td>
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<tr>
<td>Brazil</td>
<td>3.0</td>
<td>2.1</td>
<td>2.3</td>
<td>2.2</td>
<td>2.3</td>
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<tr>
<td>RoW</td>
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<td>2.5</td>
<td>2.2</td>
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<tr>
<td>Total OECD</td>
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<td>0.9</td>
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<td>1.0</td>
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<tr>
<td>Total non-OECD</td>
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<td>3.0</td>
<td>2.6</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td>World</td>
<td>1.9</td>
<td>2.1</td>
<td>2.0</td>
<td>1.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Figure 2. **Carbon emissions in the BaU scenario**

Million tons of carbon
II. AN INTERNATIONAL AGREEMENT TO STABILISE OECD CO2 EMISSIONS

This section considers an agreement whereby all the OECD countries acting jointly restrict their emissions while the non-OECD countries take no action. The target chosen for this scenario is one of stabilising CO2 emissions by the year 2000 at 1990 levels. This particular target has the merit of being in line with the Framework Convention on Climate Change. It is also very close to the announced commitments by OECD Member countries for dealing with global climate change.

The policy instrument to achieve this stabilisation target is a country-specific carbon tax, i.e. each country levies a tax on fossil fuels in proportion to the carbon they emit into the atmosphere during combustion. In all GREEN simulations, the assumption of revenue-neutrality is maintained by varying the tax rate on household income so as to offset the effects of changes in government revenues arising from carbon taxes.

In this simulation all OECD countries except Japan are assumed to stabilise their emissions in 2000 at their 1990 levels; Japan, in line with its announced commitment, is assumed to stabilise on a per capita basis. The emissions restrictions are imposed gradually over the decade starting from 1990 and the targets are maintained until 2050.

For the OECD countries to achieve this stabilisation target requires a significant cut in their emissions: relative to the BaU path, their emissions would be 44 per cent lower by 2050 (see Table 4). But OECD action alone has a marginal impact on global emissions which are only 11 per cent below their BaU level in 2050.

Table 4. Main results from scenario in which the OECD countries stabilise their emissions over the period 2000-2050 at 1990 levels

<table>
<thead>
<tr>
<th>Cut in CO2 emissions in 2050 (% relative to BaU)</th>
<th>Carbon tax in 2050 (1985$/ton of carbon)</th>
<th>Present value of real income changes over the period 1995-2050 (% relative to BaU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>-43</td>
<td>66</td>
</tr>
<tr>
<td>Japan</td>
<td>-59</td>
<td>236</td>
</tr>
<tr>
<td>EC</td>
<td>-37</td>
<td>88</td>
</tr>
<tr>
<td>Other OECD</td>
<td>-44</td>
<td>81</td>
</tr>
<tr>
<td>Total OECD</td>
<td>-44</td>
<td>93</td>
</tr>
</tbody>
</table>

1. Carbon leakages

It has been argued that emissions may increase in non-OECD countries which do not take similar action to the OECD countries in order to stabilise their emissions – the
phenomenon of so-called "carbon leakages". There are two possible sources of such carbon leakages in GREEN. First, energy-intensive industries may gain in competitiveness in the non-OECD countries as relative energy prices in the OECD countries are raised by the carbon tax. Second, if the restriction imposed by the OECD agreement is sufficiently binding, world prices of fossil fuels may fall, thereby raising emissions in the non-OECD countries. See the paper by Oliveira-Martins, Burniaux and Martin in this volume for a detailed discussion of carbon leakages.

The fall in OECD output of energy-intensive industries is quite small in response to the stabilisation target: on average over the period 1990-2050, OECD output of these industries is only 1.7 per cent below its BaU level. The largest decline is recorded in Japan (−3.1 per cent) and the smallest (−0.4 per cent) in the United States. The corresponding expansion of these industries in the non-OECD regions is even smaller: output, averaged over all eight regions, is almost 1 per cent above BaU levels. Most of the gains in competitiveness are captured by the CEECs, the DAEs and the former Soviet Union: output of the energy-intensive industries in these regions expands on average by between 0.7 and 1.5 per cent.

Carbon leakages in the non-OECD countries show differing patterns across regions and over time as emissions increase in some regions, notably in the former Soviet Union, in response to the cut in OECD countries while they decline in others, notably in the Energy-exporting LDCs and China. Emissions decrease slightly in the Energy-exporting LDCs as a result of the fall in output induced by lower oil exports to the OECD regions. In China, emissions also fall slightly as a result of substitution from coal to oil in response to the small fall in the oil price. Averaged over all non-OECD regions, some leakages do occur but they are insignificant, peaking at 3 per cent of the cut in OECD emissions in 2000.

2. Region-specific carbon taxes

Back-stop technologies play a crucial role in determining the level of carbon taxes in the long run in GREEN – see the Appendix in the paper by Burniaux et al. in this volume for a detailed discussion of the determinants of the carbon tax. Before it reaches the level at which a back-stop substitute becomes competitive, the carbon tax is determined by four main factors: average energy prices, the carbon content of primary energy demand, the emission reduction target and the overall ease of substitution between inputs. But, as soon as one conventional energy source competes with its back-stop alternative, its price (inclusive of the carbon tax) stops rising and the carbon tax stabilises at a level determined by the arbitrage condition between the two energy sources.

When the conventional energy source has been completely replaced by its back-stop alternative, the overall level of inter-energy substitution is reduced given the assumption in GREEN that all energy sources are imperfect substitutes. Thus, the expectation is that the carbon tax will start rising again until it reaches the level at which a more expensive back-stop source becomes competitive and begins to crowd out the corresponding conventional energy source.

With the exception of Japan, the carbon taxes required to achieve the stabilisation target are very similar across OECD regions. The carbon restrictions can be met by cutting back on the use of the carbon-based synthetic fuel. Therefore, as long as some synthetic fuel is being used, the implied demand for carbon is very elastic and the taxes
in the United States, EC and Other OECD regions stabilise from 2010 on in a narrow range of $50-90 per ton of carbon (in 1985 prices and exchange rates). The highest tax, at almost $240 per ton in 2050, is recorded in Japan (Table 4). The high tax in Japan reflects the fact that it has the most severe emissions restriction – it is required to cut emissions by almost 60 per cent in 2050 compared with the BaU level, as well as the highest relative fossil-fuel prices in the BaU scenario.

3. Effects on economic welfare

The imposition of carbon taxes changes economic welfare in all regions via the familiar deadweight burden of the tax; it also generates terms-of-trade movements which can raise or lower welfare depending on their direction. In GREEN, changes in economic welfare are measured in terms of the so-called “Hicksian equivalent variation”, defined as the amount of income a consumer would need before the imposition of a carbon tax to allow him to reach the welfare level he actually achieves after the tax is imposed. For convenience, this measure is referred to as “real income”. The resulting real income changes when a tax is imposed are discounted, reflecting the assumption that households assign a smaller weight to future welfare changes.9

Achieving the stabilisation target imposes a small real income loss on the OECD countries from 2005 on (Figure 3). Before then, they record small real income gains as the improvement in their terms of trade arising from the cut-back in oil imports more than offsets the efficiency losses due to the carbon tax. The OECD regions' terms of trade deteriorate from 2030 on as they substitute towards crude oil, adding to their welfare loss which reaches 1.3 per cent by 2050. Over the entire period, the real income loss to the OECD countries is 0.7 per cent (in present values). Cutting back emissions in the OECD countries alone has only marginal effects on real income in the

Figure 3. Real income changes under the stabilisation scenario
Percentage deviations relative to BaU

![Graph showing real income changes under the stabilisation scenario.](image)
non-OECD countries, with the sole exception of the Energy-exporting LDCs. This latter region experiences welfare losses over most of the simulation period: its maximum real income loss is almost $3/2$ per cent below BaU levels in 2005, with the loss declining steadily after 2010 and even turning into a small gain in 2050 as the substitution away from the carbon-based synthetic fuel in the OECD regions raises the demand for crude oil. Over the entire period, its real income loss (in present values) is 1 per cent.

In sum, if the OECD countries were to restrict their emissions in line with the Framework Convention stabilisation target using national carbon taxes, this would have only a very small restraining effect on the growth of world emissions into the next century. The next section considers the effects on global emissions of extending the agreement to encompass the non-OECD regions. It also quantifies the gains from cost-effective agreements.

III. INTERNATIONAL AGREEMENTS INCLUDING THE NON-OECD REGIONS

Any international agreement which aims to curb man-made CO₂ emissions significantly must be extended beyond the OECD area to include the major CO₂-emitting countries outside the OECD area. At the same time, a stabilisation target would require the non-OECD countries to accept a much more stringent emissions cut than the OECD regions because the BaU path shows much faster growth of emissions in some of the main non-OECD regions. Thus, the international agreement which is simulated in this section – a so-called Toronto-type agreement – imposes a lesser burden on the non-OECD regions in terms of emissions curbs than would be implied by their acceptance of a target of stabilisation in 2000 at 1990 levels.

A. A Toronto-type agreement with region-specific carbon taxes

Under a Toronto-type agreement, it is assumed that i) the OECD countries would cut back their emissions in 2010 to 80 per cent of their 1990 levels and stabilise them thereafter; and ii) emissions in the non-OECD regions would be restricted to be 50 per cent higher than their 1990 levels by 2010, and stabilised thereafter. We begin by assuming that these targets are achieved via region-specific carbon taxes. This is the benchmark against which one can assess the gains from a cost-effective version of the agreement.

The net result of this agreement is that world emissions stabilise by 2010 at 6.8 billion tons of carbon per year, one-third of the BaU level in 2050 (see Figure 4). This scenario implies a relatively larger proportional cut in emissions relative to BaU levels in the non-OECD countries (67 per cent) by 2050 compared with a cut of 55 per cent in the OECD countries, reflecting the fact that BaU emissions growth is much faster in the non-OECD regions, with the notable exceptions of the former Soviet Union
Figure 4. Impact of a Toronto-type agreement on emissions

A. Levels of emissions

Non-OECD emissions cut by 64% in 2050
OECD: emissions cut by 55% in 2050

B. Distribution of emission cuts in 2050 by region

ROW 5%
Brazil 1%
DAEs 2%
CEECS 3%
India 10%
Formen USSR 6%

38% China

and the CEECs. By 2050, the OECD area only accounts for 22 per cent of the global emissions cut whereas India and China together bear almost half of the global burden.

In order to put the magnitude of such emission cuts into some perspective, the IPCC (1990) has noted that to stabilise CO2 concentrations in the atmosphere by the middle of the next century at about 450 parts per million compared with 350 currently, might require cutting back man-made global emissions to about 4 billion tons of carbon per year by 2050. Relative to the GREEN BaU scenario, this represents a cut of 80 per cent in the year 2050.
1. Carbon taxes

Levying carbon taxes puts downward pressure on the real oil price. By the year 2030, the world oil price is 13 per cent below its BaU level. After 2030, the oil price rises faster than in the BaU scenario as carbon taxes make the carbon-based synthetic fuel unprofitable and the oil supply constraint in the Energy-exporting LDCs becomes binding.

On average, the OECD carbon tax rises to a peak of $280 per ton of carbon (in 1985 prices) in 2005, before falling back slowly to $137 in 2050 compared with a global average tax of over $170 (Figure 5). The dispersion of taxes across OECD regions is particularly wide before 2010 when no back-stop options are available. As back-stops come on stream, OECD countries tend to rely heavily in the BaU case on the carbon-based synthetic fuel, the "dirtiest" energy source. Thus, carbon taxes tend to converge on the levels at which synthetic fuel is no longer profitable as an energy source.10

Before 2010, when back-stops are not available, taxes reflect rates of emissions growth and relative energy prices across countries. As Japan has the fastest growth of emissions among the OECD regions over this period as well as the highest relative energy prices (see Table 2), it requires very high taxes to meet the emission constraint. The hump-shaped profile of the carbon tax over the period 1995-2010 reflects the interaction of the putty/semi-putty specification of technology in GREEN – the short-run elasticity of inter-energy substitution is very low relative to the long-run value – with the phasing-in of the emission restriction. In these circumstances, much higher taxes are required in the short run to meet the emissions constraint.11

Compared with the OECD countries, carbon taxes are much lower in the former Soviet Union and the CEECs. Carbon constraints do not become binding before 2005 in the former Soviet Union and 2010 in the CEECs. With low rates of emissions growth in the BaU scenario and heavily subsidised fossil-fuel prices, these regions do not require high taxes to meet their constraints: by 2050, taxes are still below $50, a level at which no back-stop options are profitable.

The other non-OECD regions fall into two distinct groups: i) low-cost countries which either rely massively on cheap, subsidised coal (China and India) or on the carbon-based synthetic fuel (RoW); and ii) high-cost countries which combine above-average GDP growth with energy demand relying mainly on oil (Brazil, DAEs and the Energy-exporting LDCs). Taxes in the low-cost countries are negligible until 2010, but they rise steadily thereafter as the constraints become more binding: by 2050, both China and India have a tax of over $280 per ton of carbon. In both China and India, the marginal cost of replacing coal as an energy source rises sharply over time as coal continues to be heavily subsidised; as a result it never gets eliminated as an energy source by the synthetic fuel back-stop in the BaU scenario. In RoW, the required carbon reduction can be achieved at a lower cost than in China and India by eliminating the carbon-based synthetic fuel.

In Brazil, the DAEs and the Energy-exporting LDCs, on the other hand, stabilising emissions post-2010 requires taxes sufficiently high to permit the carbon-free synthetic fuel to replace oil. Indeed, Brazil has the highest marginal abatement cost of all the non-OECD regions for most of the period because its electricity sector already relies mainly on hydro-power, a "clean" energy source. The Energy-exporting LDCs rely mainly on oil and, since they subsidise its use domestically, their marginal abatement cost is likely to rise rapidly over the long run.
Figure 5. Carbon taxes under the Toronto-type agreement
1985 $ and exchange rates per ton of carbon

A. OECD regions

B. Former Soviet Union and the CEECs

C. Other non-OECD regions
Thus, Figure 5 shows that marginal abatement costs under a Toronto-type agreement are higher in the OECD regions than in the non-OECD regions until the back-stops come on stream post-2010. By 2050, the situation is completely reversed: emission reductions are much more costly in some non-OECD regions, especially in the low-income, coal-based economies (China, India) and in the DAEs and Brazil.

2. **Use of back-stop options**

Total primary energy demand in the OECD regions recovers to its 1990 level in 2050 thanks to the growing penetration of the carbon-free electric option (Figure 6a). The major changes in the composition of OECD energy demands are: i) the decline in the share of the carbon-based synthetic fuel (down from 18 per cent in the BaU scenario to only 8 per cent by 2050); ii) the rise in the share of oil (up from 9 per cent in the BaU to 28 per cent); and iii) the increase in the share of the carbon-free electric option (up from 9 per cent in the BaU to 23 per cent).

The growing reliance of the OECD countries on a "clean" back-stop contrasts with its negligible market share in the non-OECD regions (Figure 6b). Cutting back on the demand for coal accounts for 85 per cent of the required emissions reduction in the latter regions.

3. **Terms of trade**

The OECD countries experience terms-of-trade gains over most of the period as the carbon constraints force them to cut back sharply on oil imports. These terms-of-trade gains peak around 2010 and begin to ebb away slowly thereafter as the restrictions can be met by using the clean back-stop options instead of cutting down on oil imports. By 2050, all the OECD regions record terms-of-trade losses as carbon taxes induce them to substitute oil imports for the carbon-based synthetic fuel.

Most non-OECD regions experience very small terms-of-trade losses or gains. But there are three exceptions: Brazil, which is very reliant on imported oil, experiences very large terms-of-trade gains up to 2030. The Energy-exporting LDCs experience a sharp terms-of-trade loss until 2030, in line with the decrease of the world oil price relative to the BaU scenario; their terms of trade, however, recover sharply after 2030 as a result of the switch by the OECD countries away from the carbon-based synthetic fuel towards imported oil. Finally, China experiences a growing terms-of-trade loss from 2030 on as it responds to the carbon restriction by substituting oil imports for coal. These substitutions reflect the initial pattern of energy prices in China: coal is heavily subsidised whereas the domestic oil price is very close to the world price.

4. **Welfare effects**

Figure 7a shows that the real income loss of the OECD countries fluctuates over the period. It reaches 2 per cent in 2010 but, as the back-stops lower the costs of cutting emissions between 2010 and 2030, the real income loss falls to 1.3 per cent in 2030. It increases again after 2030 to reach 2.4 per cent in 2050 as a result of growing terms-of-trade losses in line with the increase of the world oil price. Over the period as a whole, the OECD countries record a real income loss of 1.4 per cent (in present values - see Table 5).
The CEECs enjoy welfare gains for most of the period while the former Soviet Union records very small losses (Figure 7b). Their carbon constraints are not binding before 2010 and are moderate thereafter; at the same time, they benefit from the falling oil price until 2030 – the former Soviet Union becomes a net oil importer after 2020. Both regions experience small welfare losses in 2050 as the world oil price hardens.

Figure 7c reveals a very diverse set of welfare impacts among the other non-OECD regions. Before 2030, the largest losses are recorded by the Energy-exporting
Figure 7. Real income effects under a Toronto-type agreement
Percentage deviations relative to BaU

A. OECD regions

B. Former Soviet Union and CEECs

C. Other non-OECD regions

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Table 5. Summary of main results from a Toronto-type agreement with region-specific carbon taxes

<table>
<thead>
<tr>
<th></th>
<th>Cut in CO₂ emissions in 2050 (% relative to BaU)</th>
<th>Carbon tax in 2050 (1985$/ton of carbon)</th>
<th>Present value of real income changes over the period 1995-2050 (% relative to BaU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>-54</td>
<td>122</td>
<td>-1.4</td>
</tr>
<tr>
<td>Japan</td>
<td>-66</td>
<td>243</td>
<td>-1.8</td>
</tr>
<tr>
<td>EC</td>
<td>-49</td>
<td>118</td>
<td>-1.4</td>
</tr>
<tr>
<td>Other OECD</td>
<td>-55</td>
<td>139</td>
<td>-1.1</td>
</tr>
<tr>
<td>Energy-exporting LDCs</td>
<td>-65</td>
<td>434</td>
<td>-7.9</td>
</tr>
<tr>
<td>China</td>
<td>-83</td>
<td>284</td>
<td>-5.0</td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>-33</td>
<td>28</td>
<td>-0.2</td>
</tr>
<tr>
<td>India</td>
<td>-85</td>
<td>292</td>
<td>-2.0</td>
</tr>
<tr>
<td>CEECs</td>
<td>-41</td>
<td>49</td>
<td>0.9</td>
</tr>
<tr>
<td>DAEs</td>
<td>-69</td>
<td>461</td>
<td>-1.4</td>
</tr>
<tr>
<td>Brazil</td>
<td>-62</td>
<td>420</td>
<td>0.5</td>
</tr>
<tr>
<td>RoW</td>
<td>-59</td>
<td>165</td>
<td>-1.6</td>
</tr>
<tr>
<td>OECD</td>
<td>-55</td>
<td>137</td>
<td>-1.4</td>
</tr>
<tr>
<td>World</td>
<td>-64</td>
<td>174</td>
<td>-2.3</td>
</tr>
</tbody>
</table>

LDCs – their real income is over 10 per cent below baseline in 2030. Brazil and the DAEs record welfare gains in line with the falling world oil price. Post-2030, there is a significant shift in the patterns of welfare gains and losses. The recovery of oil demand in the OECD countries and OPEC supply shortages combine to produce an income shift in favour of the Energy-exporting LDCs. As a result, their welfare loss narrows sharply to 3.4 per cent in 2050. Over the period as a whole, the real income loss in this region is 7.9 per cent (in present values). By the end of the simulation period, China and India become the main losers among the non-OECD regions as a result of their high carbon taxes: by 2050, their welfare losses reach 9 and 4.6 per cent, respectively.

B. Cost-effective agreements

A Toronto-type agreement is not a cost-effective agreement given the very wide dispersion in marginal abatement costs across regions revealed in Figure 5. Therefore, it is important to quantify the potential magnitude of the welfare gains that could be reaped by the global economy if the agreement were extended to allow the marginal costs of cutting emissions to be equalised across regions. This is the condition for a cost-effective international agreement, defined as one which achieves a target goal for curbing global emissions at least cost.

Two alternative cost-effective versions of a Toronto-type agreement are considered in this paper: the first involves an international carbon tax and the second tradeable emission permits. Abstracting from administrative considerations, these two alternative policy instruments achieve a cost-effective solution under certain conditions e.g., all countries are “small” and there is no uncertainty. However, they do not produce the same distribution of welfare gains and losses across regions. In this section, the
magnitude of the welfare gains from a cost-effective agreement is quantified and it is shown how the distribution of the gains and losses across regions is influenced by the initial allocation of emission rights. The next section reviews some other important considerations governing the choice between a carbon tax and tradeable permits which are not modelled in GREEN.

1. **Common carbon tax in all regions**

A first scenario is simulated in which every region applies a common equilibrium tax which achieves the same cut in global emissions as under a Toronto-type agreement. However, the level of emissions cut in each region equalises its specific marginal cost to the common world tax and is in general different from that achieved under a Toronto-type agreement with region-specific carbon taxes. The revenues raised by the tax in each region are assumed to remain in the region; there is no pooling of revenues such as would occur under an international tax agency which redistributes them to all regions to achieve certain equity goals.

The global carbon tax falls to $154 per ton of carbon in 2050 compared with an average tax of $174 in the case of country-specific emission targets. The gains to the world economy from implementing a cost-effective version of a Toronto-type agreement are significant: this produces an average welfare gain to the world as a whole over the period 1995-2050 of 1.2 per cent (in present values) i.e. it reduces the global welfare loss from meeting a Toronto-type target by over 50 per cent.

Figure 8 compares the average real income changes under the Toronto-type agreement with those yielded by the imposition of a common global tax. It shows that

![Figure 8. Average real income changes under three alternative Toronto-type agreements](image-url)
the Energy-exporting LDCs gain substantially from this latter agreement. Cutting back on oil demand is an expensive way of curbing emissions and any alternative distribution of emissions curbs which cuts back more on coal demand will be more cost-effective at the world level. On the other hand, such a cost-effective agreement shifts the burden of stabilising emissions from the OECD regions and semi-industrialised LDCs to coal-based economies whose real incomes fall more than under the Toronto-type agreement. It also has a significant impact on the oil price profile. Oil demand decreases less than under the previous scenario and the oil price increase post-2030 is larger: by 2050, the world oil price is 18 per cent higher than its BaU level.

2. **Toronto-type agreement with tradeable permits**

Permits trading provides a way of disconnecting the distribution of real income losses from the cost-effective distribution of emission cuts in order to make it more compatible with equity goals, thereby increasing the likelihood that all countries will implement the agreement. An international agency which pooled the revenues from a global carbon tax and redistributed them could, of course, achieve the same aim. In this simulation, specific restrictions on CO₂ emissions in line with the Toronto-type scenario are regarded as initial endowments of emission rights which can be freely traded between regions. These endowments are fixed over the simulation period. This initial allocation rule is arbitrary and it can be varied in GREEN to reflect a variety of international distributional considerations. When trade in emission rights is allowed and all regions are assumed to be "small" in the world market for permits, *i.e.* no region has

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**Figure 9. Trade in emission rights under a Toronto-type agreement**

- US
- EC
- Other OECD
- Japan
- Energy-exporting LDCs
- CEECs
- Former USSR

1. The shaded area shows the percentage of global emissions that are traded in each period.
2. The group "Others" includes China, India, DAEs, Brazil and ROW.

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market power, emission cuts will be optimally allocated across regions when the price of permits (the shadow price of the CO₂ constraint) is equalised in all regions.

Figure 9 shows the resulting patterns of trade in permits over the period. Traded emissions rise to 12 per cent of global emissions in 2010 and this share remains rather stable thereafter. A major factor driving this large trade in permits is the generosity of the initial endowment of permits to the former Soviet Union and the CEECs relative to their low marginal abatement cost. As their emissions growth in the BaU is much lower than in the other non-OECD regions, they benefit from this allocation rule.¹³

The former Soviet Union is the major seller of permits: by 2050, it accounts for almost 80 per cent of all permits traded, with the remainder being sold by the CEECs. Before 2030, the main buyers of permits are the OECD regions, principally the United States and the EC. But as the OECD regions increase their reliance on back-stop options, their demands for permits correspondingly shrink. From 2030 on, China, Brazil, the DAEs and especially the Energy-exporting LDCs become the main buyers of permits. Because they subsidise their domestic energy prices so heavily, these regions make no use of back-stop options and, hence, have a strong incentive to buy permits instead. Thus, tradeable permits provide them with a substitute for the use of back-stops.

3. Distribution of welfare gains and losses under tradeable permits

Figure 8 shows how tradeable permits modify the regional distribution of welfare gains and losses compared with the case of a common global tax. The former Soviet Union and the CEECs benefit from permit trading to such an extent that they would record net real income gains (7 and 2 per cent, respectively) from such an allocation of emission rights. On the other hand, regions which have to buy permits suffer real income losses relative to the scenario of a common tax, although some of them still gain compared with the initial Toronto-type agreement.

Relative to the initial agreement with region-specific constraints, OECD countries and RoW are slightly better off under permit trading whereas some semi-industrialised LDCs which rely more on crude oil – such as the DAEs and Brazil – report higher welfare losses. In these latter countries, the additional burden from the international oil price increase and from buying permits is not outweighed by the benefit from applying lower carbon restrictions.

IV. OTHER CONSIDERATIONS GOVERNING THE CHOICE BETWEEN TAXES AND PERMITS

The previous section showed that an international agreement to curb emissions which was based on either a common global carbon tax or tradeable permits could produce significant welfare gains to the world economy. The amount of the global welfare gains was identical for either instrument reflecting the formal equivalence of the
two instruments under certain conditions. At the same time, they produced a different distribution of gains and losses across regions.

Abstracting from equity goals, the choice between a common tax or tradeable permits is governed by several important considerations which are not modelled in GREEN. For example, the two instruments are no longer equivalent in terms of economic efficiency once allowance is made for uncertainty about quantities and/or prices. A system of tradeable permits guarantees relative certainty about the size of emissions cuts, thereby minimising the degree of quantity uncertainty. In contrast, a carbon tax fixes the prices of fossil fuels and lets the level of emissions vary in response to the new relative price signals, thereby minimising price uncertainty.

Since climate change is related to the build-up of CO₂ and other GHGs in the atmosphere, this would seem to favour an approach based on tradeable permits as opposed to a carbon tax. But the situation is more complicated since neither the costs or the benefits of avoiding climate change are known with any certainty. In this situation it all depends on policy-makers evaluation of the relative balance of economic risks vs. environmental risks.

If it is believed that the marginal cost of controlling emissions is likely to rise rapidly whereas the marginal damage costs are likely to rise more slowly, this would tend to favour a carbon tax over tradeable permits. If, on the other hand, it is thought that the environmental risks are greater, this would favour a permits approach. Oates and Portney (1991), for example, believe that the former situation is more likely and opt for the imposition of a carbon tax, at least until the basic scientific and economic uncertainties are better clarified.

In addition to judgements about uncertainty, there are also more practical considerations which have to be taken into account in any choice between taxes and permits as instruments to control emissions, both at a domestic and international level. First, there is a range of administrative issues concerned with implementation, monitoring and enforcement. On these grounds, many observers express a preference for a carbon tax. While a tax would impose an additional collection burden on the tax authorities and economic agents, it would not require the development of new agencies and markets within individual countries – as would be the case with permits. The basic problem is that there is very little operational experience with national permit schemes, except in the United States.

This latter consideration is probably more important in the context of an international agreement. It is, of course, difficult to imagine countries agreeing on a common carbon tax and an effective system of monitoring and enforcement of such a tax to minimise "free-rider" behaviour. But this looks a less insurmountable problem compared with the difficulty of setting up an international market in permits, ensuring that the resulting market is competitive and reaching agreement on the initial allocation of permits and how this might be varied over time. This suggests that any international agreement to control CO₂ emissions which aspires to be cost-effective, should probably favour the common tax route. This was indeed the approach favoured by the EC Commission in its recent proposal for a comprehensive strategy to stabilise the Community's emissions; it proposed, however, to impose a mixed energy cum carbon tax rather than a pure carbon tax.
V. CONCLUSIONS

The threat of global warming is a result of increasing CO$_2$ concentrations in the atmosphere, among many other factors. This has given rise to international negotiations on measures to avert climate change which culminated recently in the UN Framework Convention on Climate Change which was signed in Rio. The GREEN simulations presented in this paper have been designed to assess the economic costs of such agreements and their distribution across countries.

Actions by the OECD countries alone to stabilise emissions in 2000 at 1990 levels – a target which corresponds roughly to their announced commitments to combat global climate change and is in line with the Framework Convention – would result in an average cut-back of OECD emissions of 44 per cent in the year 2050 compared with the level that would have been expected in the absence of these actions (the so-called “Business-as-Usual” (BaU) scenario). This, however, leads to a fall of only 11 per cent in global emissions in 2050; this highlights the key message that action to tackle the climate change issue must include the major non-OECD countries if it is to have any hope of success. The cost to the OECD countries of achieving this stabilisation target is reasonably small: their real income is 0.7 per cent lower in present values.

When the international agreement is extended to bring in the non-OECD regions, the resulting Toronto-type agreement would cut world emissions in 2050 by almost two-thirds below BaU levels, implying continuing growth in atmospheric concentrations of CO$_2$. Given the wide differences in marginal costs of abating emissions across regions, this is not a cost-effective agreement, suggesting that modifications to it could produce welfare gains while achieving the same global curb on CO$_2$ emissions.

A cost-effective agreement could potentially be achieved by imposing the same equilibrium carbon tax on all participating countries, leaving each country free to achieve the optimal reduction of its emissions, or by allowing countries to trade emission rights freely on a world market. Even though these two policy instruments produce a cost-effective version of a Toronto-type agreement, they do not yield the same distribution of gains and losses across regions unless the revenues from the tax are redistributed in such a way that they match the allocation rule for endowing countries with permits.

When all regions impose a common international carbon tax, the global welfare loss is only 1 per cent (in present values), 1¼ percentage points lower than under a Toronto-type agreement in which each region has to achieve specific reductions. Emission reductions are shifted from countries in which the marginal cost of cutting emissions is higher – mainly the OECD countries and some semi-industrialised LDCs – to coal-based economies where emission curbs can be achieved at a lower marginal cost. The Energy-exporting LDCs benefit from this reallocation as carbon reductions are achieved by cutting back more on coal instead of oil use. The OECD countries contribute less to the global emissions reduction than in the previous scenario and the coal-based economies (China, India, the former Soviet Union and the CEECs) bear more of the burden of stabilising world emissions.
Although a Toronto-type agreement which imposes a common carbon tax across all regions is less costly for the world as a whole, it still implies significant welfare losses for some non-OECD regions. These regions are unlikely to be willing to implement such an agreement unless they are offered some compensation. One way to achieve this would be to extend the scope of the agreement to allow participating countries to trade emission rights. A central consideration behind any such decision would be the initial allocation of emission rights and how this is to be modified over time; these choices, as a simulation with GREEN highlights, have a major impact on the distribution of gains and losses associated with a cost-effective allocation of carbon cuts across regions.

The choice between a common carbon tax and tradeable permits also depends on certain considerations which are not modelled in GREEN, e.g. administrative costs and the relative balance of economic risks vs. environmental risks. On balance, it appears that these arguments may favour a tax approach rather than a permits approach if the global economy wishes to reap the significant welfare gains that the GREEN simulations in this paper suggest could accrue from a cost-effective international agreement.
NOTES


2. The results of some sensitivity analysis around the GREEN BaU emissions path which involved changing the values of certain key exogenous variables are described in Burniaux et al. (1992a).

3. See Newbery (1992) and Hoeller and Coppel (1992) for discussions of this point.

4. Shah and Larsen (1991) review energy pricing regimes in developing countries and highlight the fact that substantial subsidies for fossil-fuel use exist in a small number of countries which emit large quantities of CO₂ into the atmosphere. The paper by Burniaux et al. in this volume quantifies the levels of energy taxes and subsidies in 1985 in all regions of GREEN and compares them with the equivalent estimates by Shah and Larsen.

5. The endogenous oil price profile in GREEN is very close to the exogenous profile laid down for EMF12. This reflects the importance of back-stop prices in determining the oil price and the fact that the EMF12 assumptions concerning the level of back-stop prices have been adopted in GREEN.

6. GREEN has also been used to simulate the effects of agreements by a sub-set of OECD countries taking joint action. See Burniaux et al. (1992b) for an attempt to quantify the effects of the recent EC Commission proposal to levy a mixed energy cum carbon tax with the explicit aim of stabilising Community emissions in the year 2000 at 1990 levels.

7. See IEA (1991) for an up-to-date overview of the status of OECD countries' formal commitments to actions to deal with climate change.

8. With the Japanese population projected to decline by 0.2 per cent per annum from 2010 on, the emissions restriction imposed in Japan is relatively more stringent than in the other OECD regions by the end of the period since the projected Japanese population in 2050 is below its 1990 level.

9. For a detailed discussion of this welfare measure and how it is computed in GREEN, see the paper by Burniaux et al. in this volume.

10. This level is higher in Japan than in the other OECD regions because it taxes oil more heavily. The higher is the price of oil (including taxes), the higher must be the carbon tax which makes synthetic fuel unprofitable.

11. See the paper by Burniaux et al. in this volume for a discussion of the putty/semi-putty specification. Other models which have been used to address the climate change issue and which include putty-clay technology and back-stop technologies also show a hump-shaped profile of the carbon tax across regions up to 2010. This is the case with the Global 2100 model of Manne and Richels (1992) and the CRTM model of Rutherford (1992). Obviously, allowing for perfect foresight would smooth out this tax profile over time. But the Manne-
Richels model which includes the assumption of perfect foresight by economic agents still produces a hump-shaped profile of the carbon tax.


13. An alternative initial endowment of tradeable permits has been simulated with GREEN. This subjected the former Soviet Union and the CEECs to the same carbon restriction as the OECD regions. This allocation rule gave them a smaller initial endowment of permits. This resulted in less permit trading and less of the global burden of emission cuts being borne by the coal-based economies. The distribution of the gains from permit trading also changed, with a shift in the distribution of the gains between non-OECD regions in favour of China. See Burniaux et al. (1992a) for details on this simulation.


15. Berger et al. (1991) provide another argument in favour of a common carbon tax. They show that the two instruments do not have the same impact on the producer prices of fossil fuels when these markets are characterised by imperfect competition. Their analysis shows that, under imperfect competition, tradeable permits tend to imply higher producer prices and larger efficiency losses than a common carbon tax giving the same level of global emissions.

16. See OECD (1992b) for a review of national experiences with tradeable permits.
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