Assessing the impacts of the Kyoto Protocol
Impacts of Kyoto mechanisms on economic outcomes

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Greenhouse gas emission abatement targets agreed to by individual countries are set out in Annex B to the Kyoto Protocol. The protocol includes provision for the use of mechanisms such as emissions trading, the clean development mechanism and joint implementation to help parties meet their target commitments. Implementation of the Kyoto Protocol would have significant global economic implications.

In this paper the economic impacts of the Kyoto Protocol are examined, with an emphasis on the importance of emissions trading in reducing abatement costs. Lower economic costs, in turn, reduce the impacts on global energy markets. The potential for the clean development mechanism to further decrease the costs of meeting abatement commitments is examined.
Introduction
The world community adopted the Kyoto Protocol in December 1997 at the third Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The main achievement was agreement by developed (Annex B) countries to reduce or limit their greenhouse gas emissions. The aggregate target is a reduction in their combined emissions of approximately 5 per cent compared with 1990 levels for the commitment period, 2008–12.

To assist parties in meeting their emissions targets the protocol sanctions the use of economic instruments such as emissions trading, joint implementation, the clean development mechanism and the EU bubble (and possibly other bubbles) as specified in Article 4. The rules governing the use of these mechanisms are still to be negotiated. (See box 1 for an outline of some of the key provisions of the Kyoto Protocol.)

**Box 1: Key provisions of the Kyoto Protocol**

**Target commitments**
Developed countries, as listed in Annex B of the Kyoto Protocol, have collectively agreed to reduce their greenhouse gas emissions to at least 5 per cent below 1990 levels for the commitment period, 2008–12.

To achieve this collective objective, individual countries were allocated differentiated targets. Japan, the United States and members of the European Union have commitments to reduce greenhouse gas emissions to 6 per cent, 7 per cent and 8 per cent below 1990 levels respectively in the first commitment period. Australia is required to constrain greenhouse gas emissions to 8 per cent above its 1990 level.

Whether a country meets its commitments will be assessed by comparing its target with its emission inventory averaged over the period 2008–12. An average is used to reduce the influence of annual fluctuations in emission levels that could be caused by factors such as unusual weather conditions or cyclical changes in economic activity.

Since the third Conference of the Parties in Kyoto, the European Union has agreed to a differentiated internal burden sharing arrangement for the purposes of collectively meeting its commitments. Under this arrangement, which is provided for under Article 4 of the protocol, Portugal and Greece, for example, can increase emissions by 27 per cent and 25 per cent respectively, while Germany and Denmark have each agreed to reduce emissions by 21 per cent. The European Union has the opportunity to further revise its individual targets. Final targets will be included in the European Union’s ratification instrument as required by Article 4 of the protocol.

**Gases covered**
Anthropogenic sources of six greenhouse gases are to be included in national greenhouse gas emission inventories, including emissions from land use change. However, for the purposes of calculating the base period inventory, emissions from land use change are not included when defining the emission targets unless land use changes were a net source of emissions in 1990. The six greenhouse gases covered by the protocol are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

**Sources and sinks**
Reductions in greenhouse gas emissions from sources and removals of carbon by sinks (such as forestry activities, subject to certain limitations and future agreement on rules and methodologies) can be used to meet target commitments.
Box 1: Key provisions of the Kyoto Protocol (continued)

Kyoto mechanisms
There are a number of flexibility provisions in the protocol that, if implemented, would reduce the costs of meeting abatement targets. Emissions trading, joint implementation and the clean development mechanism are the key Kyoto mechanisms. The rules, guidelines and procedures governing these mechanisms are subject to ongoing negotiations.

Abatement projects between Annex B parties that generate greenhouse gas emission reduction credits fall into the category of joint implementation, while credits generated from abatement projects between Annex B and non-Annex B parties are provided for under the clean development mechanism. These credits can be used by Annex B countries to meet their emission commitments.

Developing country impacts
The impacts of climate change and climate change policy of most concern to developing countries can be broadly divided into two classes. The first class of impacts is the physical impact of climate change. These issues are covered primarily in Articles 4.8 and 4.9 of the UN Framework Convention on Climate Change. There is substantial coverage in both the scientific and economic literature of the potential physical impacts of climate change (see, for example, McMichael et al. 1996; Watson et al. 1996; Mendelson and Neumann 1999) and this issue will not be dealt with further here.

The second class of impacts is the indirect impact on developing countries of the implementation of response measures in developed countries designed to meet the Kyoto targets. These issues (as they relate to measures taken under the convention) are dealt with in Article 4.8 of the convention and (as they relate to measures implemented to meet commitments under the protocol) Article 3.14 of the protocol. These articles require Annex B parties to consider the actions necessary to meet the needs and concerns of developing countries adversely affected by climate change and/or the impact of the implementation of climate change response measures and ‘to strive to implement [their] commitments … in such a way as to minimise adverse social, environmental and economic impacts on developing country Parties …’ (Article 3.14 of the protocol).
 economy developed at ABARE to address policy issues with long term, global dimensions, such as climate change. It is derived from the MEGABARE model (ABARE 1996) and the GTAP model (Hertel 1997).

Anthropogenic (human induced) greenhouse gas emissions arise from many activities throughout the economy and therefore policies designed to constrain greenhouse gas emissions will influence almost every part of the economy. Models such as GTEM are able to capture the impacts of climate change policies on large numbers of economic variables such as emissions, prices, output and trade and investment flows between regions.

GTEM is an ideal tool for analysing climate change policies with wide ranging intersectoral ramifications because of its detailed coverage of regions, sectors and greenhouse gases, and its detailed modeling of energy markets. At its most disaggregated level, GTEM includes 50 industries in 45 countries and regions. The version used in this study divides the world into 23 regions and 19 industries. The greenhouse gas coverage in GTEM includes combustion and noncombustion carbon dioxide and methane and nitrous oxide, which account for around 99 per cent of global anthropogenic greenhouse gas emissions (IPCC 1996).

A nontechnical description of the major assumptions and features of GTEM is presented in appendix A of Polidano et al. (2000). For a more detailed description of the features of the model, refer to the ABARE web page (www.abareconomics.com).

The version of GTEM used in this paper includes a simplified representation of the effects of carbon sequestration in Kyoto forests in Annex B countries. The estimates of carbon sequestration through Annex B forestry activities incorporate afforestation and reforestation activities specified in Article 3.3 of the protocol, but do not include estimates of deforestation. The method used is explained in appendix B of Polidano et al. (2000). Additional sequestration potentially allowed under Article 3.4 is not included at this stage. Land clearing (Article 3.7) is not included due to the poor quality of available data. Work is underway to improve the representation of sinks in GTEM and this will be presented in an ABARE report to be released in the second half of 2000.

Reference case projections
The reference case modeled using GTEM provides projections of emissions growth and structural change in economies from 1996 to 2010. The reference case modeling assumes no greenhouse gas abatement policies and provides a scenario against which the impacts of abatement can be assessed.
Emissions growth

Global emissions of the three major greenhouse gases are projected to rise substantially in the absence of climate change policy, from 28 billion tonnes of carbon dioxide equivalent in 1990 to 40 billion tonnes by 2010. The projected growth in global emissions is driven largely by high projected emissions growth in non-Annex B countries, highlighting the importance of engaging developing countries in reducing emissions growth. In carbon dioxide equivalent terms the share of non-Annex B regions in global emissions is projected to increase from 40 per cent in 1990 to 55 per cent in 2010 (figure 1). The importance of key developing countries in emissions growth, particularly China, can be seen in table 1.

GDP growth is a key determinant of projected emissions growth (table 1). The expected rapid economic growth in developing countries contributes significantly to the high projected emissions growth in these regions.

<table>
<thead>
<tr>
<th>Contribution to global greenhouse gas emissions</th>
<th>Average annual growth in GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Australia</td>
<td>1.4</td>
</tr>
<tr>
<td>United States</td>
<td>20.9</td>
</tr>
<tr>
<td>Japan</td>
<td>4.5</td>
</tr>
<tr>
<td>European Union</td>
<td>13.6</td>
</tr>
<tr>
<td>Russian Federation, Ukraine and eastern Europe</td>
<td>11.0</td>
</tr>
<tr>
<td>China</td>
<td>15.2</td>
</tr>
<tr>
<td>India</td>
<td>5.1</td>
</tr>
<tr>
<td>Middle East</td>
<td>3.5</td>
</tr>
<tr>
<td>Mexico</td>
<td>1.5</td>
</tr>
<tr>
<td>Brazil</td>
<td>2.0</td>
</tr>
<tr>
<td>Other non-Annex B countries</td>
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</tr>
<tr>
<td>Annex B</td>
<td>54.0</td>
</tr>
<tr>
<td>Non-Annex B</td>
<td>46.0</td>
</tr>
</tbody>
</table>

*Emissions of carbon dioxide, methane and nitrous oxide. Includes sequestration according to Article 3.3 of the protocol (in Annex B regions only). Does not include emissions from deforestation.*
The reference case projections include preliminary estimates of carbon sequestration by forestry activities in Annex B regions. Sequestration by Annex B afforestation and reforestation activities specified in Article 3.3 of the protocol is estimated around 0.25 billion tonnes carbon dioxide equivalent at 2010.

Emissions growth in the Russian Federation, the Ukraine and eastern Europe is projected to be low and emissions are projected to stay below their Kyoto target levels at 2010 even without implementing policies to curb emissions. The low and negative economic growth experienced in these regions in the early 1990s is the reason for the low projected emissions growth.

**Energy consumption in the reference case**

Energy consumption is projected to rise more strongly in non-Annex B than in Annex B regions over the period to 2010. This results from the relatively high GDP growth and high energy intensity of production, and the structural development of these economies.

Energy intensity is typically higher in developing countries because production efficiency is usually lower, and because the economic structure of developing countries tends to be more energy intensive. Heavy industries on average contribute a larger share to total output in developing countries, while the share of services in the economy is smaller than in developed countries.

The economic structure of developing countries is projected to change significantly over the reference case. Energy intensive industries are projected to grow relatively fast, leading to rapid growth in energy consumption. In contrast, energy intensive sectors will be of diminishing importance in most Annex B regions.

Among fossil fuels, gas consumption is projected to grow fastest, particularly in Annex B regions, where the role of gas in electricity generation is projected to increase. Growth in oil consumption is projected to be slowest but oil will remain the dominant fuel over the projection period. Countries without domestic oil supplies are moving to reduce reliance on oil by switching to coal and gas where possible. However, limited substitution possibilities in the transport sector mean that reliance on oil will remain high. Coal is the dominant source of fuel in electricity generation and the reserves of low cost sources in many regions mean that it will retain its importance over the projection period in the absence of climate change response policies (table 2).

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Oil</th>
<th>Gas</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Renewables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>36.8</td>
<td>10.5</td>
<td>15.4</td>
<td>18.3</td>
<td>17.9</td>
<td>1.1</td>
</tr>
<tr>
<td>2010</td>
<td>36.7</td>
<td>6.8</td>
<td>25.1</td>
<td>13.1</td>
<td>17.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Global economic impacts of the Kyoto Protocol

To achieve emission reductions, Annex B countries would have to place explicit or implicit financial penalties on emitters. The imposition of carbon equivalent penalties on production increases the cost of fossil fuel combustion and, consequently, the production costs of energy intensive commodities such as electricity, iron and steel and nonferrous metals. In addition, the penalties will lead to reductions in fossil fuel consumption with impacts on world fossil fuel markets. As a result of such effects adoption of Kyoto emissions targets and mechanisms will affect economic growth and world trade, as well as investment flows and technology adoption.

To estimate the magnitude of economic impacts of the Kyoto Protocol, two policy scenarios are analysed here: independent abatement, where Annex B countries each meet their Kyoto emission abatement target through domestic policies only; and international emissions trading, where Annex B countries can trade emissions quota to assist in meeting their commitments.

The policy simulations presented in this paper assume that countries reduce national emissions gradually until reaching their Kyoto target in 2010. The model specification requires that a particular year be defined as the time at which the Kyoto targets are met. In practice, countries must meet their emissions target over an average of the years 2008–12.

An illustrative example of the potential impact of the clean development mechanism is provided later in the paper.

Carbon equivalent penalties

The carbon equivalent penalty estimated in GTEM can be interpreted as the marginal cost to the economy associated with any least cost policy designed to achieve a given level of emission abatement. Under independent abatement, the carbon equivalent penalty can be interpreted as the quota price in a domestic emissions trading scheme, an estimate of the uniform carbon equivalent tax needed in each particular region to hit the specified target or, more generally, the cost at the margin of any suite of policies that achieve emission reduction at least cost.

International emissions trading allows more abatement to be undertaken in countries where the marginal cost of abatement (at a given quota allocation) is lowest. Modeling an international emissions trading scheme requires the aggregate emissions in participating regions to be constrained to their emission reduction commitments under the Kyoto Protocol. The model determines a uniform carbon equivalent penalty across participating regions that is sufficient to meet the aggregate emission target. The individual Kyoto commitments represent an initial allocation of emissions quota among participating countries, which can be
traded between countries. The uniform carbon equivalent penalty can therefore be interpreted as the price of the international emission quota.

Importantly, it has been assumed that any revenue generated through the imposition of greenhouse gas abatement policies will be returned to the economy in a lump sum fashion. In other words, it is assumed there is no reinstrumentation of taxation policy in the process of putting in place climate change policy.

The size of the carbon equivalent penalty in Annex B regions under independent abatement (figure 2) depends mainly on the size of the emission abatement task and the cost of abatement options. Countries are assumed to use the least costly methods of reducing emissions first. As the size of the emission abatement task increases, lower cost abatement possibilities become increasingly scarce. As a result, the marginal cost of reducing emissions by an additional unit (the carbon equivalent penalty) increases as the abatement task rises.

The emission abatement task under independent abatement is represented by the change in emissions required in each Annex B region (figure 3).

The emission abatement task in an Annex B region depends on its reference case emissions growth and Kyoto commitment. For example, Canada is projected to have the greatest abatement task because emissions growth is projected to be the highest among Annex B regions (20 per cent between 2000 and 2010) and because Canada has a stringent target (94 per cent relative to 1990). Emissions in the Russian Federation, the Ukraine and eastern Europe are projected to increase under independent abatement relative to the reference case because projected reference case emissions are below their Kyoto commitments.
in these regions, allowing carbon equivalent leakage from Annex B countries that need to abate to meet their emission targets.

Japan has the lowest emissions intensity of production of Annex B countries as a result of significant reductions in fossil fuel use over recent decades in most sectors of its economy. Consequently, Japan has already exhausted many of its low cost abatement possibilities and the cost of further abatement is projected to be relatively high.

Emissions trading is projected to greatly reduce the magnitude of the carbon equivalent penalty relative to that under independent abatement. The average Annex B carbon equivalent penalty (in 1995 US dollar terms) is projected to be reduced to US$58 a tonne of carbon equivalent in 2010, or less than a third of that needed (on average across Annex B regions) under independent abatement. The key impact of emissions trading is that it allows more emission abatement to take place in regions where pre-trade marginal emission abatement costs are low, such as in the Russian Federation, the Ukraine and eastern Europe. The Russian Federation, the Ukraine and eastern Europe regions sell emission rights to OECD Annex B regions in the form of emission quota. A general discussion of the economic mechanisms underlying emissions trading can be found in Hinchy, Hanslow, Fisher and Graham (1998). With such a redistribution of abatement tasks through trade, carbon equivalent penalties for all Annex B regions except the Russian Federation, the Ukraine and eastern Europe are reduced compared with independent abatement.

**Carbon equivalent penalties under various emissions growth scenarios in the Russian Federation and the Ukraine**

The projected size of the carbon equivalent penalty under emissions trading depends to some degree on reference case emissions in the Russian Federation, the Ukraine and eastern Europe, regions that are projected to sell quota. Given the uncertainty about the medium
term economic development in the region, particularly in the Russian Federation and the Ukraine, emission projections are also subject to a degree of uncertainty.

In the GTEM reference case, emissions in the Russian Federation and the Ukraine at 2010 are projected to be 72 per cent, and in eastern Europe 94 per cent, of 1990 emissions. Other studies estimate of emissions growth in the Russian Federation and the Ukraine to be as high as 96 per cent of 1990 levels at 2010 (Institute of Energy Strategy of the Ministry of Fuel and Energy of the Russian Federation 1998).

In alternative scenario 1, reference case emissions from these countries are assumed to equal their respective 1990 emission levels at 2010. Alternative scenario 2 assumes reference case emissions to be half way between the standard reference case and 1990 emissions.

The projected carbon equivalent penalties under these two alternative emissions growth assumptions are shown in figure 4. Higher projected reference case emissions growth increases the projected carbon equivalent penalty under emissions trading, as the Russian Federation, the Ukraine and eastern Europe would sell less emissions quota than in the standard GTEM reference case.

**Emission coverage and the carbon equivalent penalty**

While some parties to the convention initially favored a protocol that included targets for carbon dioxide emissions from fossil fuel combustion only, it was agreed at Kyoto that all the most significant gases, sources and sinks should be included. By adopting this comprehensive approach, the scope for achieving emission abatement at least cost was increased. For example, parties have the flexibility to reduce emissions of those gases with lowest marginal abatement costs, potentially reducing the costs of achieving targets in comparison with the case with a restrictive coverage of gases.
Excluding any abatement source has the effect of increasing the carbon equivalent penalty required to meet the target commitment as more of the emission abatement task falls on the sources remaining. Restricting the coverage of gases and sources within the abatement program will force larger adjustments to be made by other emitters of the gases if the overall task remains the same. In addition, excluding some emission sources may have the second round effect of altering the size of the abatement task by changing the relative competitiveness of sectors and thereby changing emissions.

The above discussion ignores monitoring and enforcement costs. These costs may limit the coverage of sources that is cost effective. For example, these costs are expected to rise with the inclusion of small and numerous sources of emissions or with diffuse sources of emissions, such as are found in the livestock and cropping sectors (Hinchy, Graham and Fisher 1998; Australian Greenhouse Office 1999). If the monitoring and enforcement costs required exceed the contribution to reducing total abatement costs, it would be cost effective to exclude the source from control.

It can be seen in figure 5 that excluding noncombustion carbon dioxide, methane and nitrous oxide emissions from the abatement scheme leads to a large increase in the projected carbon equivalent penalty. Whether or not the costs that this imposes outweigh the costs of monitoring and enforcement for these other gases is a matter for further analysis.

Restricting the coverage to combustion carbon dioxide emissions only increases the penalty for fossil fuel consumption and consequently leads to a greater reduction in fossil fuel consumption than under the comparable full coverage scenario. Industries such as iron and steel that rely on fossil fuels are particularly disadvantaged, whereas the livestock sector, which generates methane but little carbon dioxide, can be expected to benefit in comparison with the full coverage scenario.

**Aggregate economic impacts of implementation of the Kyoto Protocol**

The imposition of carbon equivalent penalties is expected to have a number of direct and indirect global economic impacts.
• Most Annex B regions experience GNP losses as the imposition of the carbon equivalent penalty leads to a redirection of resources toward less emissions intensive and less profitable activities and production methods.

• Under emissions trading there are transfers of income from buyers to sellers of quota.

• There is lower demand for fossil fuels as industrialised countries reduce their fossil fuel consumption to meet their emission reduction targets. They reduce their demand for fossil fuel imports from both Annex B and non-Annex B countries, leading to lower fossil fuel export prices and volumes than would otherwise be the case. Exporters of fossil fuels lose export earnings, while importers benefit from lower world prices.

• There is improved competitiveness of non-Annex B emissions intensive industries. The production of emissions intensive goods becomes more expensive in Annex B countries as emissions are penalised. This leads to higher world prices and increased demand for emissions intensive exports from developing countries, where emissions are not penalised. Emissions intensive industries, such as iron and steel, in those countries benefit from higher export volumes and higher export prices.

• With increased production of energy and emission intensive goods in developing countries, their emissions rise. As a result, emission reductions in abating countries are partially offset by increasing emissions in developing countries. This phenomenon is known as ‘carbon equivalent leakage’.

• Annex B emission abatement also affects import prices and investment. Increased world prices for emissions intensive products are passed on to consumers, so developing countries that import emissions intensive goods sustain some losses. The increased competitiveness of energy intensive production in developing countries generally increases the rates of return on investment and the demand for capital relative to Annex B regions. As a result, some investment tends to shift from developed to developing countries.

Impacts on GNP

Gross national product (GNP) is used to measure aggregate economic impacts. GNP is equal to gross domestic product plus foreign income transfers, and therefore provides a complete measure of the flow of income available to an economy for consumption, savings and depreciation. In the context of international emissions trading, changes in GNP from reference case levels account for both the income transfers associated with quota purchases and sales, and the changes in gross domestic product resulting from increases in the cost of emitting greenhouse gases.

In absolute terms, the loss to the global economy at 2010 associated with achieving the Kyoto emission reduction target under an emissions trading scenario is projected to be US$22 billion (in 1995 terms) and without trading the projected cost is US$138 billion (in 1995 terms). Global losses arise because emission abatement as noted above, moves
The world’s resources toward less profitable activities and production methods, generating economic losses relative to the reference case.

The reduction in the real GNP loss in the Annex B region under emissions trading (figure 6) is a result of the fall in the carbon equivalent penalty. Lowering the carbon equivalent penalty (equal to the Annex B marginal abatement cost) reduces the extent of carbon equivalent leakage and of consumer price increases in Annex B regions. In a special edition of the Energy Journal organised by the Stanford Energy Modeling Forum, results from thirteen different models on the economic impacts of the Kyoto Protocol were compared (Weyant and Hill 1999). On average, the reduction in real consumption in Annex B regions projected by these models is 70 per cent lower under emissions trading than without trading.

In aggregate, non-Annex B countries benefit as a result of Annex B regions meeting their Kyoto targets through trading or independent abatement. However, this aggregate result masks significant differences in impacts across developing countries. The implication of a net GNP gain to developing countries as a whole is that gains to emissions intensive exporters outweigh the losses to non-Annex B fossil fuel exporters and importers of emissions intensive products.

**Economic impacts on Annex B regions**
Projected GNP impacts on Annex B regions are shown in figure 7. Under independent abatement, the Russian Federation, the Ukraine and eastern Europe benefit from leakage from regions with higher carbon equivalent penalties (figure 3). Emissions trading provides increased benefits to the Russian Federation, the Ukraine and eastern Europe because they receive income from quota sales to OECD economies in Annex B. Purchasing countries (all in the OECD) transfer income to the Russia Federation, the Ukraine and eastern Europe, but the impact of this on GNP is more than offset by the lower carbon equivalent penalty under
emissions trading and the GNP loss in most purchasing countries relative to the reference case is smaller under emission trading than under independent abatement.

While the carbon equivalent penalty is an important determinant of changes in GNP it is not the only factor influencing overall economic impacts in different regions. The penalty projected for Japan, for example, is more than twice that projected for the United States under independent abatement. However, the projected economic cost is considerably higher in the United States than in Japan.

The extent to which the imposition of a carbon equivalent emission penalty affects economywide production costs and consumer prices depends on an economy’s emission intensity of output. Generally, the more extensive the use of fossil fuels and the greater the importance of agriculture in the production structure of an economy, the larger the impact of the carbon equivalent penalty on production costs. In contrast to Japan, the availability of relatively inexpensive fossil fuels in the United States has led to extensive use of fossil fuels in that country (Tulpulé et al. 1999). Consequently, the imposition of a carbon equivalent penalty will result in more widespread impacts on economic activity in the United States than in Japan.

The relatively low carbon equivalent penalty in the European Union under independent abatement allows the region to also benefit from increased competitiveness with more highly penalised Annex B regions leading to a small increase in real GNP. When the carbon equivalent penalty is equalised across regions under emissions trading this benefit is lost, leading to a small loss in real GNP at 2010 compared to the case with independent abatement.

**Economic impacts on non-Annex B regions**

The net economic impact of implementation of the Kyoto Protocol on individual developing countries’ economies is projected to vary significantly between countries (figure 8)
and will depend on a country’s trade and production structure. The magnitude of impacts on developing countries is influenced by the size of the carbon equivalent penalty in Annex B countries. Consequently, the projected impacts are significantly smaller under Annex B emissions trading than under independent abatement in most regions.

Generally, countries that rely heavily on fossil fuel exports to Annex B regions, such as the Middle East, Indonesia and Mexico, are projected to incur losses while exporters of emissions intensive goods tend to gain. The main impact on fuel exporters arises from lower Annex B fossil fuel demand, while countries specialising in energy and emissions intensive exports such as Korea, India and Brazil are positively affected mainly by increased energy intensive exports associated with increased competitiveness relative to Annex B countries.

For more diverse economies, such as China and southern Africa, GNP impacts are dominated by positive investment impacts as these countries gain a competitive advantage over Annex B countries in the production of energy intensive goods. However, under emissions trading, the gain in competitiveness over Annex B countries is reduced and a negative terms of trade impact associated with the higher import prices dominates resulting in a small decline in real GNP in China relative to the reference case.

Production and trade of energy intensive goods and emissions leakage

In general, the increase in the competitiveness of non-Annex B economies over Annex B economies is projected to be greatest in energy intensive commodities that are widely traded, such as iron and steel, and nonferrous metals. Total non-Annex B production and exports of these commodities are projected to increase substantially relative to the reference case, and Annex B production and exports to decline, as shown for iron and steel in figure 9.

Such changes in output of energy intensive commodities give rise to carbon equivalent leakage. The carbon equivalent leakage rate is estimated to be 14 per cent in 2010 under...
independent abatement. That is, carbon equivalent emissions from non-Annex B regions are projected to rise by 140 tonnes for every 1000 tonne reduction in carbon equivalent emissions in Annex B countries. Under emissions trading, the gain in non-Annex B competitiveness is reduced and the leakage rate is projected to be reduced to 8 per cent. Everything else being equal, the carbon leakage rate under emissions trading is likely to be slightly underestimated because there is no leakage estimated to the non-Annex B components of the former Soviet Union from abatement in the Russian Federation and the Ukraine.

Impacts on global energy markets
The overwhelming impact of emissions abatement will be on world energy markets. Emissions abatement in Annex B regions will lead to changes in both aggregate energy consumption and the choice of fuels consumed.

Impacts on fossil fuel production and consumption
The impacts on world energy consumption as a result of meeting the Kyoto commitments are examined assuming that an international system of tradable emission quotas is implemented. Under an independent abatement scenario, energy consumption impacts are significantly larger (Polidano et al. 2000).

In Annex B countries changes in fossil fuel consumption arise from changes in levels of electricity generation, the fuel mix and the output of energy intensive commodities — principally iron and steel, nonferrous metals, nonmetallic minerals and chemicals, rubber and plastics. Output in these sectors falls relative to reference case levels in virtually all Annex B economies as the cost of using fossil fuels rises under an emission abatement scenario. As a result, fossil fuel consumption declines in Annex B countries.
In non-Annex B countries, where no emission abatement targets apply, carbon equivalent leakage is correlated with increased demand for energy relative to the reference case (figure 10).

Globally, consumption of coal, oil and gas decline relative to the reference case by 2010 (figure 10). Different fossil fuels are projected to be affected to varying degrees. Consumption of coal is projected to fall the most as it attracts the highest carbon equivalent penalty. The use of natural gas, the least emissions intensive fossil fuel, is projected to be less affected than coal because the carbon equivalent penalty per energy unit is lower. Some substitution away from coal and into gas is projected. World oil demand is projected to be relatively stable because it is mostly consumed in the transport sector where there are limited fuel substitution possibilities.

**Structural changes in the electricity sector**

The electricity sector generated 28 per cent of emissions in Annex B regions at 1995 and is projected to bear a large share of the abatement task. Abatement in the electricity sector can be achieved through reductions in output and changes in the technology mix in the industry.

Electricity output in Annex B regions is projected to fall by 6.5 per cent under independent abatement and 4.6 per cent under emissions trading relative to the reference case at 2010. The fall in electricity output in individual regions is highly correlated with the carbon equivalent penalty and abatement opportunities elsewhere in the economy. Under independent abatement, regions with a high carbon equivalent penalty such as the United States reduce electricity production more than other regions. Electricity output in the Russia Federation, the Ukraine and eastern Europe rises (figure 11) due to carbon equivalent leakage from OECD Annex B economies.
Under emissions trading, electricity production falls most in regions where emissions intensity is the highest (figure 11). For example, Australia experiences the largest falls in electricity output because of its heavy reliance on coal fired electricity generation. Regions with low emissions intensity, such as Japan, experience smaller declines in electricity output.

Changes in the technology mix are apparent under independent abatement and emissions trading (table 3). Under independent abatement, the share of coal fired generation falls in all Annex B regions undertaking abatement while gas becomes the dominant fuel source. It is assumed that electricity generation from nuclear and hydro power in all Annex B regions except the Russian Federation, the Ukraine and eastern Europe cannot increase above reference case levels in response to emissions abatement. This reflects resource and political constraints likely to limit further growth in these sources. The share of these technologies in total electricity generation rises because of the fall output from other technologies.

In the reference case the development of renewable energy sources is constrained by low fossil fuel prices making it uncompetitive with thermal electricity. Many countries already have programs in place to increase the share of renewables in electricity generation through subsidies and assistance with research and development (Preville and AEA Technology 1997) as part of their Kyoto strategies. There is projected to be an increase in the share of other renewables relative to the reference case with the implementation of emission abate-

Figure 11: Change in electricity output at 2010, relative to the reference case

<table>
<thead>
<tr>
<th>Region</th>
<th>Reference case</th>
<th>Emissions trading</th>
<th>Independent abatement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>34.1</td>
<td>29.4</td>
<td>23.4</td>
</tr>
<tr>
<td>Oil</td>
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<td>Gas</td>
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</tr>
<tr>
<td>Other renewables</td>
<td>1.3</td>
<td>1.9</td>
<td>5.3</td>
</tr>
</tbody>
</table>
ment policies. For example, the share of other renewables in Australian electricity generation is projected to increase from 1.2 per cent in the reference case to 2.7 per cent under independent abatement.

In non-Annex B regions electricity output rises as a result of carbon equivalent leakage. Lower fossil fuel prices lead to a slight shift toward more emissions intensive fuel sources in non-Annex B regions. The share of coal fired electricity generation increases in those regions that currently rely on coal, such as Indonesia and Korea, because of the fall in coal prices.

Opportunities under the clean development mechanism in the electricity sector
The clean development mechanism is one of the three mechanisms under the Kyoto Protocol that allow flexibility in the location of emission abatement, and is the only one that involves non-Annex B countries. Under the clean development mechanism, Annex B parties or legal entities may obtain certified emission reductions by undertaking abatement in non-Annex B regions.

The operational details surrounding the implementation of the clean development mechanism have yet to be negotiated. To qualify as a clean development mechanism project, the project activity must result in reductions in emissions (or removal of carbon dioxide by sinks) that are additional to any that would occur in the absence of the certified project activity (environmental additionality).

Ensuring environmental additionality and calculating the certified emission reductions (CERs) attributable to each project will involve projecting baseline emissions (the emissions that would have occurred in the absence of the project). The CERs generated by the project are the difference between the projected baseline emissions and the actual emissions.

Under the clean development mechanism, CERs obtained from the year 2000 onward can be used toward meeting Annex B emission reduction targets in the first commitment period.

The protocol stipulates that a share of the proceeds from the CERs will be used to cover administrative expenses and to assist developing countries that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation (Article 12.8). The size of this so-called ‘share of proceeds’ is yet to be negotiated. No account is taken of the effects of the redistribution of the share of proceeds in this analysis. Distribution of the remaining CERs are expected to be the subject of negotiation on a project by project basis between the project participants, perhaps with some involvement by parties to the protocol.

It is further assumed here that, in line with the provisions of the protocol (Article 3.12), CERs are perfectly substitutable with Annex B emissions quotas (assigned amount units)
in an Annex B emissions trading scheme. As a consequence the price of a CER is the same as the international quota price.

Emission reducing opportunities are likely to derive from technology transfer in areas such as gas distribution networks, fuel switching and electricity and heat generation. Many such projects are being trialed in the pilot phase of the Activities Implemented Jointly scheme initiated at the first Conference of the Parties in Berlin in 1995.

This section contains an illustrative analysis of the potential impacts of the clean development mechanism on non-Annex B countries, focusing on energy efficiency improvements in the thermal electricity sector (coal, oil and gas fired technologies). Transaction costs, monitoring and compliance costs are ignored in this analysis.

**Implementation of the clean development mechanism in GTEM**

Thermal electricity generation is an important source of power generation and emissions in non-Annex B countries. There is likely to be scope for efficiency improvements in the thermal electricity generation capacity currently employed in non-Annex B countries. For example, based on IEA data (IEA 1998), the average thermal efficiency of OECD coal fired power stations, measured as the ratio of electricity output to coal inputs, is 37 per cent higher than the non-OECD average.

Technology transfer into the electricity sector may take the form of improving the energy efficiency of existing infrastructure through, for example, refurbishment. To undertake a comprehensive analysis of the economic effects of technology transfer under the clean development mechanism, large amounts of project specific data for each developing country would need to be collected and analysed.

Here the simplifying assumption is made that efficiency improvements resulting from clean development mechanism projects are uniform across all non-Annex B regions. An energy efficiency improvement of 2.5 per cent in the thermal electricity sector has been modeled. This efficiency improvement equates to developing countries catching up about 10 per cent of the efficiency gap between non-OECD and OECD countries applied to half the current capital stock. Efficiency improvements are introduced incrementally from 2000 onwards, with the total efficiency improvements reached in 2010.

The results should be viewed as indicative of the potential for CER generation from the thermal electricity sector and of the impacts of technology transfer on non-Annex B economies. For example, CERs generated in Korea, Chinese Taipei and the Middle East are likely to have been overestimated, given the already high levels of thermal efficiency in those regions. On the other hand, there may be additional scope to generate CERs in China and India especially in older and highly inefficient power stations.
Obviously, this scenario provides no information on the potential impact of sink or other projects in the CDM.

The amount of CERs generated will vary across non-Annex B regions depending on the size of the thermal electricity sector, its composition in terms of fuel source and its projected growth over the reference case (table 4). For example, China and India generate around half of all emissions credits generated as a result of the relatively large size of their thermal electricity sectors and their heavy reliance on coal. The Middle East generates the most CERs from technology improvements in oil and gas fired technology. Latin American countries have a low reliance on fossil fuel technologies in electricity generation, making technology transfer potential very low in this analysis.

The stream of revenue from CER projects will depend on the amount of CERs generated (table 4) and the size of the carbon equivalent penalty (figure 12).

The trade in CERs from clean development mechanism projects in conjunction with an international emissions trading scheme is projected to lead to a decline in the carbon equivalent penalty from US$58 (in 1995 terms) a tonne of carbon equivalent under emissions trading to US$55 a tonne with a 2.5 per cent efficiency improvement (figure 12). CDM offers Annex B parties access to low cost abatement options, reducing their reliance on Annex B emissions trading to meet the objectives of the Kyoto Protocol while at the same

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*Figures discounted using a 6 per cent discount rate.*
time accelerating technology transfer for developing countries.

Over the whole commitment period 2008–12 the value of CERs generated in this analysis is projected to be around US$2.6 billion (in 1995 terms). In this analysis it is assumed that one-fifth of the CERs generated for use during the commitment period would be available in 2010. Sales of CERs in 2010 are projected to be worth around US$0.5 billion (in 1995 terms). Sales of CERs from Asian countries are projected to dominate total sales. Restricting the analysis to thermal electricity generation may give a distorted picture of the regional distribution of technology transfer opportunities. Nevertheless, this analysis highlights the lack of opportunities for technology transfer in those economies in Latin America and Africa with low emissions. The inclusion of sinks in the clean development mechanism has the potential to increase the scope for projects in these regions.

Conclusions

The Kyoto Protocol contains provision for emissions trading and other mechanisms, such as the clean development mechanism, that have the potential to minimise the economic costs of achieving the protocol commitments. However, there is still significant uncertainty surrounding the Kyoto Protocol for a number of reasons. First, much of the detail in the protocol remains to be negotiated. For example, the details of emissions trading and the way in which the clean development mechanism will work are yet to be formulated. Second, uncertainty still remains about the timing of the entry into force of the protocol and the implications that may have for the size of the adjustment costs associated with meeting the target for the first commitment period.

In this paper GTEM is used to examine the economic impacts of implementing the Kyoto Protocol. The results show that international emissions trading is a more efficient mechanism than independent abatement for achieving the objectives of the Kyoto Protocol. The clean development mechanism also has potential to reduce the cost of compliance.

Consumption of fossil fuel in Annex B regions is projected to fall with the implementation of the Kyoto Protocol because of the impact of the carbon equivalent penalty on the cost of consumption of fossil fuels. The reduction in carbon equivalent penalty brought about by an emissions trading scheme, in turn, reduces the amount of structural change induced by abatement policies in OECD economies, thereby reducing the fall in fossil fuel import demand.
References


