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The Costs of Reducing CO2 Emissions: A Comparison of Carbon Tax Curves with GREEN

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THE COSTS OF REDUCING CO_2 EMISSIONS:

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This paper forms part of an OECD project which addresses the issue of the costs of reducing CO_2 emissions by comparing the results from six global models of a set of standardised scenarios. This paper provides evidence of regional differences with respect to carbon tax curves through the middle of the next century. It also develops some analytical tools that can help to explain the main mechanisms at work in GREEN. Finally, it evaluates the welfare and output costs entailed in reduction emissions.

* * * * *

Ce document fait partie d'un project de l'OCDE qui s'interroge sur les coûts de réduction des émissions de CO_2 en comparant les résultats de six modèles globaux formés d'un ensemble de scénarios standardisés de réduction. Cet étude met en évidence les différences régionales concernant des courbes de taxation du carbone jusqu'au milieu du siècle prochain. Un certain nombre de outils méthodologiques sont développés à cette fin qui peuvent expliquer les principaux mécanismes à l'oeuvre dans GREEN. Sont aussi évalués les coûts en termes de bien-être et de PIB associés à la réduction des émissions.

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THE COSTS OF REDUCING CO_2 EMISSIONS:
A Comparison of Carbon Tax Curves with GREEN

Joaquim Oliveira-Martins, Jean-Marc Burniaux,
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I. Introduction and Overview of GREEN

The OECD Secretariat has developed a multi-country, multi-sector, dynamic applied general equilibrium (AGE) model to quantify the economy-wide and global costs of policies to curb emissions of carbon dioxide (CO_2). It is called the GeneRal Equilibrium ENvironmental model, hereafter referred to as GREEN. The OECD Secretariat has also designed a Model Comparisons Project, to understand why results differ among six global models, including GREEN. For this, the models are run under common assumptions about economic growth, population dynamics and scenarios for CO_2 emission reductions. The purpose of this paper is to to present the results of standardized scenarios[2], outline the main features of GREEN in a non-technical fashion and develop some analytical tools that can help to explain the main mechanisms at work in GREEN.

The key dimensions of GREEN are set out in Table 1. It runs over a 65-year time horizon from 1985 to 2050, using time intervals of five years between 1985 and 2010 and twenty years thereafter. It consists of twelve detailed regional sub-models: four OECD regions -- United States, Japan, EC and Other OECD -- and eight non-OECD regions -- the former USSR, the Central and Eastern European Countries (CEECs), China, India, the Energy-exporting LDCs, the Dynamic Asian Economies, Brazil and the Rest of the World (ROW).

The next sections outline briefly the main characteristics of supply, demand, the dynamics and the policy instruments of the model. For full details on the technical specification of GREEN, its data base and parameters, see Burniaux *et al.* (1992b).

A. Supply, Demand and Foreign Trade

(i) *Production*

There are eleven producing sectors in GREEN. Eight sectors concern the supply and distribution of energy: coal mining, crude oil, natural gas, refined oil, electricity, gas and water distribution[3] and three back-stop technologies. The three back-stop technologies, i.e. new energy sources -- a carbon-based back-stop, a carbon-free back-stop and a carbon-free electric back-stop -- are assumed to come on stream in all regions only by 2010. The remaining sectors are broad aggregates of the rest of the economy: agriculture, energy-intensive industries and other industries and services.

All sectors are assumed to operate under constant returns to scale and cost optimisation. Production technology is modelled mainly by a nesting of constant-elasticity-of-substitution (CES) functions, which is depicted in Figures 1a-b. The key parameters intervening in this nesting are given in Table 2. There are a few exceptions to the CES nesting, all inputs are assumed to be used in fixed proportions (Leontief technology) in the production of fossil fuels (coal, crude oil, natural gas), petroleum products and the back-stop technologies.

In each period, the supply of **primary factors** listed in Table 1 is usually predetermined. However, supplies of agricultural land, the carbon-free electric resource (nuclear, hydro and geothermal), oil, natural gas and coal are all assumed to be sensitive to their contemporaneous prices.

The model includes adjustment rigidities. An important feature is the distinction between "old" and "new" capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors[4].

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions in all markets.

(ii) *Energy Prices*

When demand do not exceeds potential supply (whose determination is described below), coal and gas prices are determined by the supply elasticity of their respective fixed factor (i.e. their resource base). This elasticity is asymmetric with respect to output changes. Generally, it is higher in response to downwards than upwards variations (see Table 2).

The real world price of crude oil is endogenous in GREEN[5]. This is implemented by introducing a supply equation for oil in the Energy-exporting LDCs. This region (mainly OPEC) is assumed to have a finite supply elasticity. Nonetheless, there is an upward bound to oil production in the Energy-exporting LDCs which is set by the level of their available reserves. All other producers are price-takers, their supply of oil being strictly determined by their resource constraint.

The prices of back-stop technologies are exogenous; they were taken from the Stanford-based Energy Modelling Forum Study no. 12 (EMF 12) entitled "Global Climate Change: Energy Sector Impacts of Greenhouse Gas Emission Control Strategies". By definition, back-stop technologies, once they come on stream, are available in all regions in unlimited quantities at constant marginal costs (see Manne and Richels, 1991). As a consequence, this rules out any incentive to trade in "new" energy sources between regions. Table 3 summarizes the assumptions concerning the back-stop options.

(iii) *Consumption and the closure rule*

All income generated by economic activity is assumed to be distributed to consumers. A single representative consumer allocates optimally his/her disposable income among the four broad consumer goods (food and beverages, fuel and power, transport and communication and other goods and services) and saving. The structure of household demand is depicted in Figure 2 and the relevant parameters are given in Table 2. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demands for the other four goods, the price of saving being set arbitrarily equal to the average price of consumer goods[6]. Given energy prices, consumers choose an optimal mix of fuels, except in the transport and communication sector where the sole energy input is refined petroleum products.

The government collects carbon or energy taxes, income taxes and indirect taxes on intermediate inputs, outputs and consumer expenditures. Revenues of carbon taxation or from trade in emission rights are recycled by assuming revenue-neutrality: the changes in the government budget are automatically compensated by changes in marginal income tax rates. This assumption is considered the appropriate closure to apply to the government sector for long-term simulations. Government expenditures are exogenous in real terms, growing at the same rate as GDP.

Each region runs a current-account surplus (deficit) which is fixed in nominal terms. The counterpart of these imbalances is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

(iv) *Foreign Trade*

The world trade block is based on a set of regional bilateral flows. The basic assumption in GREEN is that imports originating in different regions are imperfect substitutes. Therefore, in each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. This specification of imports -- commonly referred to as the Armington specification -- implies that each region faces downward-sloping demand curves for its exports. This is implemented for all goods except crude oil, which is assumed to be a homogeneous commodity across regions, implying a unique world oil price. Natural gas and coal are assumed to be heterogeneous goods across regions because of their transportation costs which are much higher than for oil.

B. Dynamic Features and Calibration

The current version of GREEN has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in GREEN originate from three sources: i) depletion of fossil fuel resources; ii) accumulation of productive capital; and iii) the putty/semi-putty specification of technology.

(i) *Resource Depletion*

While coal reserves are assumed to be infinite over the current time horizon in GREEN, the supplies of crude oil and natural gas are derived from a resource depletion sub-model. The sub-model makes potential supply dependent on the initial levels of proven and unproven (so-called "yet-to-find") reserves, the rate of reserve discovery and the rate of extraction[7]. Whether potential output increases or decreases over time depends on whether extracted resources are balanced by newly discovered resources. In the version of GREEN used in this paper, the levels of yet-to-find reserves are fixed and correspond to the highest estimates of resources taken from the guidelines laid down by EMF 12. Nonetheless, the depletion mechanism embodies some price sensitivity via the rate of reserve discovery which is assumed to be a function of the world oil and gas price.

(ii) *Capital Accumulation*

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

(iii) *The putty/semi-putty specification*

The substitution possibilities among production factors are assumed to be higher with the "new" than with the "old" capital vintages -- technology has a putty/semi-putty specification. Hence, when a shock on relative prices occurs (e.g. the imposition of a carbon tax), the demands for production factors only adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution <u>and</u> the replacement rate of capital. As the latter determines the pace at which the new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

(iv) *Dynamic calibration*

The model is calibrated on exogenous growth rates of population, GDP per capita and an autonomous energy efficiency improvement in energy use (the so-called AEEI). In the so-called Business-as-Usual (BaU) scenario, the dynamics is calibrated in each region by imposing the assumption of a **balanced growth** path. This implies that the ratio between labour and the capital/fixed-factor bundle (in efficiency units) is held constant over time[8]. When alternative scenarios around the baseline are simulated, the growth of capital is endogenously determined by the saving/investment relation.

C. Policy Instruments

GREEN embodies several policy instruments to achieve CO_2 emission reductions: i) carbon, energy or mixed taxes (computed either as equilibrium shadow prices of a carbon constraint or set exogenously); and ii) tradeable permits. In this paper only equilibrium carbon taxes and tradeable permits are considered[9].

The *carbon tax* is an excise tax, which is expressed as a fixed absolute amount of US$ per ton of carbon emitted by each fuel. The tax is applied at the level of consumers of primary fuels[10], thereby avoiding distortions between domestic and imported fuels; it is applied prior to any indirect taxation included in the model.

GREEN also incorporates the possibility that any international agreement to curb CO_2 emissions could include a provision allowing countries to *trade emission rights*. In the present version of the model, countries are endowed with initial quotas of emission rights set equal to the upper bounds on emissions imposed in the no-trade case and this is fixed in all time periods. In this case, a unique constraint on carbon emissions is imposed at the world level and a single world price of permits -- the shadow price of carbon -- is determined with free trade in permits. Regions with a lower carbon tax in the no-trade case will want to sell rights, while those in the opposite situation will want to buy them. Trade in emission rights gives rise to flows of income between regions which modify the current account constraint. It is assumed that these income flows increase or decrease government revenues, depending upon whether the region in question is a seller or a buyer of emission permits.

II. Fossil-Fuel Demands and CO_2 Emissions in the BaU Scenario

The assumptions about population, GDP per capita and the oil and gas reserves underlying the BaU scenario are those laid down by the EMF 12 study[11]. World CO_2 emissions in the GREEN baseline are projected to grow at an annual average rate of around 2 per cent a year: the level of emissions increases from 5.8 billion tons in 1990 to approximately 19 billion tons in 2050 (Table 4). There is also a major shift in the projected regional distribution of world emissions, away from the OECD countries to some non-OECD regions. The share of the OECD countries is projected to decline from around 47 per cent in 1990 to about 25 per cent in 2050 (Figure 3). On the other hand, China's share increases dramatically from 11 per cent in 1990 to 29 per cent in 2050 and India's share increases from 2.5 to almost 8 per cent. The shares of the former USSR and the other regions are quite stable over the whole period.

Figure 4 shows the contributions of the three fossil fuels and the backstop synthetic fuel to total world emissions. It illustrates a major dilemma for policy makers, namely that future economic growth, in the absence of explicit policy actions to curb the burning of fossil fuels, is likely to rely more and more on coal, the "dirtiest" fossil fuel (in terms of CO_2 emissions). Emissions from coal burning are projected to increase their share of global emissions from 42 per cent in 1985 to almost 70 per cent in 2050. This switch to coal occurs partly in response to increasing real oil prices and the projected exhaustion of natural gas reserves in Europe and the Pacific, but the main impetus comes from above-average growth in China, which is the main coal consumer.

III. Curbing CO_2 Emissions: A Comparison of Carbon Tax Curves

One of the aims of the OECD Secretariat's Model Comparisons Project is to obtain comparable cost curves across the different models. To this end, three standardized carbon reduction scenarios are specified in terms of the rate of growth of CO_2 emissions relative to the BaU scenario, as follows:

<u>Scenario I:</u> Reduction in all regions of the CO_2 emission growth rate by 1 percentage point per year compared with the BaU scenario.

<u>Scenario II:</u> Reduction in all regions of the CO_2 emission growth rate by 2 percentage point per year compared with the BaU scenario.

Scenario III: Reduction in all regions of the CO_2 emission growth rate by 3 percentage point per year compared with the BaU scenario.

Moreover, an additional scenario was specified (scenario IV), where CO_2 emissions are stabilised at 1990 levels in all regions.

The chosen policy instrument to achieve these emission curbs is a carbon tax. Table 4 shows the emission levels in each of the first three emission-reduction scenarios[12]; the outcomes from scenario IV are presented as percentage deviations relative to BaU.

Scenario I is roughly equivalent to the stabilisation of CO_2 emissions at 1990 levels in OECD countries and the former USSR. Under this scenario, China and India continue to produce emissions at a high rate (around 2.7-2.8 per cent per year). In all other non-OECD regions, emissions also continue to increase during the simulation period. Global emissions in 2050 are cut by around 50 per cent compared with the BaU level.

Scenario II imposes a marked decline of emissions in OECD countries and the former USSR. Despite a considerable decline in emission growth, China almost triples its level of emissions over the period. Other Developing countries' emissions increase by 33 per cent between 1990 and 2050. Relative to baseline, the proportionate cut in global emissions by 2050 is about 70 per cent by 2050. At the world level, emissions are approximately stabilised at their 1990 levels.

Scenario III corresponds to a very sharp reduction in global emissions compared with the baseline (more than 80 per cent) by 2050. All regions except China and India have to reduce their emissions relative to 1990 levels. Such a severe target cuts global emissions sufficiently to stabilise world climate change by the middle of the next century[13].

Scenario IV -- the stabilisation of emissions at their 1990 levels -- imposes different constraints across regions[14]. The tightest constraints are in China and India, where emissions are reduced by almost 90 per cent below BaU levels in 2050. In the other regions, the reduction is lower than under scenario III. At the world level, emissions are reduced by 70 per cent relative to BaU. Hence, the stabilisation scenario achieves the same world emissions target by 2050 as scenario II, but with a very different regional distribution of emission cuts. In the latter, they are equiproportional whereas the stabilisation scenario imposes a higher burden in the non-OECD, and particularly in China, than in the OECD regions.

A. Cross-region Comparison of Carbon Taxes

Table 5 reports the carbon tax levels in real terms (expressed in 1985 $/ton of carbon) required to meet the targets in the four scenarios. Depending upon the scenario, there is a wide variation in the carbon tax across regions. The lowest carbon taxes in the first three scenarios are in China and India, while the Energy-exporting LDCs, Brazil and the DAEs regions tend to have the highest regional taxes. The OECD regions are in an intermediate position. The reasons for these divergences will be discussed in the next section; they relate to the structure of the production sector, relative energy prices, the carbon content of primary energy and the interaction between the back-stop options and conventional fuels.

In the first three scenarios, the tax in 2050 varies from a low of $22-$278 in China to a high of $137-$999 in the Energy-exporting LDCs. Averaged over the four OECD regions, the tax varies from a low of $80 to a high of $530. In scenario IV, the picture is quite different. When emissions are stabilised at their 1990 levels, China and India have a carbon tax which is more than four times the OECD average. The energy-exporting LDCs have the highest tax ($594) and the United States has the lowest tax ($51).

Figures 5 and 6 illustrate the wide variability of the time profiles and regional dispersion of the tax in scenario II. Given their more similar economic structures, the regional dispersion of the tax is lower in OECD than in non-OECD regions. In the latter group, Brazil and the Energy-exporting LDCs have the highest taxes. The non-monotonic shape of the tax in some regions is related to the presence of back-stop technologies. Such back-stops are particularly important in the OECD regions and the sharp fall in the tax by the middle of the simulation period is due to the fact that back-stops only come on stream between 2005-2010.

Comparing the sequence of taxes with increasingly stringent targets[15] demonstrates clearly that the marginal efficiency of the tax can be very low in some regions, particularly in the Energy-exporting LDCs, the DAEs and Brazil. This means that attempts to reduce emissions with a country-specific tax would be very costly and inefficient. An internationally-organised market for trade in emissions rights is one route to a cost-efficient agreement. Indeed, it is apparent from Figure 6 that the former USSR, China or India could use a carbon tax to achieve larger emissions cuts and sell emission rights to other countries. This process of trading could achieve the desired cut in global emissions at a lower global cost. In Section V, an emissions trading scenario is presented to illustrate this welfare-improving mechanism.

B. Interpretation of the Tax Curves

The different regional and time profiles of carbon taxes can be explained by focusing on the key variables underlying the determination of the marginal costs of reducing CO_2 emissions.

-- Firstly, the level of the carbon tax is directly linked to the levels of *real energy prices.* Table 6a summarizes this information for the benchmark year. Energy prices are characterised by a large dispersion, with each primary fossil fuel having a specific pattern. With respect to coal, Japan and the EC have notably higher prices than the other regions. On the other hand, China, followed by the former USSR and India, have the cheapest coal. The U.S. coal price is in an intermediate position. For crude oil and natural gas, the former USSR is a very striking outlier as its price levels are between 5 to 8 times lower than in other regions.

It is important to bear in mind that the benchmark-year energy price dispersion is assumed to remain throughout the simulation period. Hence, these wedges are a very important element determining the regional profiles of the carbon tax in GREEN[16]. Depending on the regions, the real exchange rate movements may somewhat modify the base-year dispersion observed in table 6a.

-- The second key element underlying the carbon tax is the *average carbon content* of energy demand [17]. The latter, of course, is closely linked to the pattern of energy prices. Table 6b shows the shares of each fossil fuel in total CO_2 emissions by region. For coal, by far the highest shares are in China and India with respectively, 86 and 74 per cent of their emissions. At the opposite extreme, coal consumption in the Energy-exporting LDCs and Brazil only accounts for 20 per cent of total emissions.

Putting these two elements together explains part of the observed carbon tax differences across regions. By calculating the ratio between the average energy price and the average carbon content of primary energy demand, one gets the "unit value of carbon" or the "average carbon price" (π):

$$\pi = \frac{\text{Primary Energy Expenditure (in real terms)/Energy Demand}}{\text{Carbon Emissions/Energy Demand}}$$

This indicator can be used as a first approximation for the marginal cost of reducing carbon emissions. The lower the level of energy prices and the greater the carbon content of primary energy demand, *ceteris paribus*, the lower is the marginal cost of reducing CO_2 emissions[18]. As coal has the lowest price and the highest carbon content among fossil fuels, the share of coal in primary energy demand is a key element determining this marginal cost of reducing emissions. With the proportionate emission reduction targets -- virtually identical across regions -- the different profiles of the carbon tax can therefore arise from the divergences with respect to relative energy prices and the composition of primary energy demand.

The cases of China, India and former USSR are indeed very specific. China and India rely very heavily on cheap coal - their coal prices are the lowest among all regions. The pattern for the former USSR is mainly explained by the extremely low prices for all fossil fuels.

On the other hand, the DAEs and Brazil have a high average carbon price because they combine a low share of coal with relatively high energy prices. Among the OECD regions, the case of Japan deserves attention because despite the high price in the BaU scenario, its fossil-fuel demand has a higher average carbon content than the other OECD countries because of a low share of gas (see Table 6b).

--As can be readily seen from the non-linear profiles of the taxes in Figure 5 and 6, the "average carbon price" can only explain part of the carbon tax levels. A further element of explanation has to do with the *substitution effects induced by the tax.* These effects are two-fold: i) they are related to the shift from energy towards non-energy goods; and ii) they lead to substitution among different energy sources (fossil fuels, electricity and back-stops). The former is usually called the "energy conservation effect", the latter the "energy substitution effect".

A very simple partial equilibrium calculation can show the relation between the carbon tax, the average carbon price (the π indicator described above) and the relevant demand elasticities embodied in the model represented by an average elasticity (ε)[19]. Indeed, the level of the carbon tax is negatively related to the magnitude of substitution possibilities in production. The lower they are, the higher the required shift in relative prices (and hence the carbon tax) needed to attain a given reduction target. This "carbon tax indicator" (τ) can be calculated as follows (see Annex):

$$\tau = \pi . \left[(1-R)^{-1/\varepsilon} - 1 \right]$$

where R is the percentage emission reduction relative to baseline. In spite of roughly similar demand elasticities, the resulting "average elasticity" (ε) can be different across regions. These "average elasticity" differences are mainly related to differences in the structure of the production sector, with the average elasticity being determined as the outcome of a complicated interaction among different nesting levels (recall Figure 1). For example, the elasticity of substitution inside the energy bundle is much higher than the elasticity between the energy and capital-fixed factor bundles. Also, as all the inputs in the fossil-fuel sectors are assumed to be complements, one should expect that a high share of energy in total output (as in the energy-producing regions) will lower the average elasticity of substitution. The price elasticities of final demand and factor supplies also affect the overall elasticity of substitution. Finally, when back-stops become available around 2010, the substitution possibilities can increase substantially, as the back-stops are assumed to be highly substitutable with conventional energies. Thus, each specific parameter has a different impact, depending on the structure of energy demand[20].

An overall view of the substitution effects induced by the carbon tax is given in Figures 7 and 8. These Figures show the breakdown of primary energy consumption into conventional fossil fuels, synthetic fuels, conventional carbon-free electricity (nuclear, hydro and geothermal/solar) and the carbon-free electric back-stop for the cases of the baseline and the 2 per cent reduction scenario. In the BaU scenario there is a steady increase of primary energy demand from 1985 to 2050 for the OECD regions (Figure 7). This upward pressure on energy demand increases the prices of oil and gas relative to coal and the share of coal tends to increase in all regions. This share more than doubles during the simulation period as the counterpart of the decline in crude oil consumption. By 2010 and especially after 2030, synthetic oil also comes on stream, inducing a further decrease in the share of crude oil. The penetration of the carbon-free electric option remains quite limited at the OECD level.

These patterns are radically modified by the carbon tax. Figure 8 shows the energy conservation effect induced by the tax, as primary energy consumption is roughly stabilised at its 1985 level in scenario II. Moreover, there are two important energy substitution effects. First, there is a shift between crude oil and coal in the opposite pattern to that shown by the BaU scenario. Secondly, there is an important penetration by the carbon-free electric option and a moderate increase of the carbon-free conventional electricity. As a result, synthetic oil is virtually eliminated from energy demand. The composition of primary energy demand in non-OECD regions has less marked changes than in the OECD (Figure 7), but the energy conservation effect is much more important. Total energy demand more than halves form 1985 to 2050. The major part of this effect comes from the elimination of coal: this fuel accounts for the major part of the total energy increase in the baseline whereas its demand is roughly stabilised in the reduction scenario.

All these elements explain the broad pattern of the carbon taxes displayed in Figures 5 and 6. The profile of the tax in the low-cost regions -- China, India, the former USSR and the CEECs -- results from a very low "average carbon price". In these regions, no back-stop technologies become profitable. In some regions, mainly the OECD regions, the tax displays an inverted-V shaped profile. The down-turn in the middle of the simulation period corresponds to the arrival of the electric back-stop option technologies in competition with conventional electricity. When a back-stop potentially become active, this creates an additional layer of flexibility in the production function with a high elasticity of substitution. Hence, the average elasticity increases and this lowers the carbon tax. Also, the use of the carbon-based synthetic fuel option raises the average carbon content, thus lowering the average carbon price.

The back-stops are available at a rather high price, so they only become competitive in those regions where energy prices are already sufficiently high, such as Japan and the EC. Among the non-OECD regions, the electric back-stop option becomes profitable in the DAEs, the Energy-exporting and the ROW. However, the penetration of this back-stop is less marked than in the OECD because the electric sector relies heavily on oil consumption. Given the benchmark-year price wedges, the oil price is lower in these non-OECD regions than in the OECD average. Also, the world oil price tends to fall relative to baseline because the carbon tax induces an overall cut in energy demand. The high profile of the tax in Brazil has two causes. Firstly, this country has the highest price levels among non-OECD regions and one of the lowest shares of coal. Secondly, its electricity sector relies mainly on hydro-electric power, a "clear" source of energy which is not affected by the carbon tax.

The dynamic pattern of the putty/semi-putty specification also determines the carbon tax profile. Indeed, substitution possibilities tend to increase in the long-run with the replacement of old capital vintages. In consequence, the tax may overshoot strongly after the introduction of back-stops, in spite of the fact that the emission constraint continues to increase. After a certain time lag the tax can therefore stabilise because the increase in the "average elasticity" compensates for the decreasing returns of the tax. The flat profile of the tax in Japan and the EC can be explained by this dynamic feature.

The time pattern of the carbon tax curves then depends crucially on the competition between conventional and back-stop technologies and the dynamic features of the model. Before 2010, when back-stops are not available, the carbon tax exhibits diminishing returns in terms of curbing emissions when coal use is eliminated and energy demand switches to "cleaner", but also more expensive fuels. As a result, the more stringent is the emissions constraint in any region, the greater is the carbon tax. After 2010, the possibility of shifting towards carbon-free back-stop technologies creates a major technological change given that the back-stop energies are available at constant marginal costs and infinite supply.

In order to illustrate more specifically this dynamic interaction, Figures 9 and 10 plot the carbon tax curves in the case of two contrasting countries: Japan and China. For each period, the tax curve gives the carbon tax as a function of the emission reduction. Each curve is an interpolation of the points derived from scenarios I, II and III.

The convexity of the tax curves indicates the degree of decreasing returns of the tax. The introduction of back-stop technologies is directly related to the downward shift in the tax curve between 2005 and 2010. This shift occurs for Japan but does not occur in China. On the other hand, in both countries, the tax curve shifts systematically to the left during the simulation period: this is the effect of the putty/semi-putty specification. With a putty-putty production function, the tax curves before and after 2005 would lie approximately on top of each other.

IV. Effects on Real income and GDP

Meeting these emission targets via a carbon tax gives rise to costs, in terms of lower welfare and GDP. Estimates of the real income and GDP effects in selected years for the four scenarios are reported in Tables 7 and 8. The changes in real income are measured as the so-called "Hicksian equivalent variation" and they are an appropriate measure of welfare[21].

The typical pattern across regions is for the real income loss to increase over time in line with the carbon tax. By the year 2050, household real income, averaged across all regions, is respectively 1.5, 4.7 and 12.9 per cent lower than BaU in scenarios I, II and III (Table 7). The estimated costs are much smaller in the OECD regions than in the Energy-exporting LDCs, which suffer on average the largest welfare losses in all three scenarios. The former USSR, China and India typically suffer the smallest losses. In some cases, the carbon tax induces net welfare gains. This apparently counter-intuitive result is due to terms-of-trade effects that are explained below.

Real GDP falls compared with BaU because of lower energy use and lower capital accumulation. Averaged across all regions real GDP is between 1.4 and 9.3 per cent lower by 2050, depending on the scenario (Table 8). The differences across regions do not follow exactly the same pattern as for real income losses; this mainly reflects the terms-of-trade effects. The dispersion of the output losses is smaller than the dispersion of the real income losses. Also, an important difference compared with the welfare measure is that the former USSR records real output declines close to the average for the OECD regions. Nonetheless, the energy-exporting LDCs still record higher losses than other regions and the opposite applies to China and India.

Explaining the reasons why the size and the sign of welfare effects may differ from the pattern of the carbon tax sheds some light into the general equilibrium mechanisms of GREEN. Indeed, the main sources of the welfare effects in GREEN are two-fold:

(i) the deadweight loss incurred by consumers as a new price distortion -- the carbon tax -- is introduced into the economy[22]; and
(ii) terms-of-trade effects induced by reallocation of trade flows and real exchange rate changes.

Table 9 below summarises the main regional effects of the carbon tax with respect to the terms-of-trade and the real exchange rate.

Levying a carbon tax will affect trade flows, the terms of trade and the real exchange rate in different directions, depending on whether the region in question is an energy importer or an energy exporter. The carbon tax cuts the demand for imported fossil fuels in energy-importing regions, thereby giving rise to a reduced trade deficit in energy goods. Given the closure rule in GREEN, this has to be balanced by a corresponding reduction in the trade surplus on non-energy goods and services. This is achieved by a rise in relative export prices (an improvement in the terms of trade) and an appreciation of the real exchange rate. Energy-exporting countries, on the other hand, suffer a terms-of-trade loss and a real exchange rate depreciation to compensate for the decline in their energy exports as a result of carbon taxes being applied in their export markets. Energy-importing regions are, therefore, likely to experience a terms-of-trade gain from imposing a carbon tax, while the effect of the tax on their real exchange rate is ambiguous. This explains the observed welfare gains for regions like China, India or the CEECs. Energy-exporting regions are likely to experience a real exchange rate depreciation, but, conversely, the effect on their terms of trade is ambiguous. It could improve in energy-exporting regions where the trade balance relies less on energy exports; this is the case in the former USSR.

Table 9. Effects of a carbon tax on the real exchange rate and terms of trade in energy-importing and energy--exporting regions

	Energy-importing regions		Energy-exporting regions	
	real exchange rate	Terms of trade	real exchange rate	Terms of trade
Energy trade				
-cuts in imports	+	+		
-cuts in exports			-	-
non-Energy trade				
-cuts in exports	-	+	-	+
Total effect	?	+	-	?

V. Trade in Emission Rights

In the following scenario the global emission constraint is the same as in the 2 per cent reduction scenario, but with the possibility of trade in emissions rights. Specific curbs on CO_2 emissions can be considered as initial endowments of emission rights. In this case permits are allocated to each region in line with the emission path set out in scenario II. Emission cuts are then optimally distributed across regions leading to a unique world equilibrium price of permits (implicitly, a unique carbon tax).

The price of permits rises continuously to reach $182 per ton of carbon in 2050, implying that trade in emission rights serves to lower the tax compared with the no-trade scenario in the OECD regions. This also occurs in all non-OECD regions, except China, India and the former USSR, because these countries sell emissions rights to other regions (see Table 10). For example, China earns $145 billion by 2050 from selling emissions rights. In return, this country has to cut its yearly emissions faster and by more than in the no-trade scenario. Table 11 shows the changes in the emission cuts. In China and India, the emission cuts increase by around 15 per cent relative to the no-trade case whereas the OECD regions are able to cut their emissions by 10 per cent less; the largest change is in Brazil where the emission reduction is 30% lower.

The patterns of welfare and GDP changes compared with baseline are shown in Table 12. Household real income gains are important in the regions exporting emissions rights. For example, Chinese real income is 4.5 per cent higher than in the no-trade case by 2050 - a comparison of its loss of only 0.3 per cent in Table 12 with its loss of 4.7 in the no-trade scenario (see Table 7). As expected, other regions also have lower welfare losses compared with scenario II, the major winner being the energy-exporting LDCs (a loss of only 2.1 instead of almost 8 per cent relative to baseline in the no-trade scenario). Among the OECD regions, the largest welfare gains are in the EC.

As described above, the welfare effects reflect not only gains from trading emissions rights but also induced changes in the terms of trade. In the scenario with tradeable permits, there is an increase in the world oil price resulting from higher demand pressure (see Figure 11) which leads to adverse terms-of-trade effects in some regions. This occurs in Brazil and the DAEs where the welfare losses are higher with permits trade than in scenario II.

Averaged over all the regions the Real income loss is around 1 per cent lower than in the no-trade scenario.

VI. Sensitivity Analysis with Two Key Parameters

In order to assess the robustness of the results described above a limited sensitivity analysis was undertaken with respect to two key parameters. In the first simulation, the "autonomous energy efficiency improvement" (AEEI) parameter was halved from 1 to 0.5 per cent per year in all regions. This cut implies, *ceteris paribus*, a higher energy demand because the autonomous energy conservation effect is lower. Secondly, the inter-energy elasticity of substitution was halved in the long-run from 2 to 1, and in the short-run from 0.25 to 0.125. Lowering this elasticity reduces the overall capability of the system to respond to an increase of energy prices. These two specifications were tested in the case of the 2 per cent emissions reduction scenario. The results of this sensitivity analysis are shown in Tables 13 and 14.

Halving the AEEI coefficient generates higher emissions than the central BaU scenario. However, as the emissions cut is equi-proportional, the percentage reduction relative to the baseline is the same in both cases. Hence, the changes in the tax levels are necessarily due to modifications in the other key variables underlying the determination of the carbon tax (see Annex).

Comparing Table 13 with Table 5 shows that, by the end of the period, a lower AEEI induces a lower tax in all regions where back-stops technologies are active, such as the OECD regions and some of the non-OECD regions; in other regions the tax tends to be slightly higher. Averaged over the OECD regions the tax reaches $ 240 by 2050 compared with $ 319 in scenario II; the average tax in non-OECD regions, excluding China and USSR is equal to $ 170 instead of $ 329. This fall in the tax occurs because a lower autonomous energy conservation effect leads to upward pressure on energy demand, thus increasing world oil prices (see Figure 11). The rise in the oil price fosters the introduction of back-stops in the regions where they can be competitive with conventional energies and contributes to lowering the tax following the mechanisms described in section III. In the non-OECD regions where the back-stops are not competitive the tax increases because the rise in world oil price simply increases the average carbon price.

In some regions, in spite of a lower tax, the economic costs, measured by the welfare losses shown in Table 13, are higher because of the terms-of-trade losses related to the higher world oil price: the average welfare loss for the OECD region is 3.1% compared with 2.9%. GDP losses are much more similar with respect to the change in the AEEI.

The reduction of the inter-fuel elasticity of substitution has a different impact on the results. As the average substitution elasticity decreases, the resulting carbon taxes are higher than under scenario II in all regions. The world average increases from $ 230 per ton of carbon in 2050 (Table 5) to $ 400 (Table 14). At the world level, the household real income loss in 2050 is larger: 4.9 per cent relative to the baseline (Table 14) instead of a loss of 3.7 per cent (Table 7) in scenario II. By the end of the period, the world GDP loss also increases from 2.6 per cent to 3.7 per cent.

VII. Concluding Remarks

This paper reports the results from the GREEN model for the standardized emissions reduction scenarios of the OECD Secretariat's Model Comparisons Project. GREEN is a multi-regional, multi-sectoral general equilibrium model that incorporates the following features:

- it has a fully consistent treatment of world trade linkages;
- it has a recursive dynamic structure over the period 1985-2050;
- it includes an explicit treatment of back-stop technologies;

-- it models the depletion of exhaustible resources;
-- it captures adjustment costs via the assumption of imperfect capital mobility across sectors and a putty/semi-putty type specification for the production functions.
-- it endogenises the world oil price.

The simulations show a wide regional variation of both the carbon tax levels and welfare losses required to achieve a given emissions reduction target. Taxes tend to be lower in the less-developed regions that use coal more intensively than other regions, e.g. China, India and the former USSR. Welfare losses, as measured by household real income, are around 3 to 4 per cent by 2050 for the average of OECD countries in the most stringent scenario (which implies a cut of 3 per cent per annum in emission growth compared with baseline). The energy-exporting LDCs have the highest welfare losses because they incur both the costs induced by imposing the tax and an additional income reduction arising from a significant contraction of their oil exports to other regions. Measured by GDP losses, the costs are less significant but still reach 2.2 per cent for the average of the OECD countries over the period 1990-2050 under the most stringent scenario. The different regional patterns can be explained by means of a simple indicator that synthesizes the main determinants of the carbon tax.

The effects of an international agreement on trade in emissions rights are also assessed. This type of agreement leads to significant welfare improvements compared with the no-trade case in countries that are able to export emissions rights, such as China, India and the former USSR.

Finally, a sensitivity analysis was carried out with respect to two key parameters: the autonomous energy efficiency improvement (AEEI) and the inter-fuel elasticity of substitution. In some cases, alternative assumptions on these parameters can have significant impacts on carbon taxes, namely, the when the inter-fuel elasticity is halved from its base level the carbon tax roughly doubles.

ANNEX: A Carbon Tax Indicator

By means of a simple partial equilibrium calculation, it is possible to derive an indicator[23] combining the main determinants of the carbon tax. Consider the expression for the amount of total emissions Em:

(1) $$Em = \alpha_c C + \alpha_o O + \alpha_g G + \alpha_s SF$$

where C, O, G and SF are, respectively, the demands for coal, oil, gas and synthetic fuels expressed in common units (teraJoules for example) and $\alpha_c, \alpha_o, \alpha_g$ and α_s the carbon content per unit of each fuel. We define the average carbon content or the "carbon intensity" of primary energy demand α_m as:

(2) $$\alpha_m = \frac{\alpha_c C + \alpha_o O + \alpha_g G + \alpha_s SF}{W}$$

where W is the carbon-based primary energy demand expressed in teraJoules. Then, total emissions are also equal to:

(3) $$Em = \alpha_m . W$$

Suppose, for simplicity, that W is derived at the optimum from a CES production function F(W,K,L,...). Then the demand function for W will be:

(4) $$W = k . \left[\frac{P_W}{P_Q}\right]^{-\varepsilon} . Q$$

where P_W is the average price, P_Q the average producer price and Q total output; ε is the elasticity of substitution among inputs and k is a constant. By substituting [3] into [4], it is possible to express total emissions as a function of relative prices and total output:

(5) $$Em = \alpha_m . k . \left[\frac{P_W}{P_Q}\right]^{-\varepsilon} . Q$$

Now suppose that emissions have to be reduced by a certain amount R. The equivalent expression for emissions once the necessary carbon tax t has been imposed will be:

$$(6) \qquad (1-R) \, . \, Em = \alpha_m \, . \, k \, . \left[\frac{P_w + (t.\alpha_m)}{P'_Q} \right]^{-\varepsilon} . \, Q$$

As this is a partial equilibrium calculation, it is assumed that all the RHS variables, except P_Q, are virtually unchanged. Of course, in a GE model like GREEN the average carbon content, pre-tax prices and the outputs will change after imposing the tax. The dot indicates the new value for the average producer price. The expression $(t.\alpha_m)$ corresponds to the conversion of the carbon tax into a fuel-specific tax (expressed in 1985 \$ per TeraJoules). By dividing [6] by [5] and solving for t, one gets:

$$(7) \qquad t = \frac{P_w}{\alpha_m} . \left\{ \left[\frac{P'_Q}{P_Q} \right] . \, (1-R)^{-1/\varepsilon} - 1 \right\}$$

This expression is an approximation for the carbon tax provided we know the variation in the average producer price induced by the tax. The latter is quite cumbersome to derive directly given that P_Q is a CES price index. However, it is likely that the ratio between average output prices remains close to one. As our aim is to understand the key determinants underlying the differences in the carbon tax profiles across regions, we can use a looser, but more tractable approximation, by assuming that the producer price ratio is equal to one. Moreover, in order to compare the carbon tax across regions it must be converted into a common unit by means of the real exchange rate, E. Defining τ as the carbon tax indicator expressed in \$ 1985, one gets:

$$(8) \qquad \boxed{\tau = \frac{1}{\alpha_m} . \frac{P_w}{E} . \left[(1-R)^{-1/\varepsilon} - 1 \right]}$$

This simple formula states that the carbon tax is directly proportional to the real energy price level and inversely proportional to the average carbon content of primary energy demand. Note that the first part of the indicator corresponds to a pre-tax "average carbon price" (see the text). The second part of the formula (in brackets) makes the tax depend on the emissions reduction target and the average elasticity of substitution in energy demand. In the equiproportional emission reduction scenarios I-III discussed in the text, the former is roughly equal across regions. With respect to the elasticity of substitution parameter (ε), it is rather difficult to give a simple assessment of what its equivalent is in GREEN, since the production structure is a nested framework embodying different levels and different values for the substitution elasticities. It varies over time because the putty/semi-putty specification creates a dynamic pattern whereby the medium-term elasticities (by five-year periods) converge gradually to the long-run value. Hence, the growth path of each region also intervenes in the level of the medium-term elasticities because higher growth rates are likely to induce a higher amount of new investments and the latter have higher substitution possibilities than old capital vintages. The introduction of back-stop technologies from 2010 on also contributes to a major break in the value of the average elasticity, as the back-stops are assumed to be highly substitutable with conventional fuels.

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NOTES

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[1] We wish to thank Andrew Dean and Peter Hoeller for helpful comments. Thanks are also due to Laurent Moussiegt for expert statistical assistance. The opinions expressed in this paper are our own and cannot be held to represent the views of the OECD or its Member governments

[2] See Dean and Hoeller (1992) for details on the model comparisons project and an overview of the results. For a presentation of more policy-oriented scenarios simulated with GREEN, see Burniaux et al. (1992a).

[3] Because of data constraints it was not possible to isolate the electricity sector from the gas and water distribution sector.

[4] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model (see Fullerton, 1983).

[5] The real world price of oil is computed with respect to a weighted average of real exchange rates in the OECD regions. In each country, the real exchange rate is defined as the ratio of a weighted average of domestic primary factor prices to the numéraire of the model, which is the price of labour in the United States.

[6] The demand system used in GREEN is a version of the Extended Linear Expenditure System (ELES) which was first developed by Lluch (1973). The formulation of the ELES used in GREEN is based on atemporal maximisation -- see Howe (1975). In this formulation, the marginal propensity to save out of supernumerary income is constant and independent of the rate of reproduction of capital.

[7] The rate of reserve discovery is the rate at which unproven reserves are converted into proven reserves, while the rate of extraction is the rate at which proven reserves are converted into output.

[8] This involves computing in each period a measure of Harrod-neutral technical progress in the capital/fixed factor bundle as a residual, given that the growth of the labour force (in efficiency units) is equal to the exogenous growth in GDP. This is a standard calibration procedure in dynamic AGE modelling -- see Ballard et al. (1985).

[9] See Burniaux et al. (1992b) for simulations results with a wider range of policy instruments.

[10] Alternative implementations of the carbon tax in the model e.g. levying it at the point of production, would probably produce different results (see Whalley and Wigle, 1991).

[11] Some additional information was necessary to disaggregate the EMF 12 assumptions so that they matched the regions modelled separately in GREEN. It was assumed that relative growth differentials between regional groupings projected by the World Bank - the basic source for the EMF 12 GDP projections - for the period 1986-1995 were maintained over the entire time horizon. For the fossil fuel resource base, the regional details were derived from Masters et al. (1991)

[12] Note that scenarios I-III impose an identical relative reduction target across regions. Indeed, the ratio between emissions in a given percentage reduction scenario and the BaU level is approximately equal to $(1-r)^t$, where r is the growth-rate reduction to be achieved and t the number of periods.

[13] See Hoeller, Dean and Nicolaisen (1990) and IPCC (1990).

[14] See footnote 11.

[15] We recall that during the simulation period (1990-2050), the equiproportionate cut in the growth rate of emission of 2 percentage points per year induces an increasingly stringent emission reduction relative to baseline.

[16] Burniaux et al. (1992a) derived regional energy price wedges from the observed benchmark data and average world prices. The removal of these wedges could have a major impact on the pattern of energy demand (hence, emissions) mainly in the non-OECD regions.

[17] The carbon content of energy demand can be defined as the ratio between total emissions (in tons of carbon) and the volume of energy demand (in energy units, e.g. terajoules).

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[18] Among OECD countries there appears to be a strong negative relationship between the implicit price of carbon emissions and emission intensities which corroborates this argument empirically (see Hoeller and Wallin, 1991).

[19] See Table 2 for the numerical values of the key supply and demand parameters of GREEN.

[20] By solving the above equation with respect to ε, it could be possible to derive the *ex-post* average elasticity of the system.

[21] See Burniaux et al. (1992b) for a discussion of this welfare measure and how it is computed in GREEN.

[22] The term "deadweight loss" may be misleading in this context as the carbon tax is a "corrective" tax, i.e. it aims to raise the price of fossil fuels to reflect more adequately their social cost.

[23] Further details of the construction of this indicator are available from the authors upon request. See also Boero, Clarke and Winters (1991) for an analysis of the supply-side determinants of the carbon tax.

Table 1. Key dimensions of the GREEN model

Producer Sectors

1) Agriculture
2) Coal mining
3) Crude oil
4) Natural gas
5) Refined oil
6) Electricity, gas and water distribution
7) Energy-intensive industries
8) Other industries and services
9) Carbon-based back-stop
10) Carbon-free back-stop
11) Carbon-free electric back-stop

Consumer Sectors

1) Food, beverages and tobacco
2) Fuel and power
3) Transport and communication
4) Other goods and services

Regions

1) United States
2) Japan
3) EC
4) Other OECD (b)
5) Energy-exporting developing countries (c)
6) China
7) The former USSR
8) India
9) Central and Eastern Europe countries (CEECs) (d)
10) Dynamic Asian Economies (e)
11) Brazil
12) Rest of the World (RoW)

Primary Factors (a)

1) Labour [1]
2) Sector-specific "old capital" [8]
3) "New" capital [1]
4) Sector-specific fixed factors for each fuel [4]
5) Land in agriculture [1]

a) Figures in brackets represent the number of each primary factor in each regional sub-model.

b) This grouping excludes Iceland and Switzerland.

c) This grouping includes the OPEC countries as well as other oil-exporting, gas-exporting and coal-exporting countries. For a full listing of the countries, see Table 4 in Burniaux et al. (1992b)

d) Bulgaria, Czech and Slovak Federal Republic, Hungary, Poland, Rumania and Yugoslavia.

e) Hong Kong, Philippines, Singapore, South Korea, Taiwan and Thailand.

Table 2. Key parameters in the GREEN model

Production structure			
CES elasticities	Old vintages		New vintages
Elasticity L-KEF	0.12		1.0
Elasticity E-KF	0.0		0.6
Elasticity intra-energy	0.25		2.0
Elasticity between conventional and back-stop technologies (a)		10.0	
Fixed factor own-price elasticity	Upward		Downward
Land (b)	1.0-3.0		0.5
Coal (b)	4.0-5.0		∞
Oil, in the Energy-exp. LDCs		3.0-1.0	
Oil, in all other regions		∞	
Natural gas (b)	0.0		3.0-4.0
Carbon-free electric	0.2		∞
Demand structure			
ELES Income elasticities			
Food and beverages (b)		0.5-0.7	
Fuel and power (b)		0.5-0.8	
Transport & communication (b)		0.8-1.2	
Other goods & services (b)		1.1-1.5	
Inter-energy elasticity		1.2	
Foreign Trade			
Price elasticities for export demand			
Fossil-fuels		5.0	
Agricultural goods		4.0	
Other goods & services		3.0	
Substitution elasticities between domestic and imported goods			
Fossil-fuels		4.0	
Agricultural goods		4.0	
Other goods & services		2.0	
Other			
Disinvestment elasticity		0.7	
Depreciation rate (b)		0.013-0.032	
AEEI		1.0	

N.B: Abbreviations: L = Labour; K = capital; E = Energy: F = Fixed factor.
AEEI = Autonomous Energy Efficiency Improvement.
(a) There is no adjustment cost related to new equipments.
(b) Depending on the regions.

Table 3. Exogenous prices and CO_2 emission coefficients for the back-stop options

Back-stop options	Unit costs (in 1985 $)	Unit costs per TeraJoule (in 1985 $)	CO_2-emission coefficient (tons of carbon per TeraJoule)
Carbon-based (synthetic fuel)	50 $ per barrel	8 473	39
Carbon-free liquid fuel	100 $ per barrel	18 950	0
Carbon-free electric option	75 mills per Kwh	28 126 [a]	0

Source: EMF 12.

(a) As the EMF 12 refers to producers costs, a fixed distribution margin of 35 per cent is added to the estimated unit costs. In addition, a second, region-specific adjustment is made to correct for the aggregation bias arising from the fact that the electricity sector in GREEN also includes the distribution of gas and water. The region-specific margins are calculated by comparing the average unit costs for the electricity, gas and water sector calculated from the 1985 I/O tables with electricity prices from the IEA publication *Energy Prices and Taxes*. The resulting margins for the OECD regions are: 33.3 mills/Kwh in the US; 14.5 mills/Kwh in Japan; 35.9 mills/Kwh in the EC; and 20.6 mills/Kwh in the Other OECD. In the absence of any reliable data, an average margin of 30 mills/Kwh was assumed for all the non-OECD regions.

Table 4. CO2 Emissions in the various scenarios (in million tons of carbon)

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	WORLD	*non-OECD, exc. China & former USSR*
BaU scenario																
1990	1339	316	813	291	423	608	1010	149	354	105	95	312	*1419*	*2758*	**5815**	*1438*
2000	1497	417	884	323	553	875	1221	214	415	145	128	400	*1624*	*3120*	**7071**	*1855*
2005	1560	457	906	335	626	1050	1315	256	443	167	144	446	*1698*	*3258*	**7704**	*2082*
2010	1684	399	944	361	715	1363	1536	328	515	190	157	513	*1704*	*3388*	**8705**	*2418*
2020	1852	452	1010	402	950	2142	1756	524	611	249	201	658	*1864*	*3716*	**10806**	*3193*
2030	2020	505	1076	442	1184	2921	1975	720	708	307	245	803	*2023*	*4043*	**12907**	*3967*
2050	2295	741	1273	524	1830	5531	2394	1475	909	496	381	1149	*2539*	*4833*	**18998**	*6240*
Scenario I: Reduction of growth rate of CO2 emissions by 1% per year compared with BaU																
2000	1355	378	800	292	502	794	1106	195	376	132	116	363	*1471*	*2826*	**6408**	*1682*
2005	1344	395	780	288	541	908	1134	221	382	144	124	385	*1464*	*2807*	**6647**	*1797*
2010	1381	327	773	296	588	1124	1262	270	423	158	129	422	*1396*	*2777*	**7153**	*1990*
2020	1369	333	748	297	694	1555	1296	380	450	184	147	482	*1377*	*2746*	**7934**	*2338*
2030	1357	339	722	297	800	1985	1330	489	477	211	166	542	*1359*	*2715*	**8716**	*2686*
2050	1263	409	700	289	1017	3094	1322	826	502	282	211	637	*1399*	*2661*	**10551**	*3475*
Scenario II: Reduction of growth rate of CO2 emissions by 2% per year compared with BaU																
2000	1226	342	724	264	454	720	1001	176	340	120	105	329	*1330*	*2556*	**5800**	*1523*
2005	1156	340	671	248	466	784	977	191	329	125	107	332	*1259*	*2414*	**5724**	*1549*
2010	1130	268	632	242	483	925	1034	223	346	129	106	346	*1142*	*2272*	**5864**	*1633*
2020	1019	247	557	221	511	1134	963	277	333	136	109	355	*1025*	*2044*	**5862**	*1720*
2030	908	227	482	199	539	1344	892	331	320	142	111	365	*908*	*1816*	**5860**	*1808*
2050	691	225	383	158	561	1721	725	460	276	156	117	351	*765*	*1456*	**5821**	*1920*
Scenario III: Reduction of growth rate of CO2 emissions by 3% per year compared with BaU																
2000	1107	310	654	239	411	652	906	160	307	108	95	297	*1203*	*2310*	**5246**	*1378*
2005	992	293	576	213	401	676	840	165	283	107	92	286	*1082*	*2074*	**4922**	*1333*
2010	923	218	516	198	395	760	846	183	283	106	87	283	*932*	*1854*	**4797**	*1337*
2020	764	185	418	165	378	833	721	203	249	101	81	264	*768*	*1532*	**4361**	*1275*
2030	605	151	321	132	361	906	596	223	214	96	75	244	*605*	*1210*	**3925**	*1213*
2050	375	123	208	86	308	951	395	255	151	85	64	192	*416*	*792*	**3192**	*1054*
Stabilization of CO2 emissions at 1990 levels (in per cent deviations relative to BaU)																
2000	-11	-24	-8	-10	-23	-30	-17	-30	-15	-28	-26	-22	*-13*	*-12*	**-18**	*-22*
2005	-14	-31	-10	-13	-32	-42	-23	-42	-20	-37	-34	-30	*-16*	*-15*	**-25**	*-31*
2010	-21	-22	-14	-20	-41	-55	-34	-55	-31	-45	-40	-39	*-17*	*-19*	**-33**	*-41*
2020	-28	-31	-20	-28	-55	-72	-42	-72	-42	-58	-53	-53	*-24*	*-26*	**-46**	*-55*
2030	-34	-37	-25	-34	-64	-79	-49	-79	-50	-66	-61	-61	*-30*	*-32*	**-55**	*-64*
2050	-42	-57	-36	-45	-77	-89	-58	-90	-61	-79	-75	-73	*-44*	*-43*	**-69**	*-77*

Table 5. Carbon tax (in 1985 $ per ton of carbon)

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	WORLD	*non-OECD, exc. China & former USSR*
Scenario I: Reduction of growth rate of CO2 emissions by 1% per year compared with BaU																
2000	31	54	56	25	33	5	10	9	12	47	70	16	*49*	*40*	**27**	*26*
2005	42	77	80	35	48	6	13	10	16	67	105	22	*70*	*57*	**37**	*37*
2010	39	46	71	36	49	8	16	11	18	70	148	23	*58*	*48*	**34**	*40*
2020	48	67	86	45	71	10	25	13	23	95	201	28	*73*	*60*	**43**	*54*
2030	57	89	101	53	92	13	33	16	28	120	255	33	*88*	*72*	**51**	*67*
2050	65	103	104	57	137	22	49	24	43	151	286	45	*94*	*80*	**62**	*90*
Scenario II: Reduction of growth rate of CO2 emissions by 2% per year compared with BaU																
2000	122	142	186	100	112	13	24	24	38	139	183	62	*158*	*140*	**89**	*82*
2005	200	216	313	174	181	16	34	30	58	217	294	112	*259*	*231*	**141**	*132*
2010	139	116	180	179	151	20	44	31	65	172	407	115	*165*	*152*	**105**	*127*
2020	223	197	251	255	237	26	69	39	97	287	458	184	*239*	*231*	**149**	*184*
2030	307	277	321	332	322	32	94	47	129	402	510	253	*312*	*309*	**192**	*241*
2050	340	268	294	357	500	67	180	71	233	495	485	343	*299*	*319*	**230**	*329*
Scenario III: Reduction of growth rate of CO2 emissions by 3% per year compared with BaU																
2000	353	280	492	284	262	25	46	56	108	315	381	190	*396*	*375*	**229**	*201*
2005	662	442	992	546	460	34	69	79	203	515	679	395	*755*	*711*	**415**	*364*
2010	224	215	293	438	257	44	94	77	201	264	549	253	*305*	*265*	**193**	*239*
2020	376	357	396	523	444	65	163	109	334	462	578	411	*414*	*395*	**282**	*370*
2030	527	499	499	609	631	86	231	142	466	660	607	569	*523*	*525*	**371**	*500*
2050	629	614	567	682	999	278	507	280	702	834	684	732	*605*	*616*	**530**	*702*
Stabilization of CO2 emissions at 1990 levels																
2000	45	221	59	35	216	44	22	83	26	303	342	96	*90*	*69*	**77**	*144*
2005	52	259	66	41	351	67	26	112	31	432	482	154	*104*	*78*	**103**	*219*
2010	58	1	53	53	180	220	59	203	75	261	464	183	*42*	*50*	**102**	*182*
2020	65	57	60	63	303	279	62	260	80	407	492	263	*60*	*63*	**133**	*255*
2030	72	114	67	73	426	337	65	317	85	554	520	342	*78*	*76*	**164**	*328*
2050	51	167	61	61	594	467	89	466	106	605	487	360	*85*	*69*	**197**	*404*

Table 6. Fossil-fuel prices and emission shares in the benchmark data sets by country/region, 1985

(a) Relative Fossil-Fuel Prices (1)

(average price in USA = 100)

	United States	Japan	EC	Other OECD	Energy-exporting LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	WORLD
Coal	35.4	126.4	63.9	27.0	30.8	20.5	24.8	25.6	26.2	68.5	110.6	25.7	35.8
Crude Oil	152.2	178.3	166.7	136.8	99.4	155.0	24.1	95.4	100.1	135.2	123.8	142.5	119.9
Gas	92.5	167.1	140.6	81.9	84.4	106.7	17.0	61.3	44.9	166.1	71.9	198.6	76.4
Average	100.0	162.6	131.2	92.4	87.8	46.9	21.8	47.8	48.4	118.5	120.1	106.7	81.6

(b) Share of Fossil Fuels in Total CO2 Emissions (in %)

	United States	Japan	EC	Other OECD	Energy-exporting LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	WORLD
Coal	34.7	30.5	32.9	32.8	20.0	86.2	38.1	74.1	66.9	37.5	21.0	45.3	42.0
Crude Oil	46.7	61.4	51.8	51.1	61.6	12.5	33.4	24.4	20.1	60.2	76.1	46.7	42.2
Gas	18.6	8.1	15.3	16.1	18.4	1.4	28.6	1.6	13.0	2.3	2.9	8.0	15.8

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 (TeraJoules).
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 7. Welfare (Household real income) losses (in per cent deviations relative to BaU)

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	WORLD	*non-OECD, exc. China & former USSR*
Scenario I: Reduction of growth rate of CO2 emissions by 1% per year compared with BaU																
2000	0.0	0.3	0.1	0.0	-2.2	-0.5	0.2	0.1	0.3	0.2	0.9	-0.5	*0.1*	*0.1*	**-0.2**	*-0.9*
2005	0.0	0.5	0.1	-0.1	-3.5	-0.6	0.1	0.1	0.5	0.2	1.2	-0.6	*0.2*	*0.1*	**-0.3**	*-1.4*
2010	-0.1	-0.4	-0.2	-0.1	-4.2	-0.6	0.1	0.2	0.6	0.3	1.6	-0.5	*-0.3*	*-0.2*	**-0.6**	*-1.6*
2020	-0.3	-0.5	-0.6	-0.2	-3.6	-0.9	0.0	0.1	0.5	0.2	1.1	-0.5	*-0.5*	*-0.4*	**-0.7**	*-1.4*
2030	-0.4	-0.6	-0.9	-0.3	-3.2	-1.1	0.0	0.0	0.5	0.2	0.8	-0.4	*-0.7*	*-0.5*	**-0.8**	*-1.3*
2050	-1.1	-1.2	-2.0	-0.7	-1.1	-1.5	-0.5	-1.0	-1.2	-2.3	-3.1	-1.0	*-1.5*	*-1.3*	**-1.3**	*-1.5*
Scenario II: Reduction of growth rate of CO2 emissions by 2% per year compared with BaU																
2000	0.0	0.7	-0.2	-0.1	-6.0	-1.2	0.2	0.1	0.8	0.0	1.5	-1.2	*0.1*	*0.1*	**-0.6**	*-2.5*
2005	-0.1	0.9	-0.6	-0.4	-10.1	-1.6	-0.2	0.2	1.2	-0.2	1.7	-1.5	*0.0*	*-0.1*	**-1.2**	*-4.2*
2010	-1.3	-0.9	-1.7	-0.8	-12.5	-1.2	-0.3	0.6	1.3	-0.5	1.9	-1.6	*-1.2*	*-1.3*	**-2.3**	*-5.2*
2020	-1.3	-0.7	-2.3	-1.4	-16.0	-1.7	-1.2	0.5	1.0	-0.7	1.1	-1.3	*-1.5*	*-1.4*	**-3.0**	*-6.7*
2030	-1.3	-0.6	-2.8	-1.8	-17.7	-1.9	-1.8	0.5	0.8	-0.7	0.7	-1.2	*-1.8*	*-1.6*	**-3.5**	*-7.5*
2050	-2.7	-2.3	-4.0	-2.6	-7.9	-4.7	-3.3	-1.2	-2.8	-3.0	-1.5	-4.1	*-3.0*	*-2.9*	**-3.7**	*-4.7*
Scenario III: Reduction of growth rate of CO2 emissions by 3% per year compared with BaU																
2000	-0.3	1.0	-1.2	-0.5	-11.1	-2.2	0.0	0.2	1.5	-0.7	1.8	-2.0	*-0.3*	*-0.3*	**-1.4**	*-4.7*
2005	-1.1	1.0	-3.2	-1.4	-18.0	-2.8	-0.8	0.1	1.9	-1.8	1.2	-2.7	*-1.4*	*-1.3*	**-3.0**	*-7.8*
2010	-4.3	-1.7	-4.9	-2.8	-21.6	-1.5	-1.0	0.9	0.3	-2.7	0.6	-4.2	*-3.4*	*-3.8*	**-5.2**	*-9.9*
2020	-4.0	-1.2	-4.7	-3.4	-28.9	-1.7	-3.2	0.6	-1.7	-2.5	0.4	-3.9	*-3.1*	*-3.5*	**-6.2**	*-13.0*
2030	-3.7	-1.0	-4.6	-3.8	-32.7	-1.9	-4.6	0.5	-3.0	-2.4	0.3	-3.7	*-3.0*	*-3.3*	**-6.8**	*-14.5*
2050	-3.6	-2.0	-4.6	-4.1	-29.7	-3.0	-8.0	0.2	-5.5	-3.2	-0.4	-4.5	*-3.4*	*-3.5*	**-6.9**	*-12.9*
Stabilization of CO2 emissions at 1990 levels																
2000	0.2	0.5	0.5	0.0	-6.1	-1.2	0.2	0.5	0.7	-0.9	0.9	-1.4	*0.4*	*0.3*	**-0.5**	*-2.7*
2005	0.2	0.5	0.7	-0.1	-9.6	-1.8	-0.1	-0.2	1.0	-1.9	0.2	-1.9	*0.5*	*0.4*	**-1.0**	*-4.5*
2010	-0.1	-1.0	0.4	-0.1	-10.4	-1.1	0.3	-0.4	0.8	-2.9	-0.1	-2.1	*-0.2*	*-0.2*	**-1.5**	*-5.1*
2020	-0.2	-0.7	0.1	-0.2	-12.4	-4.6	-0.7	-2.3	0.3	-2.9	-0.6	-2.2	*-0.2*	*-0.2*	**-2.3**	*-6.2*
2030	-0.2	-0.5	-0.1	-0.2	-13.4	-6.2	-1.4	-3.2	0.1	-2.8	-0.9	-2.3	*-0.3*	*-0.2*	**-2.7**	*-6.8*
2050	-1.4	-1.9	-1.3	-1.1	-6.0	-10.3	-1.7	-5.1	-2.0	-3.8	-2.2	-4.6	*-1.6*	*-1.5*	**-3.4**	*-4.7*

Table 8. GDP losses (in per cent deviations relative to BaU)

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	**WORLD**	*non-OECD, exc. China & former USSR*
Scenario I: Reduction of growth rate of CO2 emissions by 1% per year compared with BaU																
2000	-0.1	-0.1	-0.1	0.0	-0.8	-0.1	-0.1	0.0	0.1	-0.1	-0.1	-0.1	*-0.1*	*-0.1*	**-0.1**	*-0.4*
2005	-0.1	-0.1	-0.1	-0.1	-1.2	-0.2	-0.2	-0.1	0.1	-0.2	-0.3	-0.1	*-0.1*	*-0.1*	**-0.2**	*-0.6*
2010	-0.2	-0.3	-0.2	-0.1	-1.6	-0.2	-0.3	-0.1	0.2	-0.3	-0.5	-0.1	*-0.2*	*-0.2*	**-0.4**	*-0.7*
2020	-0.2	-0.4	-0.4	-0.2	-1.6	-0.3	-0.4	-0.2	0.2	-0.5	-1.5	-0.2	*-0.4*	*-0.3*	**-0.5**	*-0.9*
2030	-0.3	-0.4	-0.5	-0.2	-1.6	-0.3	-0.5	-0.2	0.3	-0.7	-2.0	-0.2	*-0.4*	*-0.4*	**-0.6**	*-1.0*
2050	-0.4	-0.8	-0.7	-0.4	-1.8	-0.9	-1.0	-0.6	-0.2	-1.4	-3.2	-0.5	*-0.7*	*-0.6*	**-0.9**	*-1.4*
Scenario II: Reduction of growth rate of CO2 emissions by 2% per year compared with BaU																
2000	-0.3	-0.2	-0.3	-0.2	-2.2	-0.3	-0.3	-0.2	0.0	-0.4	-0.4	-0.3	*-0.3*	*-0.3*	**-0.5**	*-1.0*
2005	-0.5	-0.4	-0.7	-0.4	-3.7	-0.5	-0.6	-0.2	-0.1	-0.8	-1.0	-0.5	*-0.5*	*-0.5*	**-0.9**	*-1.8*
2010	-0.9	-0.8	-1.1	-0.6	-5.0	-0.5	-0.9	-0.3	-0.1	-1.3	-1.6	-0.6	*-0.9*	*-0.9*	**-1.3**	*-2.5*
2020	-1.1	-0.9	-1.6	-1.0	-7.4	-0.7	-1.7	-0.4	-0.6	-2.0	-3.3	-1.1	*-1.2*	*-1.2*	**-1.9**	*-3.8*
2030	-1.2	-0.9	-1.9	-1.3	-8.7	-0.7	-2.2	-0.5	-0.9	-2.4	-4.0	-1.4	*-1.4*	*-1.3*	**-2.3**	*-4.5*
2050	-1.3	-1.4	-1.9	-1.6	-7.2	-1.5	-3.5	-1.1	-2.5	-3.0	-4.5	-2.2	*-1.6*	*-1.5*	**-2.6**	*-4.4*
Scenario III: Reduction of growth rate of CO2 emissions by 3% per year compared with BaU																
2000	-0.7	-0.5	-0.9	-0.6	-4.3	-0.7	-0.7	-0.4	-0.5	-0.9	-0.9	-0.7	*-0.7*	*-0.7*	**-1.0**	*-2.1*
2005	-1.4	-1.0	-1.8	-1.2	-7.3	-0.9	-1.4	-0.7	-1.2	-1.8	-2.2	-1.3	*-1.4*	*-1.4*	**-2.0**	*-3.8*
2010	-2.3	-1.5	-2.6	-1.6	-9.5	-1.0	-1.9	-0.7	-1.5	-3.0	-3.0	-1.7	*-2.1*	*-2.2*	**-2.8**	*-5.0*
2020	-2.4	-1.5	-2.9	-2.1	-14.5	-1.4	-3.5	-1.2	-3.3	-3.7	-4.4	-2.7	*-2.2*	*-2.3*	**-3.8**	*-7.6*
2030	-2.5	-1.5	-3.1	-2.5	-17.2	-1.5	-4.6	-1.4	-4.5	-4.1	-5.0	-3.3	*-2.3*	*-2.4*	**-4.4**	*-8.9*
2050	-2.1	-1.8	-2.7	-2.6	-18.0	-2.3	-7.1	-2.0	-6.6	-4.2	-5.0	-3.5	*-2.3*	*-2.2*	**-4.9**	*-9.3*
Stabilization of CO2 emissions at 1990 levels																
2000	-0.1	-0.5	0.0	-0.1	-1.8	-0.7	-0.3	-0.6	0.1	-0.9	-0.9	-0.5	*-0.2*	*-0.1*	**-0.4**	*-1.1*
2005	-0.2	-0.7	0.0	-0.1	-3.1	-1.1	-0.5	-1.0	0.0	-1.8	-2.0	-0.8	*-0.3*	*-0.2*	**-0.7**	*-1.9*
2010	-0.3	-0.8	0.0	-0.2	-4.4	-1.8	-0.9	-1.5	-0.1	-2.7	-2.7	-1.1	*-0.3*	*-0.3*	**-1.0**	*-2.7*
2020	-0.3	-0.6	-0.1	-0.2	-5.9	-3.4	-1.4	-2.8	-0.4	-3.5	-4.3	-1.8	*-0.3*	*-0.3*	**-1.6**	*-3.9*
2030	-0.3	-0.5	-0.1	-0.2	-6.7	-4.1	-1.7	-3.4	-0.7	-3.9	-5.0	-2.2	*-0.3*	*-0.3*	**-1.9**	*-4.5*
2050	-0.4	-1.1	-0.2	-0.4	-5.7	-5.6	-2.1	-4.4	-1.5	-4.1	-5.2	-2.7	*-0.6*	*-0.5*	**-2.4**	*-4.5*

Table 10: Emission trading under the 2 per cent reduction scenario.
(in billion 1985 $)

	2000	*2005*	*2010*	*2020*	*2030*	*2050*
USA	-4.3	-9.2	-11.0	-23.3	-35.5	-46.5
Japan	-2.1	-4.5	-3.6	-6.9	-10.1	-14.0
EEC	-4.5	-9.4	-11.4	-20.8	-30.2	-40.0
Other OECD	-0.7	-1.6	-2.3	-4.7	-7.1	-9.7
Energy LDCs	-1.6	-4.0	-5.5	-15.1	-24.8	-48.9
China	6.6	14.8	20.1	51.6	83.1	145.5
former USSR	6.5	13.6	14.8	22.0	29.2	20.8
India	0.9	2.4	3.4	10.6	17.8	40.0
CEECs	0.7	1.4	1.3	2.2	3.1	0.7
DAEs	-0.7	-1.5	-2.1	-5.1	-8.1	-15.1
Brazil	-0.8	-1.8	-2.7	-7.1	-11.5	-22.3
ROW	-0.2	-0.7	-1.3	-3.4	-5.5	-10.2
Common Price of Permits in 1985 $	*50*	*75*	*74*	*106*	*137*	*182*

NB: A negative (positive) sign indicates a net purchase (sale) of tradeable permits.

Table 11: Emission reductions with tradeable permits under the 2 per cent reduction scenario.
(deviations between the trade and no-trade scenario in percentage of BaU emissions)

	2000	*2005*	*2010*	*2020*	*2030*	*2050*
USA	6.1	8.3	9.5	11.7	13.6	12.0
Japan	10.1	13.5	12.9	14.2	15.2	11.5
EEC	10.4	14.2	16.8	19.3	21.6	18.7
Other OECD	4.3	6.5	8.7	10.8	12.5	11.0
Energy LDCs	6.0	8.4	10.7	14.1	16.2	15.7
China	-15.5	-19.5	-20.8	-21.5	-21.9	-15.6
former USSR	-11.1	-14.4	-13.6	-12.3	-11.3	-5.2
India	-8.9	-13.0	-14.8	-17.7	-19.0	-16.1
CEECs	-3.5	-4.5	-3.8	-3.6	-3.4	-0.5
DAEs	9.3	12.3	15.1	18.1	20.0	17.8
Brazil	12.1	17.1	23.5	31.1	36.1	34.9
ROW	0.7	1.9	3.3	4.6	5.4	5.3

NB: A negative (positive) indicates an increase (a decrease) of emission reduction relative to BaU.

Table 12. Welfare and GDP losses (in per cent deviations relative to BaU)

Scenario with tradeable permits under the 2 per cent reduction scenario

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	WORLD	*non-OECD, exc. China & former USSR*
Welfare (Household real income)																
2000	-0.1	0.3	-0.1	-0.1	-2.8	1.0	1.7	0.9	0.3	-0.1	0.6	-0.7	*0.0*	*0.0*	**-0.2**	*-1.1*
2005	-0.3	0.3	-0.2	-0.3	-4.7	1.7	2.1	1.1	0.2	-0.3	0.6	-1.0	*-0.1*	*-0.2*	**-0.4**	*-2.0*
2010	-0.6	-0.6	-0.6	-0.4	-5.9	1.6	1.4	1.1	0.0	-0.4	0.9	-1.0	*-0.6*	*-0.6*	**-0.9**	*-2.5*
2020	-1.0	-0.9	-1.3	-0.9	-6.2	2.7	0.5	1.4	-0.8	-1.0	0.1	-1.3	*-1.1*	*-1.0*	**-1.3**	*-2.8*
2030	-1.2	-1.1	-1.9	-1.2	-6.4	3.2	-0.1	1.6	-1.3	-1.3	-0.3	-1.4	*-1.4*	*-1.3*	**-1.5**	*-3.0*
2050	-2.6	-2.1	-3.3	-2.3	-2.1	-0.3	-2.8	-0.3	-5.8	-4.5	-5.6	-4.0	*-2.6*	*-2.6*	**-2.6**	*-3.1*
GDP at market prices																
2000	-0.1	0.0	0.0	-0.1	-0.9	-0.7	-0.7	-0.3	-0.2	-0.1	-0.1	-0.3	*0.0*	*-0.1*	**-0.2**	*-0.5*
2005	-0.2	-0.1	-0.1	-0.2	-1.5	-1.1	-1.3	-0.7	-0.5	-0.3	-0.1	-0.4	*-0.1*	*-0.1*	**-0.4**	*-0.8*
2010	-0.3	-0.4	-0.2	-0.2	-2.1	-1.3	-1.7	-0.8	-0.5	-0.4	-0.2	-0.4	*-0.3*	*-0.3*	**-0.6**	*-1.1*
2020	-0.5	-0.5	-0.4	-0.4	-2.6	-2.0	-2.7	-1.5	-1.3	-0.9	-0.6	-0.8	*-0.5*	*-0.5*	**-1.0**	*-1.6*
2030	-0.6	-0.6	-0.6	-0.6	-2.9	-2.3	-3.3	-1.8	-1.8	-1.1	-0.8	-1.0	*-0.6*	*-0.6*	**-1.2**	*-1.9*
2050	-0.9	-1.2	-1.1	-1.1	-3.1	-3.3	-4.3	-2.7	-3.4	-2.3	-2.6	-1.8	*-1.1*	*-1.0*	**-1.9**	*-2.6*

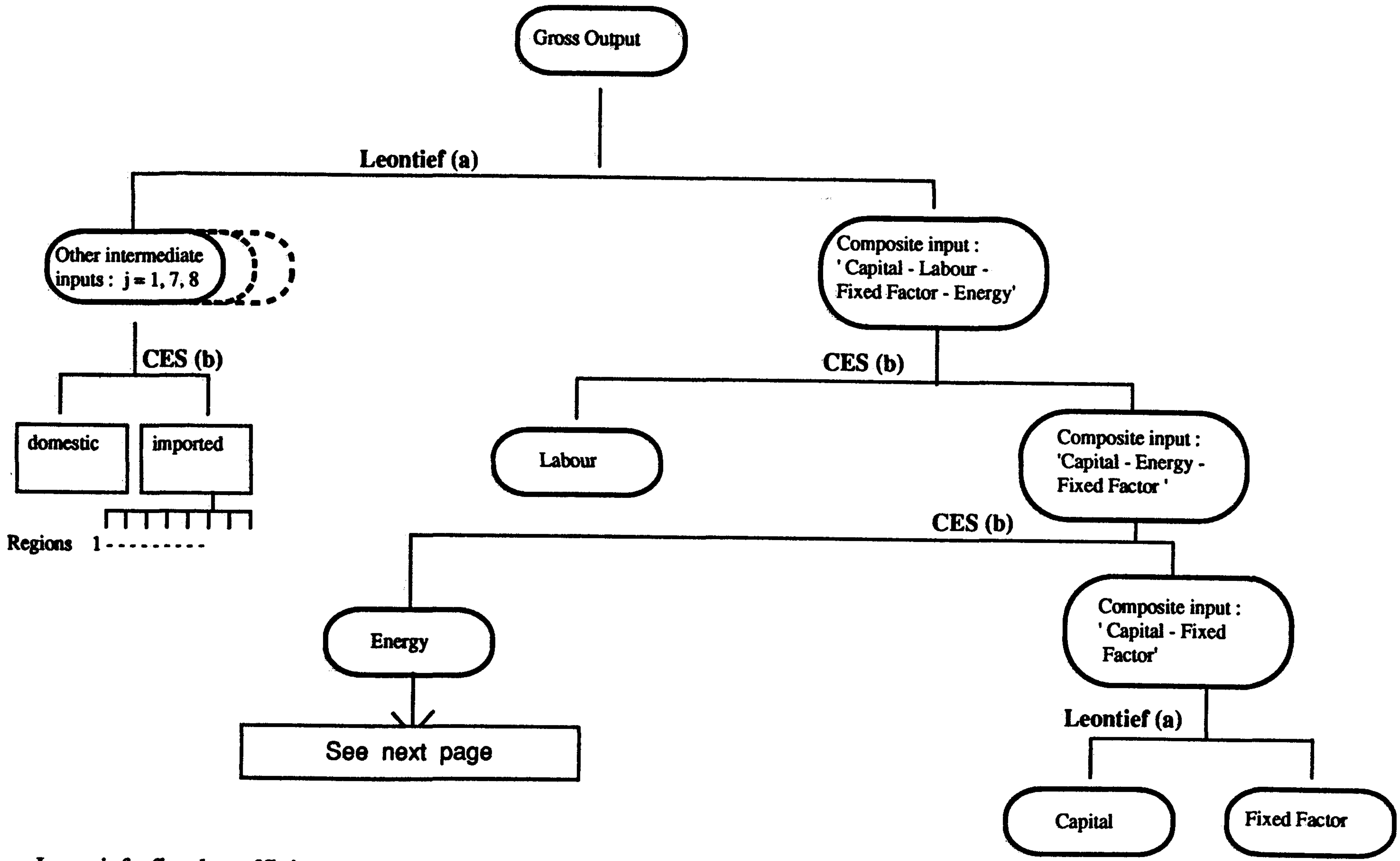
Table 13. Effects of alternative parameterisations: scenario II with AEEI=0.5% per year.

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	WORLD	*non-OECD, exc. China & former USSR*
Carbon tax (in 1985 $ per ton of carbon)																
2000	123	153	198	101	114	13	25	25	39	147	205	62	*167*	*146*	**92**	*65*
2005	207	238	345	180	186	16	36	31	60	236	349	113	*284*	*246*	**150**	*104*
2010	98	118	142	160	102	21	46	31	65	142	447	98	*141*	*119*	**88**	*78*
2020	187	189	203	232	180	29	77	40	100	274	484	156	*206*	*197*	**132**	*109*
2030	276	259	264	304	258	37	108	49	134	405	521	215	*272*	*274*	**176**	*139*
2050	252	222	215	275	354	81	196	76	222	403	414	248	*230*	*240*	**193**	*170*
Welfare (Household real income) (in per cent deviations relative to BaU)																
2000	0.1	0.8	-0.2	-0.1	-6.2	-1.3	0.2	0.2	1.0	0.1	1.8	-1.2	*0.2*	*0.1*	**-0.6**	*-2.6*
2005	-0.1	1.1	-0.6	-0.3	-10.6	-1.7	-0.2	0.2	1.6	-0.1	2.1	-1.5	*0.1*	*0.0*	**-1.2**	*-4.3*
2010	-1.8	-0.8	-2.1	-0.8	-11.8	-1.1	-0.2	0.7	1.3	-0.8	2.1	-1.5	*-1.4*	*-1.6*	**-2.4**	*-4.7*
2020	-2.1	-1.0	-2.8	-1.2	-12.3	-2.1	-1.1	0.5	1.2	-0.7	1.7	-1.5	*-1.8*	*-2.0*	**-2.9**	*-5.0*
2030	-2.4	-1.1	-3.3	-1.5	-12.5	-2.6	-1.7	0.5	1.1	-0.7	1.5	-1.4	*-2.1*	*-2.2*	**-3.2**	*-5.1*
2050	-3.7	-2.4	-4.5	-2.9	-4.9	-4.8	-3.7	-2.8	-5.1	-4.7	-3.0	-5.1	*-3.3*	*-3.5*	**-3.9**	*-4.5*
GDP at market prices (in per cent deviations relative to BaU)																
2000	-0.3	-0.2	-0.4	-0.2	-2.1	-0.3	-0.4	-0.2	0.0	-0.4	-0.5	-0.3	*-0.3*	*-0.3*	**-0.5**	*-1.0*
2005	-0.6	-0.5	-0.7	-0.5	-3.5	-0.5	-0.7	-0.2	-0.1	-0.9	-1.2	-0.5	*-0.6*	*-0.6*	**-0.9**	*-1.7*
2010	-1.0	-0.8	-1.2	-0.6	-4.7	-0.5	-1.0	-0.2	0.0	-1.5	-1.9	-0.6	*-0.9*	*-1.0*	**-1.3**	*-2.2*
2020	-1.3	-0.9	-1.6	-0.9	-5.4	-0.7	-1.8	-0.4	-0.5	-2.1	-3.5	-1.1	*-1.2*	*-1.3*	**-1.8**	*-2.7*
2030	-1.5	-1.0	-1.9	-1.1	-5.8	-0.8	-2.3	-0.5	-0.9	-2.4	-4.3	-1.3	*-1.4*	*-1.5*	**-2.1**	*-3.0*
2050	-1.4	-1.6	-1.8	-1.4	-6.0	-2.3	-3.9	-1.5	-2.8	-3.3	-4.7	-2.2	*-1.6*	*-1.5*	**-2.6**	*-3.7*

Table 14. Effects of alternative parameterisations: scenario II with low inter-fuel elasticity of substitution.

	USA	Japan	EEC	Other OECD	Energy-exp. LDCs	China	former USSR	India	CEECs	DAEs	Brazil	ROW	*OECD, exc.USA*	*Total OECD*	WORLD	*non-OECD, exc. China & former USSR*
Carbon tax (in 1985 $ per ton of carbon)																
2000	205	200	260	169	135	24	30	45	62	187	213	107	*226*	*216*	**133**	*88*
2005	329	309	439	286	211	35	44	62	98	291	354	188	*374*	*352*	**211**	*137*
2010	170	217	219	278	167	46	59	68	110	216	456	162	*231*	*200*	**142**	*124*
2020	289	334	302	383	274	67	98	98	176	386	494	265	*327*	*308*	**211**	*179*
2030	409	450	384	487	381	87	136	127	243	557	531	367	*423*	*416*	**280**	*234*
2050	499	509	436	550	740	176	301	238	445	702	573	550	*481*	*489*	**400**	*371*
Welfare (Household real income) (in per cent deviations relative to BaU)																
2000	-0.1	0.7	-0.4	-0.3	-7.7	-1.2	0.0	0.1	1.1	-0.2	1.8	-1.5	*0.0*	*0.0*	**-0.9**	*-3.2*
2005	-0.5	0.9	-1.1	-0.8	-12.7	-1.5	-0.5	0.0	1.5	-0.6	2.0	-2.0	*-0.3*	*-0.4*	**-1.7**	*-5.2*
2010	-2.0	-0.7	-2.2	-1.4	-15.6	-0.9	-0.5	0.5	1.3	-1.0	2.2	-2.4	*-1.5*	*-1.7*	**-3.0**	*-6.2*
2020	-2.3	-0.8	-2.9	-2.2	-20.1	-1.6	-1.8	0.1	0.3	-1.6	1.6	-2.2	*-1.9*	*-2.1*	**-4.1**	*-8.0*
2030	-2.5	-0.8	-3.4	-2.8	-22.5	-1.9	-2.7	-0.2	-0.4	-2.0	1.3	-2.1	*-2.2*	*-2.4*	**-4.7**	*-8.9*
2050	-3.1	-2.2	-4.0	-3.4	-16.7	-4.2	-4.9	-0.6	-2.7	-3.4	0.1	-4.0	*-3.1*	*-3.1*	**-4.9**	*-7.3*
GDP at market prices (in per cent deviations relative to BaU)																
2000	-0.5	-0.3	-0.5	-0.4	-2.9	-0.5	-0.5	-0.3	-0.2	-0.6	-0.4	-0.5	*-0.4*	*-0.4*	**-0.7**	*-1.4*
2005	-0.9	-0.6	-1.0	-0.7	-5.0	-0.7	-0.9	-0.5	-0.5	-1.1	-1.1	-0.8	*-0.8*	*-0.8*	**-1.2**	*-2.3*
2010	-1.4	-1.0	-1.4	-0.9	-6.4	-0.8	-1.2	-0.6	-0.7	-1.7	-1.7	-1.0	*-1.2*	*-1.3*	**-1.8**	*-3.0*
2020	-1.8	-1.3	-2.0	-1.5	-9.7	-1.4	-2.4	-1.2	-1.9	-2.7	-3.3	-1.8	*-1.6*	*-1.7*	**-2.7**	*-4.6*
2030	-2.1	-1.4	-2.3	-1.9	-11.4	-1.7	-3.1	-1.5	-2.7	-3.2	-4.0	-2.3	*-1.9*	*-2.0*	**-3.3**	*-5.4*
2050	-2.0	-2.0	-2.4	-2.3	-10.5	-2.6	-5.1	-2.2	-5.0	-3.9	-4.1	-2.9	*-2.2*	*-2.1*	**-3.7**	*-5.4*

Figure 1a : Structure of production in GREEN



a. Leontief : fixed coefficients

b. CES : constant elasticity-of-substitution

Figure 1b: Energy and backstop technologies in GREEN

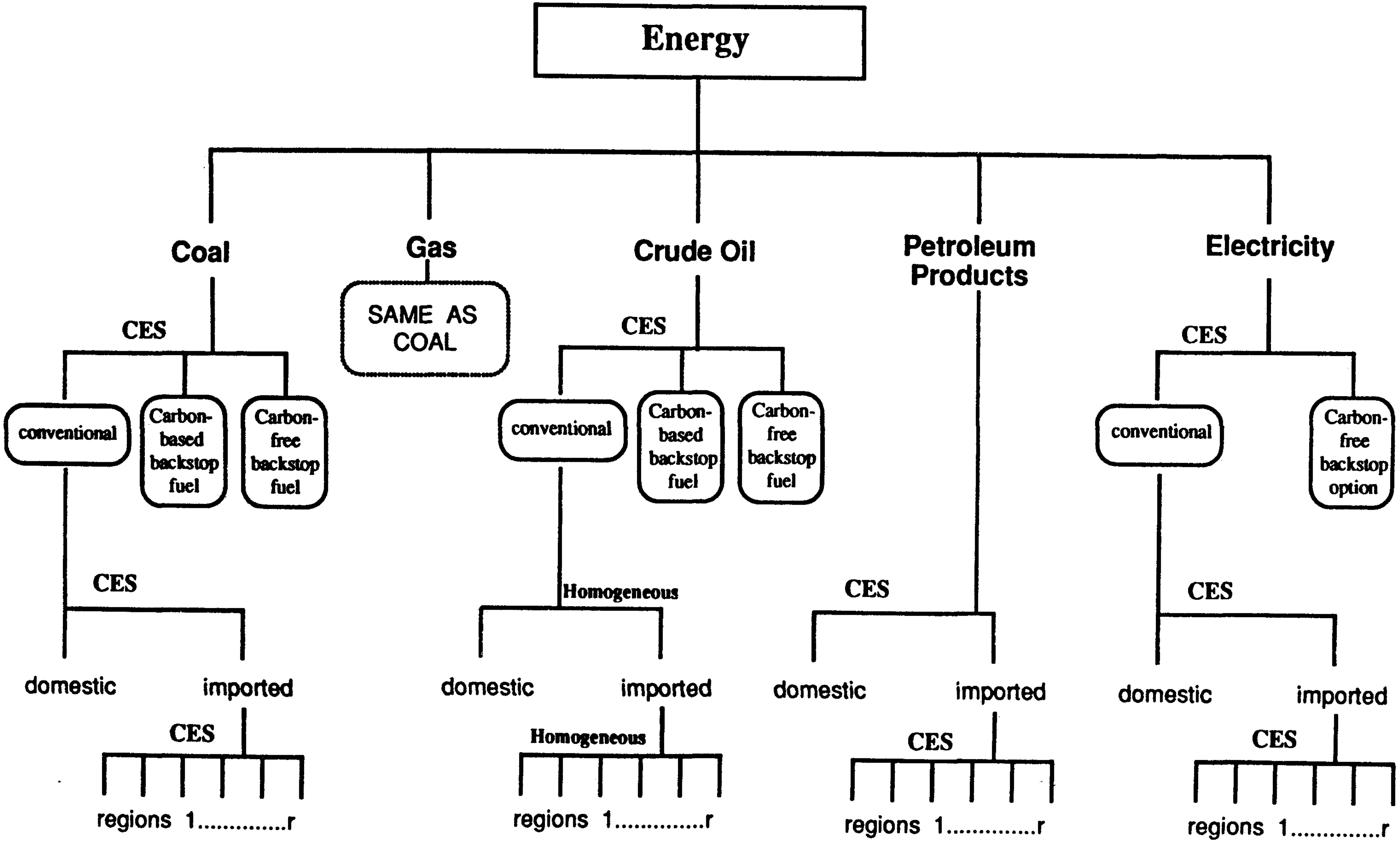


Figure 2. Structure of household demand in GREEN

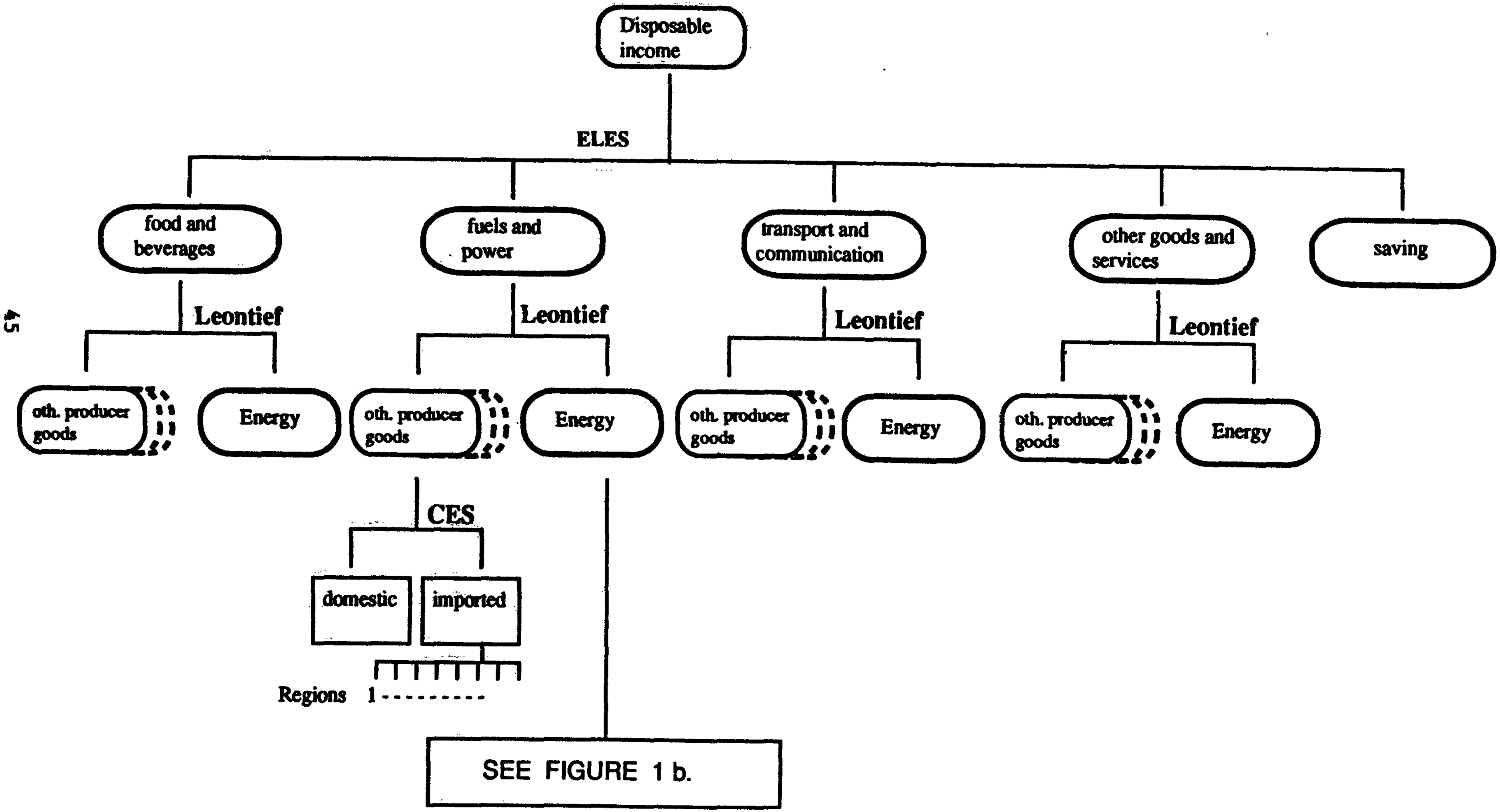
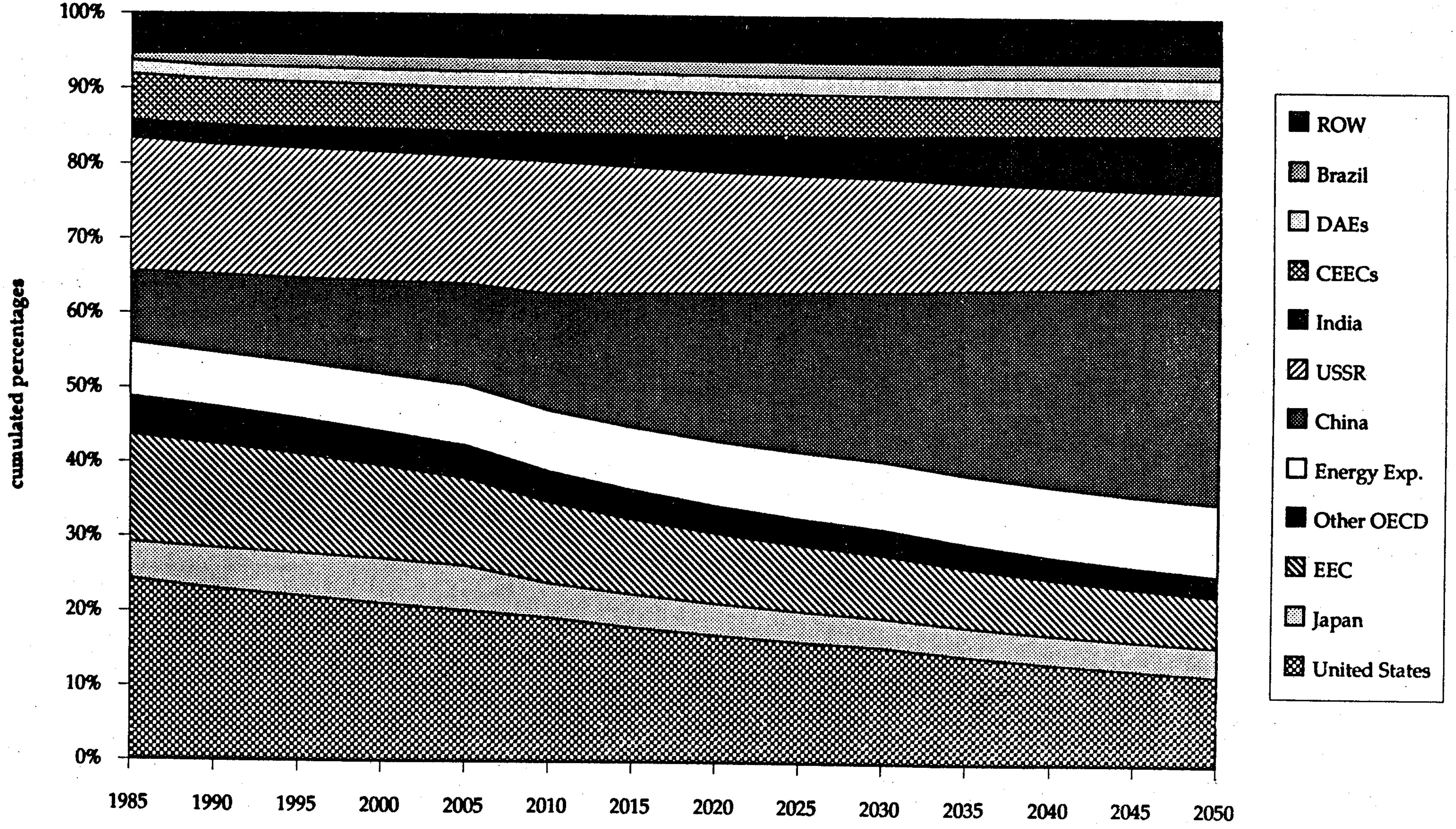
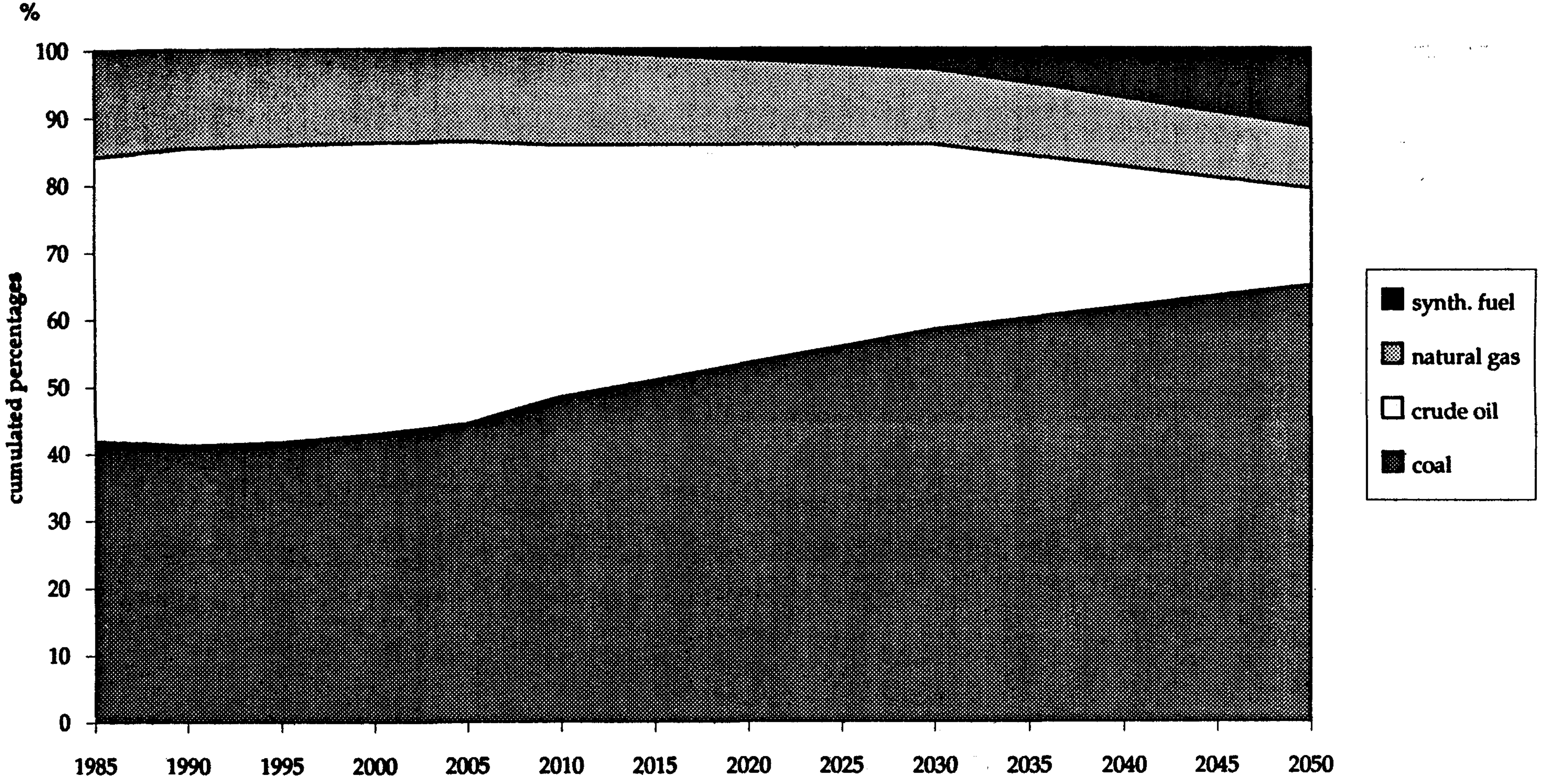


Figure 3. Regional shares of global CO2 emissions in the BaU scenario



NB. The regions are ranked in the figure in the same order as in the legend

Figure 4. CO2 emissions shares by fossil fuel source in the BaU scenario, 1985-2050.



NB. The fuels are ranked in the figure in the same order as in the legend

Figure 5. Time Profiles of the Carbon tax, OECD regions.

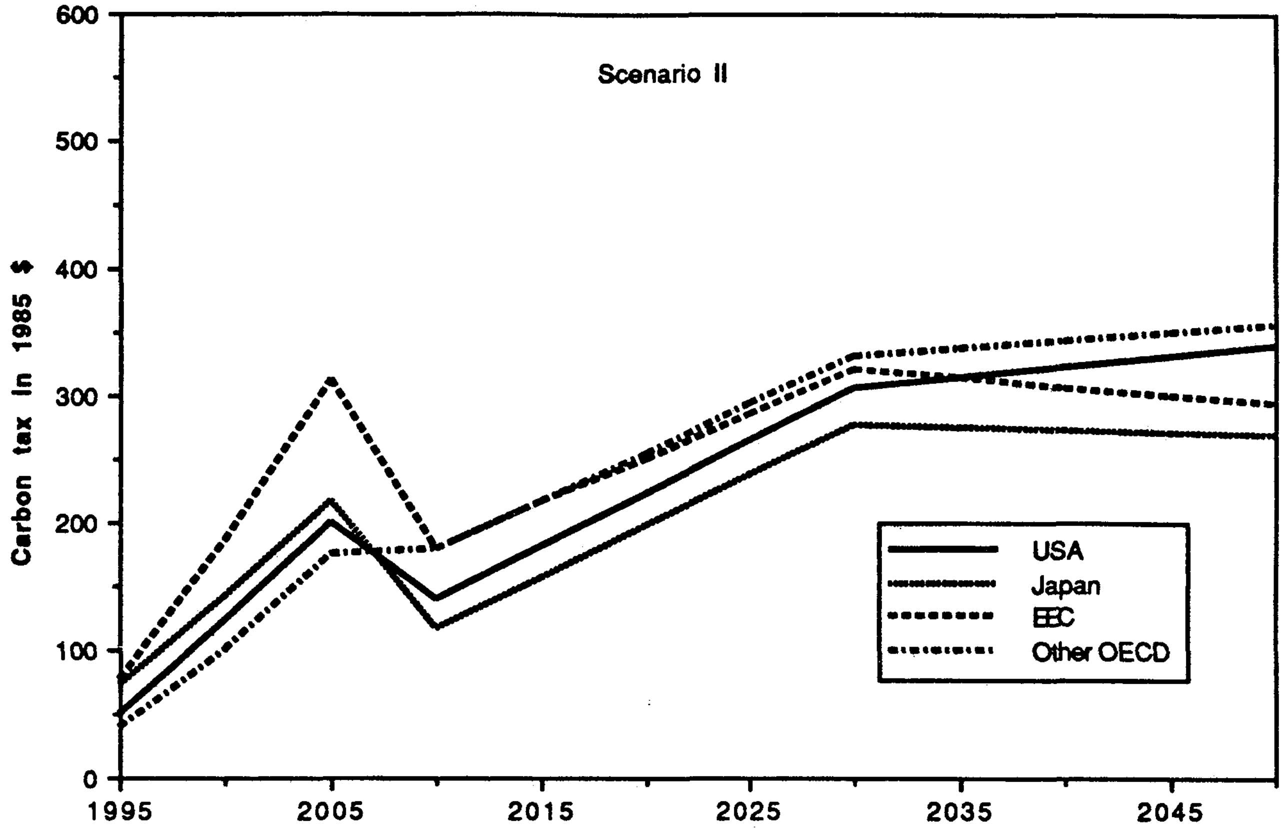


Figure 6. Time profiles of the carbon tax, non-OECD regions.

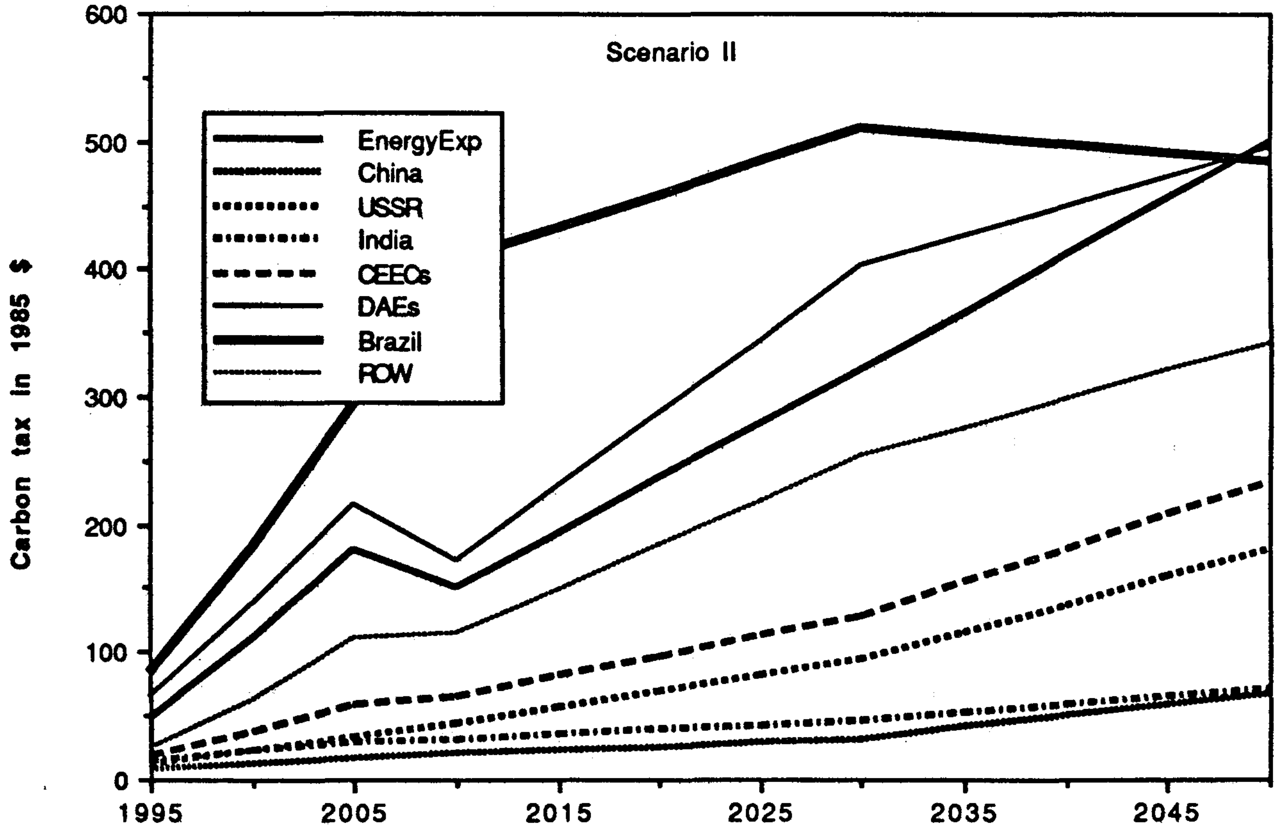
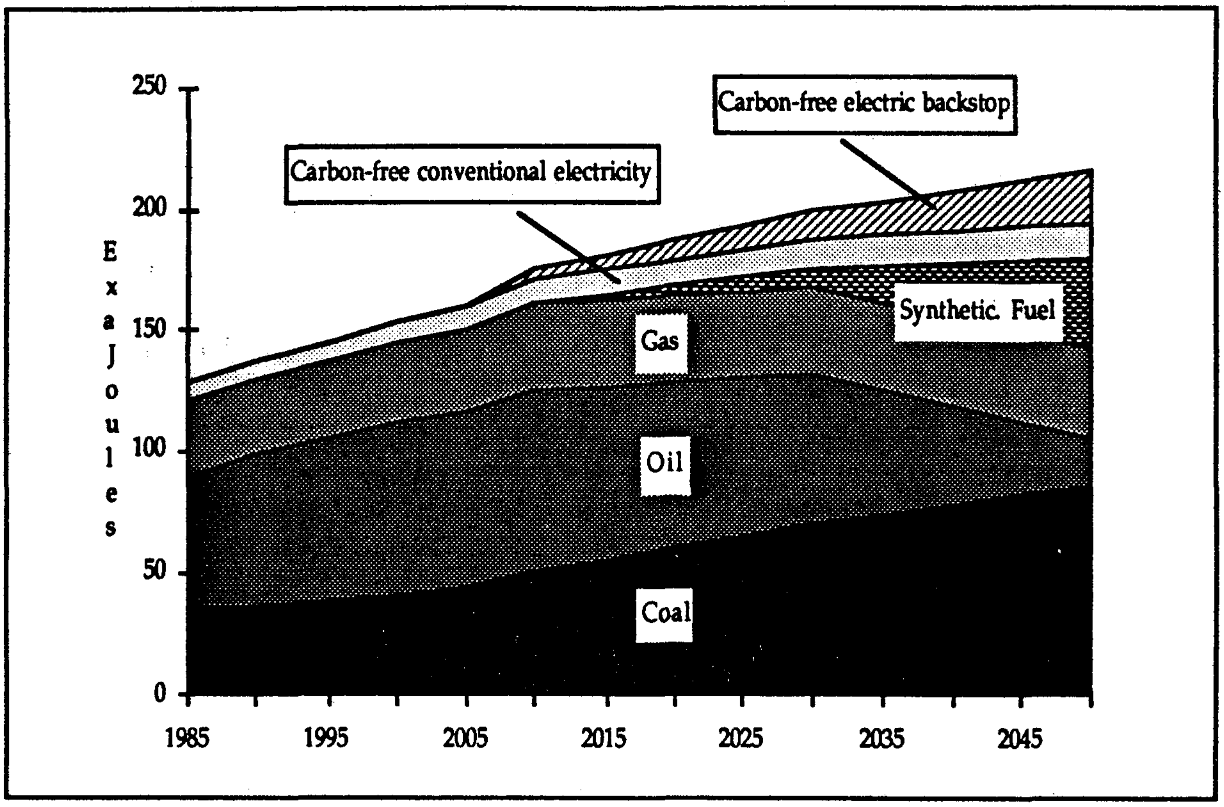


Figure 7. Primary Energy Demand by source, OECD regions.

BaU scenario



scenario II : 2 per cent reduction relative to baseline

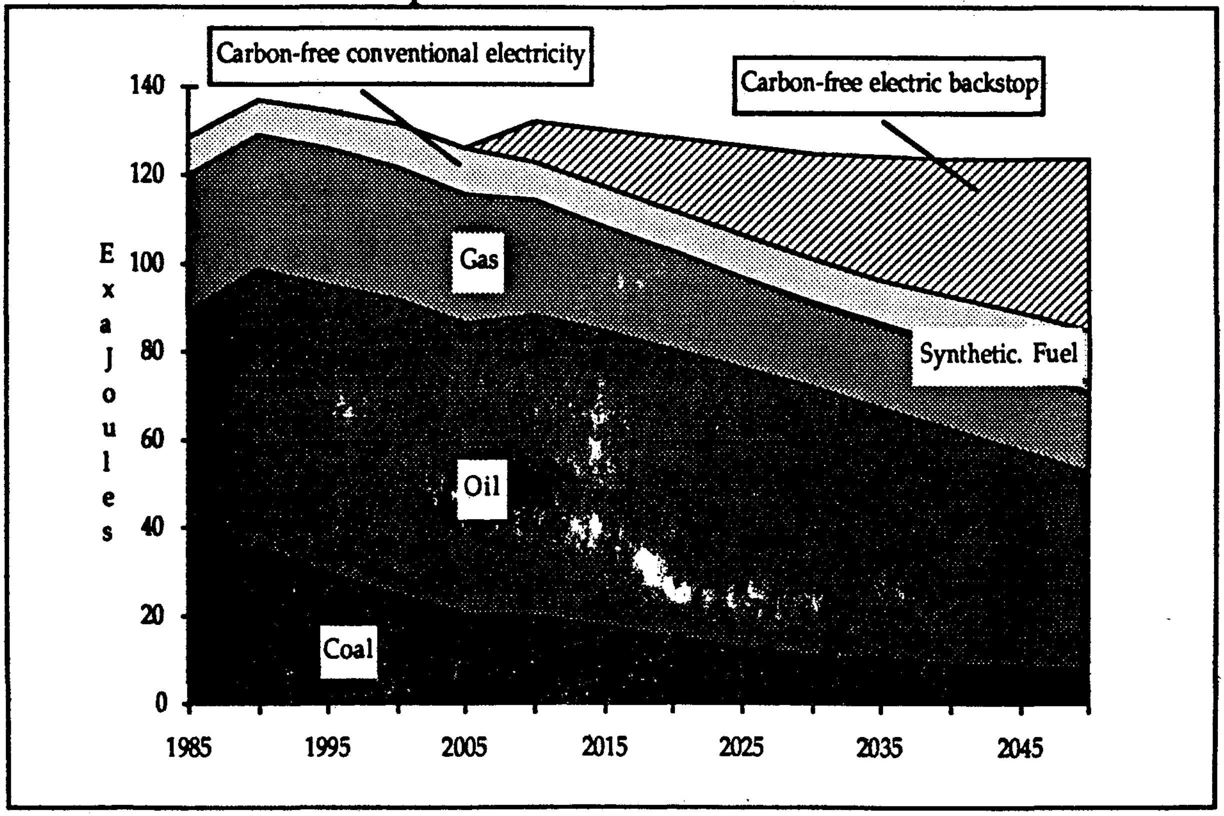
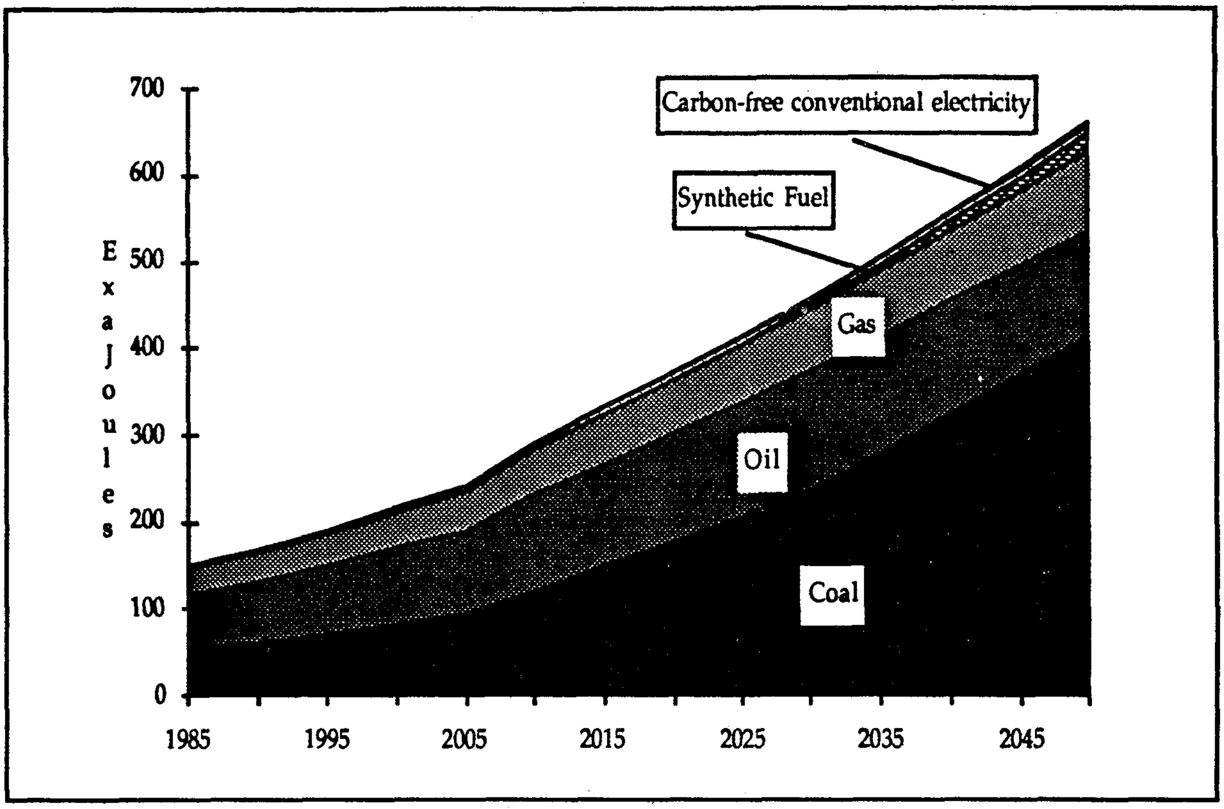


Figure 8. Primary Energy Demand by source, non-OECD regions.

BaU scenario



scenario II : 2 per cent reduction relative to baseline

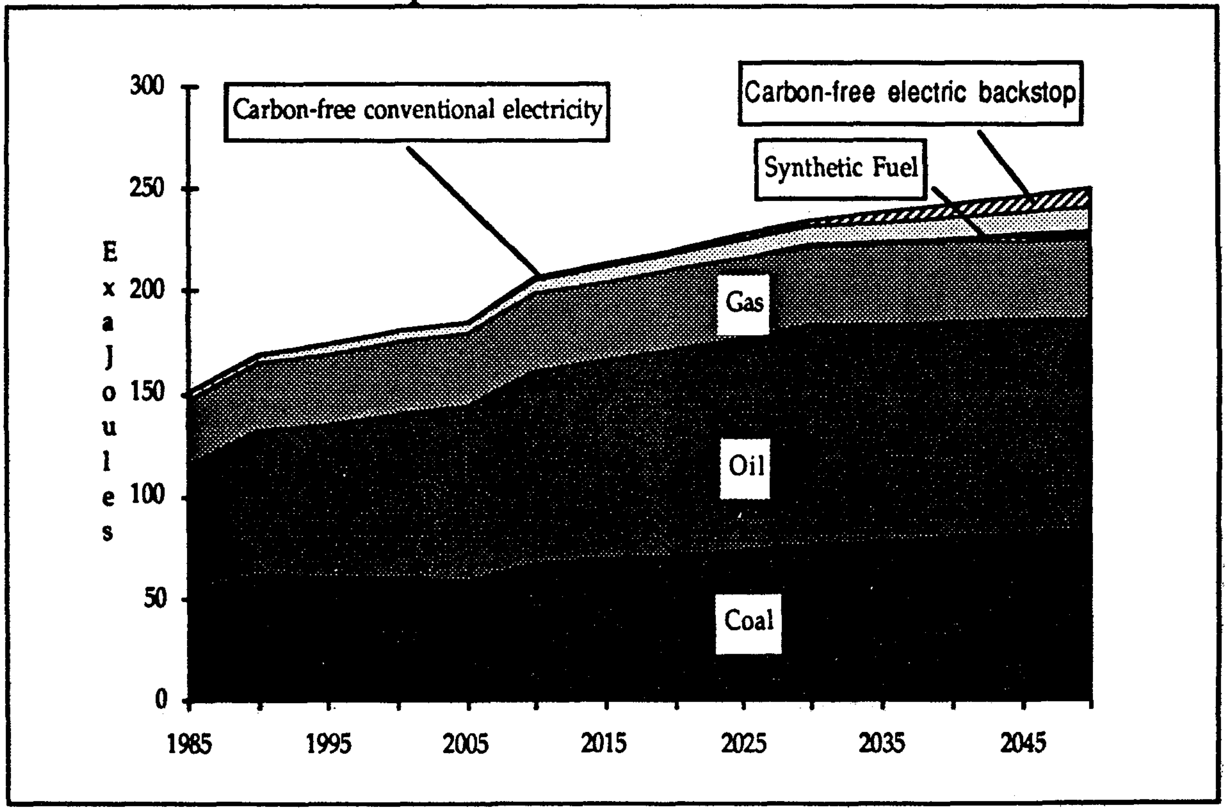


Figure 9. Tax curves in Japan

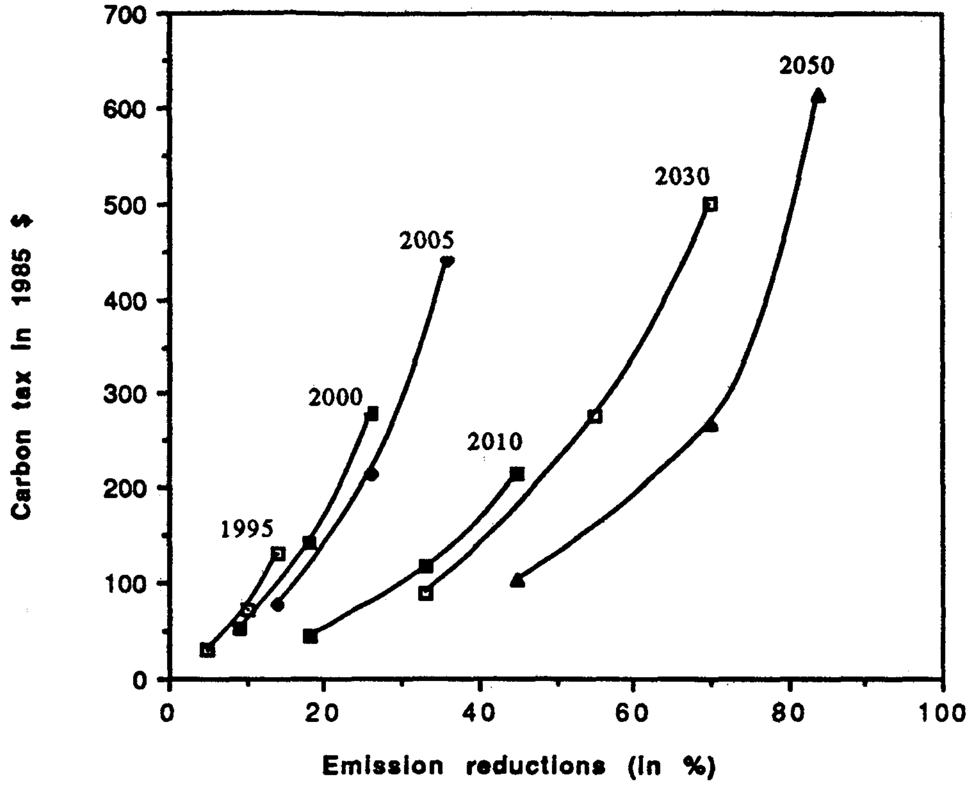


Figure 10. Tax curves in China

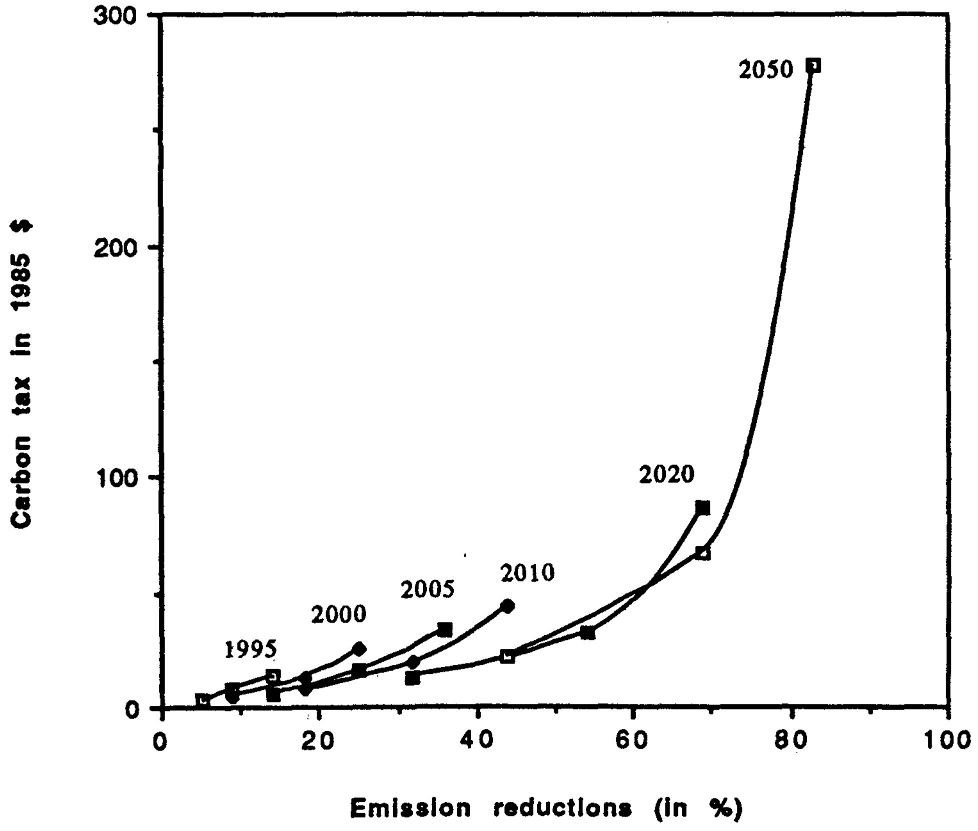
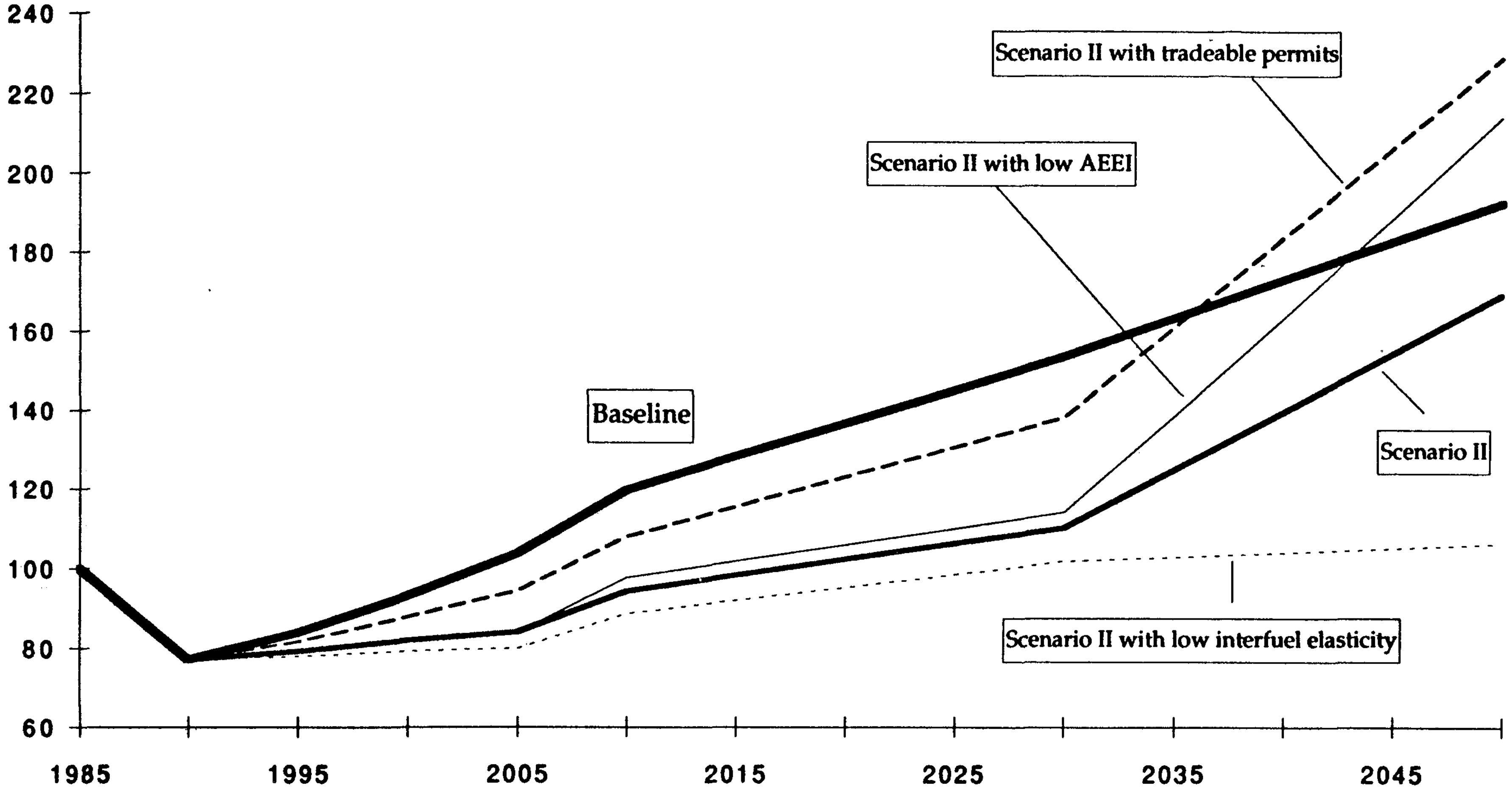


Figure 11. Effects of alternative specifications on the world real oil price

(index 1985=100)



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