OECD Economics Department Working Papers No. 114

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https://dx.doi.org/10.1787/431042862776

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CARBON TAXES AND CO_2 EMISSIONS TARGETS: RESULTS FROM THE IEA MODEL

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 reduction scenarios. The IEA model is an econometric energy model with a projection horizon to 2005. One of the major conclusions to emerge from the results presented in this paper is that even seemingly moderate CO_2 emissions reduction targets would require very high carbon taxes. The reasons for this are, firstly, that the carbon taxes need to be very high to have any material impact on final prices, especially those of transportation fuels and electricity, and, secondly, that most of the decline in emissions would have to come from a reduction in energy demand because the scope for substitution is very limited over a period of 10-15 years. The model also suggests that the required carbon taxes for any target are likely to be much lower in North America than in the Other OECD region, because North America has much lower primary fuel prices, lower taxation of energy products and a higher starting carbon intensity.

* * * * *

Ce document fait partie d'un projet 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. Le modèle de l'AIE est un modèle économétrique d'énergie avec une projection à l'horizon de l'an 2005. Une des principales conclusions qui émerge des résultats présentés dans ce document est que même des objectifs de réduction d'émissions de CO_2 apparemment modérés supposeraient des taxes sur le carbone très élevées. Ceci tient premièrement au fait que les taxes sur le carbone doivent être très élevées pour avoir un impact matériel quelconque sur les prix finaux, en particulier sur ceux des carburants utilisés dans les transports et sur ceux de l'électricité, et deuxièmement au fait que la majeure partie de la baisse des émissions devrait provenir d'une réduction de la demande d'énergie, les possibilités de substitution étant très limitées pour les 10 à 15 années à venir. Le modèle suggère aussi que les taxes requises sur le carbone, quelque soit l'objectif retenu, seront vraisemblablement beaucoup plus faibles en Amérique du Nord que dans les autres régions de l'OCDE parce que l'Amérique du Nord a des prix de combustibles primaires beaucoup plus bas, une taxation des produits énergétiques beaucoup plus faible et une intensité initiale en carbone plus élevée.

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The author is grateful to Andrew Dean, George Kowalski and Sean O'Dell for useful comments on earlier drafts of this paper. Jonathan Coppel, apart from commenting on the paper, provided significant technical assistance. The present version of the IEA model, on which the results reported in this paper are based, was built mostly by Niko Kouvaritakis with substantial help from Jonathan Coppel, Kiyoshi Goto and a number of other IEA colleagues. The views expressed in this paper are those of the author and do not necessarily reflect those of the IEA.

I. Introduction

This paper presents the IEA model results for a variety of CO_2 emissions target scenarios requested for the OECD Comparisons Project. After a brief description of the model and its key features in the first section of the paper, the reference case projections are discussed in Section II. Section III describes the way in which carbon taxes are implemented in the model and the mechanisms which determine their effectiveness in reducing CO_2 emissions. The simulation results are then presented and analysed.

It is hoped that the discussion that follows will be useful, in the context of the Comparisons Project, in complementing the results of the very long-term models on the economic cost of reaching an emissions target. Indeed, the time-span of the results presented here is equivalent to a single time period of some of these models. The IEA model suggests that the level of carbon tax required to reach any given emissions target in the medium term is much higher than that suggested by many of the long-term models that include estimates of the tax in the medium term. The most important reason for this difference is likely to be the concentration of the IEA model on the existing rigidities in the energy system and the exogeneity of the non-energy part of the economy within the model. The major conclusion drawn in this paper is that a severe emissions target, if introduced rapidly, would require very high taxes over the next ten years. There is, of course, no contradiction in the required taxes being lower in the long run than in the medium term and, according to the results presented here, any emissions target would need to be introduced gradually, taking into account existing rigidities and the very slow turnover of a large proportion of the energy using capital stock.

II. A brief description of the IEA model

A. *Key features of the model*

The IEA Medium Term Energy Model has been developed over the past five years as an analytical tool for examining trends in energy markets and for carrying out sensitivity analysis of the energy system. Its key features are:

-- It is an energy model, and it treats the macroeconomy exogenously;

-- Its frequency is annual, currently running to 2005;

-- Most of its parameters are econometrically estimated, usually over the 1965 to 1989 period;

-- Adjustment factors complement econometric forecasts in obtaining reference case projections;

-- Its treatment of energy markets is especially detailed for the OECD regions, primarily because of the availability of high quality data.

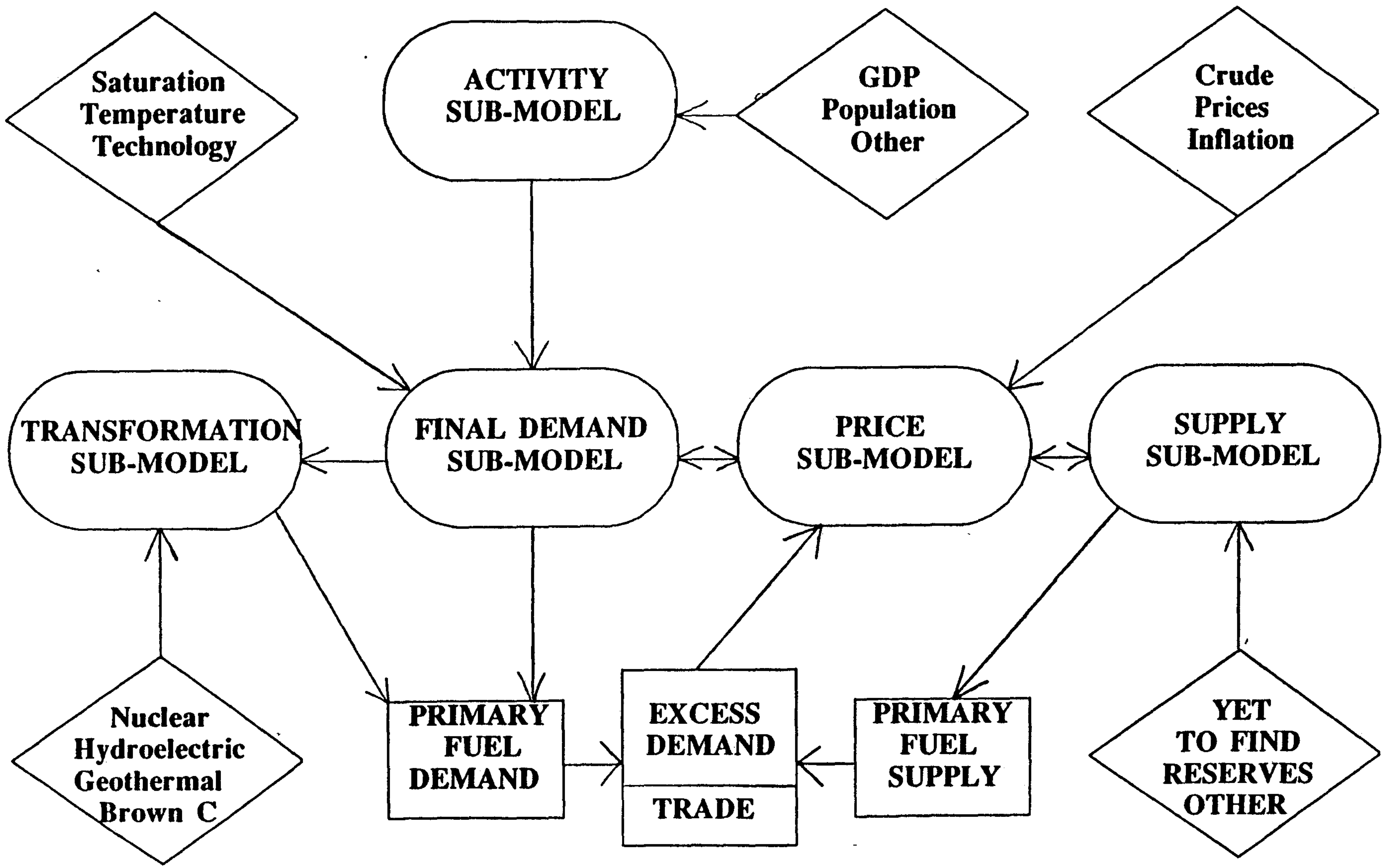
These features of the model determine, to a large extent, the limitations of the results presented below regarding the time horizon, regional aggregation and absence of economic cost estimates. The econometric nature of the model precludes analysis beyond the medium term without fundamental changes to the design of the model. While, technically, it would be easy to extend the projection horizon to any period, the confidence attached to such projections would be very limited, given the period of estimation. The lack of fully endogenous technology and industrial structure would also become an increasingly important weakness. Indeed, the strength of the model's design lies precisely in that it attempts to capture the short and medium-term rigidities of energy markets that originate from the very gradual changes in the energy using capital stock and the slow introduction of technology.

This paper's concentration on results for the OECD is due to the fact that the model is much more detailed in its coverage of the three OECD regions. The rest of the world is also modelled in some depth but resource and, especially, data limitations do not allow the same degree of detail as for the OECD. The data for non-OECD regions is especially weak on end-use prices and their link to primary fuel prices, an issue of special significance for the determination of carbon taxes.

B. Basic structure[1]

Graph 1 presents the basic structure of the model for each of the regions it covers and Graph 2 presents the product, sectoral and regional disaggregation of final energy demand within the model. As can be seen from Graph 1, for each of the OECD regions the model effectively consists of four interdependent sub-models and one relatively self-contained sub-model. The latter, the activity sub-model, effectively converts exogenous assumptions on GDP and population into the relevant activity variables for the sectors whose energy demand is endogenous within the model.

Graph 1: MODEL STRUCTURE



Graph 2: MODEL DISAGGREGATION

FINAL DEMAND

PRODUCTS	SECTORS
<u>OIL PRODUCTS</u>	TRANSPORTATION
GASOLINE DIESEL KEROSENE GASOIL HEAVY FUEL OIL BUNKERS OTHER	INDUSTRY OTHER
<u>OTHER PRODUCTS</u>	**REGIONS**
INDUSTRIAL GAS OTHER GAS INDUSTRIAL COAL COKE OTHER COAL INDUSTRIAL ELECTRICITY OTHER ELECTRICITY	OECD NORTH AMERICA OECD EUROPE OECD PACIFIC AFRICA* ASIA* LATIN AMERICA* MIDDLE EAST* EAST EUROPE* SOVIET UNION* CHINA**

(*) Less detailed

(**) Exogenous

Personal expenditure, industrial production by the iron and steel sector, and cars per head are examples of the output of this sub-model. For the purposes of the exercise reported in this paper, this semi-exogenous determination of the industrial structure and of the components of GDP precludes any estimate of the economic cost of carbon taxes as well as the feedback from carbon taxes to the economic structure. In principle, a feedback effect from energy prices is possible and one has, in the past, been implemented between oil prices and GDP. However, the full endogenisation of macroeconomic variables is beyond the present design and objectives of the IEA model.

The other sub-models are strictly energy related. Demand is organised by end-use product, and the final demand sub-model solves for final energy demand on the basis of sector activity, the end-user price and assumptions about other sector specific variables, like saturation, technology etc. As can be seen from Graph 2, the model distinguishes three final demand sectors, namely industry, the "other" sector (a combination of residential and commercial demand), and the transportation sector; seven oil products, namely gasoline, diesel, gasoil, kerosine, heavy fuel oil, other products, and bunkers; two sectors for gas and electricity; and, in the case of coal, the industrial use of coke is treated separately from the other two sectors. The demand for final electricity is then converted into primary fuel demand within the transformation or power generation sub-model, given the structure of the electricity industry in each region, conversion efficiencies, and assumptions about non-fossil fuels. The power generation sub-model output, together with a suitable aggregation of the output of the final energy demand sub-models, result in a set of primary fuel demands.

The supply sub-model feeds off the output of the price sub-model and assumptions on reserves, discovery rates and other relevant variables, to produce a set of primary fuel supplies. These are then compared with the previously derived demands and, after allowing for trade, any surplus or shortfall feeds into the price sub-model. This takes the exogenous assumptions on crude oil price and inflation and solves for end-use and primary fuel prices by taking into account costs, any excess demand, and the competitive position of each product. One of the most important aspects of energy markets and a major reason for the high level of carbon taxes in the following sections is the relatively small part that the prices of primary fuels often play in the determination of final prices. Extreme cases of this phenomenon are gasoline and electricity prices which, among other things, are subject to high consumption taxes or strong regulation.

Graph 2 also presents the regional aggregation of the model. Apart from the three OECD regions, there are six additional regions modelled in less detail. The former Centrally Planned Economies (CPEs) are divided into the ex-USSR and Eastern Europe regions while the Less Developed Countries (LDCs) are divided into three continental regions plus the Middle East. China's energy system is presently imposed on the model exogenously.

III. Reference case projections[2]

In the reference scenario, presented in Table 1, OECD total energy demand is projected to grow at a moderate average rate of 1.2 per cent per annum over the period to 2005. Growth is roughly equal between the two regions because European demand growth, under the assumptions laid down for this exercise[3], is projected to be especially weak. Given an average economic growth rate of close to 2.3 per cent, overall OECD energy intensity is projected to decline substantially, at an average annual rate of more than 1 per cent. This decline is due to the assumed higher oil price, further technological advances, the continued structural shift of OECD economies toward less energy intensive sectors, and continued turnover of older less energy efficient capital equipment.

The share of oil in total primary energy requirements is projected to continue its long decline. By 2005, it is expected to decline from about 43 per cent in 1989 to 39 per cent in the OECD, with the decline being somewhat larger outside North America. Most of the oil demand within the OECD originates from the road and air transportation sectors and the petrochemical industry. Oil demand accounted for by the transportation needs (inclusive of bunkers) rises by more than 200 million tons from its 1990 level of around 940 million tons, accounting for more than 60 per cent of total 2005 OECD oil demand. The corresponding shares for North America and other OECD are 68 and 53 per cent. This greatly limits the scope for substitution of the projected oil demand, especially in North America, as will be seen below.

The share of natural gas in total OECD demand is expected to rise by three percentage points, to reach 21.6 per cent by 2005. Consumption of natural gas in the OECD is expected to grow at an average annual rate of 2.2 per cent, almost twice as fast as overall energy demand, due to strong demand by the power generation sector. Natural gas for electricity generation, which has been stagnating during the past decade, is projected to give way to very robust growth of 6 per cent per annum to 2005 as a result of technological and cost improvements in the design, efficiency and operation of gas turbines. In the case of Europe, gas demand for power generation is expected to increase by two and a half times between 1990 and 2005. Obviously, in the event of carbon taxes, the environmental benefits of gas will further strengthen its position regarding

TABLE 1. REFERENCE CASE ENERGY REQUIREMENTS AND EMISSIONS

	1990	1995	2000	2005	1990-2005	SHARES (%)	
	---------- MTOE	----------			% change p.a.	1990	2005
OECD North America							
Oil	885.9	937.5	959.7	983.9	0.7	39.5	36.6
Natural Gas	494.4	569.3	630.7	661.1	2.0	22.0	24.6
Solid Fuels	562.4	634.2	672.3	701.2	1.5	25.1	26.1
Nuclear	160.2	163.7	160.1	163.2	0.1	7.1	6.1
Hydro and other	141.5	149.7	164.2	178.9	1.6	6.3	6.7
TOTAL	2244.4	2454.4	2587.0	2688.3	1.2	100.0	100.0
CO2 EMISSIONS(Mn Tons)	1652.4	1821.2	1920.3	1991.3	1.3		
OTHER OECD							
Oil	927.6	939.6	961.0	984.0	0.4	47.8	42.4
Natural Gas	289.2	337.7	387.3	419.9	2.5	14.9	18.1
Solid Fuels	393.0	412.7	451.5	500.5	1.6	20.3	21.5
Nuclear	208.4	229.6	246.9	261.1	1.5	10.7	11.2
Hydro and other	122.0	134.1	142.6	157.3	1.7	6.3	6.8
TOTAL	1940.2	2053.7	2189.3	2322.8	1.2	100.0	100.0
CO2 EMISSIONS(Mn Tons)	1390.6	1453.5	1546.2	1640.6	1.1		
OECD TOTAL							
Oil	1813.5	1877.1	1920.7	1967.9	0.5	43.3	39.3
Natural Gas	783.6	907.0	1018.0	1081.0	2.2	18.7	21.6
Solid Fuels	955.4	1046.9	1123.8	1201.7	1.5	22.8	24.0
Nuclear	368.6	393.3	407.0	424.3	0.9	8.8	8.5
Hydro and other	263.5	283.8	306.8	336.2	1.6	6.3	6.7
TOTAL	4184.6	4508.1	4776.3	5011.1	1.2	100.0	100.0
CO2 EMISSIONS(Mn Tons)	3043.0	3274.7	3466.5	3631.9	1.2		

other fossil fuels. However, meeting this growth implies substantial growth in the producer price of gas towards the end of the projection period.

Due to strong residential and commercial demand, electricity consumption in the OECD is projected to grow by 2.3 per cent per annum. As growth in non-fossil generation decelerates, and in the absence of high carbon taxes, hard coal used for power generation is expected to grow almost in line with total electricity demand. The shares of nuclear and hydro are projected to remain relatively stable and satisfy a relatively small percentage of OECD energy requirements. Total hydro, geothermal and nuclear power generation is exogenously projected to grow from 2865 TeraWatt hours in 1990, to 3449 TeraWatt hours in 2005.

Total OECD emissions exceed 3 600 million tons of carbon by 2005 (including emissions from bunkers, non-energy use of fossil fuels, petrochemical feedstocks and commercial vegetal fuel emissions), a near 20 per cent increase on 1990 levels and in line with energy demand growth. North America accounts for nearly 55 per cent of the 2005 emissions. More than a quarter of total emissions originates from coal used in power generation and a similar amount from oil products used in transportation. Other single major polluting sectors include the residential use of oil and gas and the industrial and power generation use of gas. More details of the different carbon intensities among regions and sectors under reference assumptions are presented in the following section.

While this paper does not deal with the non-OECD regions, in order to put the OECD trends in a global context, Table A1 presents the reference case projections of world energy and emissions. It can be seen that the OECD becomes increasingly less important for both energy consumption and emissions. Thus, its share in overall energy consumption declines from 50 per cent in 1990 to 43 per cent in 2005 while that of emissions declines from 45 per cent to just under 40 per cent. The obvious implication is that any policy not taking into account the non-OECD regions would be unlikely to have any major impact on emissions.

IV. Carbon tax scenarios

A. Implementation and effectiveness of a carbon tax

Carbon taxes have been applied directly at the level of final consumption of energy by increasing the tax component of the price equation of each energy product according to the carbon content of the product and the level of carbon tax imposed. Thus, it is initially assumed that the tax is fully passed on to the consumer. This does not, of course, mean that there are no effects on the endogenously determined producer prices of primary fuels. As demand for final products adjusts to the imposition of the carbon tax, the demand for primary fuels is also reduced and, through the excess demand factor, part of the tax is borne by the producers of coal and gas. (The crude oil price is specified to be exogenous for the purpose of the OECD Comparisons Project and is, therefore, not subject to any feedback.)

Within the model, the effect of a given level of carbon tax will depend on the degree to which it affects the end-use prices and on the price elasticities of demand which, in turn, depend on the availability of close substitutes. The effect of a carbon tax on final prices is determined by (a) the carbon content of the end-use energy product, (b) the level of the relevant primary fuel price in the specific region prior to the imposition of the carbon tax, and (c) by the size of the non-fuel component of the price of final products. Clearly, the higher the first and the lower the second and third factors, the higher the percentage increase in the final price as a result of the imposition of any given carbon tax. It will be seen below that, because of a higher carbon intensity, lower starting primary fuel prices and lower taxation on final energy products, North America is more sensitive than the other OECD to any given level of carbon tax. Consequently, a lower carbon tax is required in North America to reach any given emissions target.

In the results that follow, carbon taxes are different across regions and over time. In order to facilitate understanding of the results, Table 2 gives the impact of a global, constant $50 carbon tax on end-use prices by region (in per cent). The importance of the carbon content for the effect on final prices can be seen by the impact on the prices of primary fuels, at the bottom of the table. Thus, the price of a ton of oil equivalent of coal will increase by nearly $60, while that of gas by little more than half that amount. The effect of the pre-carbon tax level of primary prices can be seen by the difference between regions in the increase in the prices of coal and gas (oil by assumption is a world commodity and the price of crude is equal in all regions). For example, because the delivered prices of coal are very low in North America, when compared to those in Europe, the percentage coal price increases are nearly four times as high in North America. Similarly, the lower starting value of North American delivered gas prices, when compared to the Pacific region, imply that when the same tax is applied the effect is much higher in North America. Finally, the effect of the non-fuel component is most obvious in Table 2 in the case of gasoline, which is the most heavily taxed of oil products and, consequently, is affected relatively little by the tax. Similarly, the very small impact on electricity prices is due to the fact the cost of power generation includes a very high non-fuel component unrelated to tax. Again,

TABLE 2: IMPACT OF A CONSTANT $50 CARBON TAX ON PRICES

	N.America	Europe	Pacific	Eur+Pac	Total
		(2005 Percent Change)			
Oil Products					
Gasoline	9.76	3.68	5.34	4.15	7.97
Gas Diesel Transport	10.31	7.44	9.50	7.95	9.18
Other Gas Diesel	11.97	10.18	15.78	11.79	11.36
HFO P. Generation *	29.09	15.53	21.34	18.66	20.33
HFO Other	29.09	15.53	21.34	16.79	20.33
Natural Gas					
Industry	19.33	14.41	8.00	13.50	17.65
P. Generation	19.33	14.41	8.00	10.97	17.65
Other	11.93	7.91	6.34	7.73	10.73
Hard Coal					
Industry	83.62	23.52	59.68	40.74	65.81
P. Generation	83.62	23.52	59.68	32.48	65.81
Electricity					
Industry	22.54	6.07	13.23	9.25	15.12
Domestic	9.91	4.49	7.68	5.39	8.07

Impact on Primary Fuel	Crude	Gas	Coal
$ Per TOE	45.5	34.7	59.6

* Heavy fuel oil used in Power Generation.

the effect of the tax on North American prices tends to be higher due to the generally lower level of tax on end-use energy.

Given the importance of the electricity sector for energy demand and emissions, one of the key determinants of the overall carbon intensity between the two regions is the structure of the power generation and the proportion of generation by non-fossil fuels. Table 3 shows the structure of this sector in the two OECD regions presented here and the implied carbon intensities. It can be seen that North American power generation is significantly more carbon-intensive than other OECD. There are two reasons for this: firstly, the share of non-fossil fuel generation in North America, at 36 per cent in 1990, is much lower than the 45 percent share in other OECD. Secondly, even the generation through fossil fuels in North America is more carbon-intensive due to the very high proportion of power generated from coal. Thus, the carbon intensity of fossil-fuel generated power in North America is 0.98 tons of carbon per ton of oil equivalent energy, as opposed to 0.9 in other OECD. The overall intensities are 0.63 and 0.49, a near 30 per cent premium for North America. While both gaps narrow somewhat between 1990 and 2005, they remain significant and explain to some extent why the impact of the tax on electricity prices is twice as high in North America.

The final determinant of the effectiveness of carbon taxes in reducing emissions within the model is the translation of the increased final prices into reduced demand for energy and substitution towards the least carbon-intensive fuels. Price elasticities are clearly specific to the product, sector and region affected. Transportation, a sector with no readily available substitutes, would be expected to have a relatively low price elasticity. The price elasticity of individual fuels in the power and industrial sectors is likely to be quite high in the long run as power generating stock turns over and the appropriate infrastructure is put in place. Even in the short term, the elasticities of individual fuels will be at least as high as that of final electricity because of interfuel substitution. Apart from the availability of substitutes, the elasticities will also be affected by other factors like climate, population density, the size of the consuming region and the traditional orientation of industry in terms of the basket of produced goods. These factors account for some part of the large differences in the energy intensity of GDP among regions.

In iterating towards the appropriate carbon tax level for any given emissions target a simple linear scheme was followed of the form Tax=a0+a1*time. Thus, the calibration process consisted of finding an appropriate initial tax and an annual increment. Due to the simplicity of this scheme and the complexity of the dynamics within the model, the emissions targets in the simulations that follow were only approximately reached. It will be apparent in the results that follow, that the level of

TABLE 3 : POWER GENERATION ENERGY, SHARES AND INTENSITIES

	1990	1995	2000	2005
		North America		
Total Energy (MTOE)	835.48	930.33	1023.18	1090.67
Of Which : Thermal %	0.64	0.66	0.68	0.69
Oil	0.04	0.03	0.03	0.02
Natural Gas	0.08	0.11	0.15	0.16
Solid Fuels	0.51	0.52	0.51	0.51
Non Thermal	0.36	0.34	0.32	0.31
Emission Intensity(TC /TOE)*				
Thermal	0.98	0.97	0.95	0.95
Total	0.63	0.64	0.65	0.65
		Europe and Pacific		
Total Energy (MTOE)	732.70	838.08	943.63	1028.93
Of Which : Thermal %	0.55	0.57	0.59	0.59
Oil	0.11	0.10	0.09	0.07
Natural Gas	0.09	0.12	0.14	0.15
Solid Fuels	0.35	0.35	0.36	0.37
Non Thermal	0.45	0.43	0.41	0.41
Emission Intensity(TC /TOE)*				
Thermal	0.90	0.89	0.89	0.90
Total	0.49	0.51	0.52	0.53
		Total OECD		
Total Energy (MTOE)	1568.17	1768.41	1966.81	2119.60
Of Which : Thermal %	0.60	0.62	0.64	0.64
Oil	0.08	0.06	0.06	0.05
Natural Gas	0.09	0.12	0.15	0.15
Solid Fuels	0.44	0.44	0.44	0.44
Non Thermal	0.40	0.38	0.36	0.36
Emission Intensity(TC /TOE)*				
Thermal	0.94	0.93	0.92	0.92
Total	0.56	0.58	0.59	0.59

(*) Tons of carbon emitted divided by tons of oil equivalent energy.

tax is not linearly related to the level of emissions reductions as various opportunities for interfuel substitution are fully utilised at a certain level of tax and higher taxes simply further reduce the amount of energy demand.

B. Case 1: 1 per cent reduction

This scenario implies a 14 per cent reduction in emissions by 2005 from reference case levels. The carbon tax required for North America is $25 per ton of carbon in 1991, increasing by $7 each year to reach $123 in 2005. For the rest of OECD the corresponding numbers are an initial tax of $35 per ton of carbon, rising by $14 increments to reach $231. The effect of these taxes on some of the key end-use prices are presented in Table 4. It can be seen from there that the sharp contrast between North America and other OECD which was shown in Table 2 has now all but disappeared as the much higher taxes outside North America compensate for the much higher pre-tax prices.

Table 5 summarises the results of all scenarios in terms of growth rates, and changes in the shares of primary fuels and further details for this scenario are presented in Table A2. The much sharper fall in oil demand in other OECD, when compared to North America, where oil demand actually increases somewhat, is due to the much higher proportion of oil demand in North America which is accounted for by transportation needs and which tends to be rather inelastic. The share of natural gas in 2005 is much higher than in the reference case in both regions and gas demand in absolute terms is similar to that in the reference case despite the nearly 50 per cent increase in delivered gas prices.

The near double carbon tax required in other OECD as compared to North America is the result, primarily, of the much higher coal use in North American power generation which, in absolute terms, is nearly two and a half times that of the rest of OECD in 1990. However, the effect is even more pronounced because of the higher share of coal in electricity production and the low price of coal in North America which results in a higher impact on electricity prices despite the lower level of carbon taxes. Given that the elasticities of electricity demand are similar in the two regions, the overall impact is to reduce electricity and coal demand more sharply in North America than in other OECD.

Thus, of the 488 million tons reduction in 2005 emissions from their reference case level, more than two-thirds originates from the decline in coal consumption and

TABLE 4 : 1% PA REDUCTION SCENARIO
IMPACT OF CARBON TAX ON PRICES

	N.America	Eur+Pac
	(2005 Percent Change)	
Oil Products		
Gasoline	24.14	18.03
Gas Diesel Transport	24.44	35.86
Other Gas Diesel	28.08	50.46
HFO P. Generation	66.82	84.98
HFO Other	66.82	74.59
Natural Gas		
Industry	46.22	60.38
P. Generation	46.22	45.18
Other	27.05	33.95
Hard Coal		
Industry	208.83	184.41
P. Generation	208.83	157.50
Electricity		
Industry	54.30	34.65
Domestic	27.23	22.11
Memo item:		
Carbon tax ($/ton in 2005)	123	231

TABLE 5: ENERGY AND EMISSIONS GROWTH RATES, SHARES AND CARBON TAXES

	PER CENT GROWTH IN 1990-2005					SHARES IN PRIMARY ENERGY IN 2005				
	REF	1%	2%	3%	S	REF	1%	2%	3%	S
OECD North America										
Oil	0.7	0.1	-0.8	-1.7	-0.1	36.6	37.0	36.6	36.0	36.9
Natural Gas	2.0	2.1	1.4	0.6	2.0	24.6	27.8	28.6	28.2	28.3
Solid Fuels	1.5	-0.6	-2.2	-3.2	-1.1	26.1	21.2	18.9	18.0	20.3
Nuclear	0.1	0.1	0.1	0.1	0.1	6.1	6.7	7.6	8.5	6.9
Hydro and other	1.6	1.6	1.6	1.6	1.6	6.7	7.4	8.3	9.3	7.6
TOTAL	1.2	0.5	-0.3	-1.0	0.3	100.0	100.0	100.0	100.0	100.0
EMISSIONS *	1.3	0.3	-0.8	-1.7	0.0					
CARBON TAX $	.	123.0	376.0	700.0	176.0					
OTHER OECD										
Oil	0.4	-0.4	-1.1	-2.2	-0.5	42.4	42.1	40.6	38.3	41.9
Natural Gas	2.5	2.5	2.2	1.7	2.5	18.1	20.1	20.9	21.6	20.2
Solid Fuels	1.6	-0.4	-1.3	-2.2	-0.5	21.5	17.8	16.8	16.1	17.6
Nuclear	1.5	1.5	1.5	1.5	1.5	11.2	12.5	13.6	15.0	12.6
Hydro and other	1.7	1.7	1.7	1.7	1.7	6.8	7.5	8.2	9.0	7.6
TOTAL	1.2	0.5	-0.1	-0.7	0.4	100.0	100.0	100.0	100.0	100.0
EMISSIONS *	1.1	0.1	-0.6	-1.5	-0.0					
CARBON TAX $		231.0	548.0	1222.0	260.0					
OECD TOTAL										
Oil	0.5	-0.1	-1.0	-1.9	-0.3	39.3	39.3	38.5	37.1	39.2
Natural Gas	2.2	2.3	1.7	1.0	2.2	21.6	24.2	24.9	25.0	24.5
Solid Fuels	1.5	-0.5	-1.8	-2.8	-0.8	24.0	19.6	17.9	17.1	19.0
Nuclear	0.9	0.9	0.9	0.9	0.9	8.5	9.4	10.4	11.6	9.6
Hydro and other	1.6	1.6	1.6	1.6	1.6	6.7	7.4	8.3	9.2	7.6
TOTAL	1.2	0.5	-0.2	-0.9	0.4	100.0	100.0	100.0	100.0	100.0
EMISSIONS *	1.2	0.2	-0.7	-1.6	0.0					

NOTE: For the level of Carbon Tax before 2005, see Tables A2, A3, A4, and A5.
* Million tons of carbon.

the bulk of this from coal used for power generation. Overall energy demand declines by 10 per cent in the period to 2005 from reference case levels, nearly 50 per cent less than the decline in emissions.

It should be noted that the imposition of these taxes in the OECD regions reduces global CO2 emissions in 2005 by only 5 per cent.

C. Case 2: 2 per cent reduction

This case requires a reduction in emissions by a quarter in 2005 from reference case levels, or nearly 6 per cent below 1990 levels. The carbon tax required for North America is an initial $40 per ton of carbon in 1991, increasing by $24 each year to reach $376 in 2005. For other OECD the corresponding numbers are an initial tax of $100 per ton of carbon rising by $32 increments to reach $548. These numbers, especially towards the end of the period, are very close to the capabilities of the model and the tax numbers are likely to be somewhat overestimated (see discussion at end of section). What is clear, however, is that extremely high levels of taxation would be required to achieve the 2 per cent reduction target.

The results, in Table 5 and A3, indicate that, increasingly, reductions in emissions are achieved through direct reductions in energy consumption (which are presumably far more costly in terms of economic welfare) than through substitution. This can be seen from Table 6, where the proportion of emissions reduction that is due to substitution has declined by three percentage points.

D. Case 3: 3 per cent reduction

This case requires a near 15 per cent reduction in emissions by 1995, compared to the reference case. Given the very limited substitution possibilities in the space of five years the bulk of this decline in emissions is likely to come from a reduction in total energy demand. The only period in recent history of such a sharp decline in energy consumption was between 1979 and 1982 when energy demand in the OECD declined by more than 8 per cent, the result of a very sharp increase in energy prices and a very severe recession (this fall in GDP was quickly and sharply reversed in the years that followed).

It was technically possible, of course, to run this case through the model but great care must be taken in interpreting the results from this case (see Table 5 and A4). The required 2005 taxes of $700 for North America and $1 222 for the rest of the

OECD, are far too high for the economic, industrial, and energy structure not to change quite dramatically even within the space of 15 years. Even by 1995, the taxes required would be close to $400 and it is most unlikely that such level of energy price increase would not lead to an unprecedented recession and general economic restructuring.

The reasons for the limited plausibility of these results is further discussed in the last part of this section. In the concluding remarks it is argued that the scenario itself may lack realism. Even if the 3 per cent target were "optimal" in the long term, it is most unlikely that it would be cost-effective for it to be introduced without a long period of adjustment when the emission target would be less severe. In terms of long-term CO2 concentrations the effect of a more gradual adjustment period would be very small.

E. *Case 4: Stabilisation at 1990 levels*

This scenario was applied by keeping emissions close to their 1990 level throughout the projection period. Since, under reference assumptions, emissions in 1990 to 2005 grow by 20 per cent, it is more severe than the 1 per cent scenario which required a 14 per cent reduction from the reference emissions level by 2005. The selected tax path that achieved stabilisation consisted of a $50 tax per ton of carbon in both regions in 1991, and an annual increment of $9 for North America, leading to a tax of $176 by 2005, and $15 for the rest of the OECD, leading to a $260 tax by the end of the period. While these are quite high levels of tax, they remain within historical experience, with the highest of the two increments implying an increase of just under two dollars a year per barrel of oil equivalent. The results are presented in Table 5 and Table A5.

While total emissions are held constant, there are large changes in the pattern of consumption. Many of the trends in primary energy consumption are similar to the results in the 1 per cent case, with an increase in the share of gas and a reduction in the share of coal. Compared to the reference case, half of the near 600 million tons emissions reduction originates from the one-third reduction in the use of coal in power generation, and almost two-thirds of that is due to North America. Quite a significant reduction, in absolute terms, takes place also in the transportation sector although this is quite limited in percentage terms for reasons that have already been mentioned. The reduction in industrial coal is also quite significant and it is the highest reduction in emissions in any sector, in percentage terms. There is a notable increase in the use of gas in power generation with its share rising to 20 per cent in 2005, compared to 9 per cent in 1990 and 15 per cent in 2005 under reference case assumptions.

While the above scenario is plausible, it is worth mentioning that the required carbon taxes in 2005 would be roughly equivalent to current oil prices and would lead to an increase in the oil price in 2005 of more than 50 per cent compared with the reference case level. Thus, even stabilisation of emissions within the OECD, an objective far less ambitious than that of the Toronto conference, seems to require rather substantial taxes.

F. Evaluation of results

Comparison of the results across the various scenarios indicates the presence of a number of non-linearities. The effectiveness of the carbon tax instrument in reducing emissions decreases as the tax gets higher. This non-linearity, implicit in the results already presented, can be most clearly seen in Graph 3 where the application of a series of OECD-wide taxes is plotted against the resulting reductions in emissions. Within the model this can be explained by the decreasing scope for substitution: as taxes get higher, reductions in emissions are increasingly the result of reduced energy demand. Table 6 presents the percentage reductions in emissions that is due to substitution, rather than direct reduction in overall energy, and the proportion of total emission reduction accounted for by substitution. It can be seen that this latter proportion remains broadly constant across time as the level of tax rises linearly (which would imply that end-use prices increase at a decreasing rate, reducing the impact of the tax). However, as the target gets more severe, for example from the 1 per cent case to the 2 per cent case, the amount of substitution declines. Beyond a certain point, further reductions in emissions can only be obtained through a faster scrapping, or less intensive use, of energy using capital, leading to a decline in overall energy demand.

The econometric nature of the model's parameters and the present design of the model imply that confidence in the results should be inversely related to the level of tax imposed and to the length of the period simulated. This is partly due to the statistics of confidence intervals which suggest that these tend to widen with time and as the scenarios examined move beyond "average" values. While it is very difficult to work out precise confidence intervals for the numbers presented here, it seems obvious that the more extreme cases examined in this paper are far from being average. Of course, reduced confidence does not mean that the model's numbers are too high -- they could equally well be too low!

Graph 3

CARBON TAX VERSUS CARBON EMISSIONS
OECD 2005 (M tonnes of carbon)

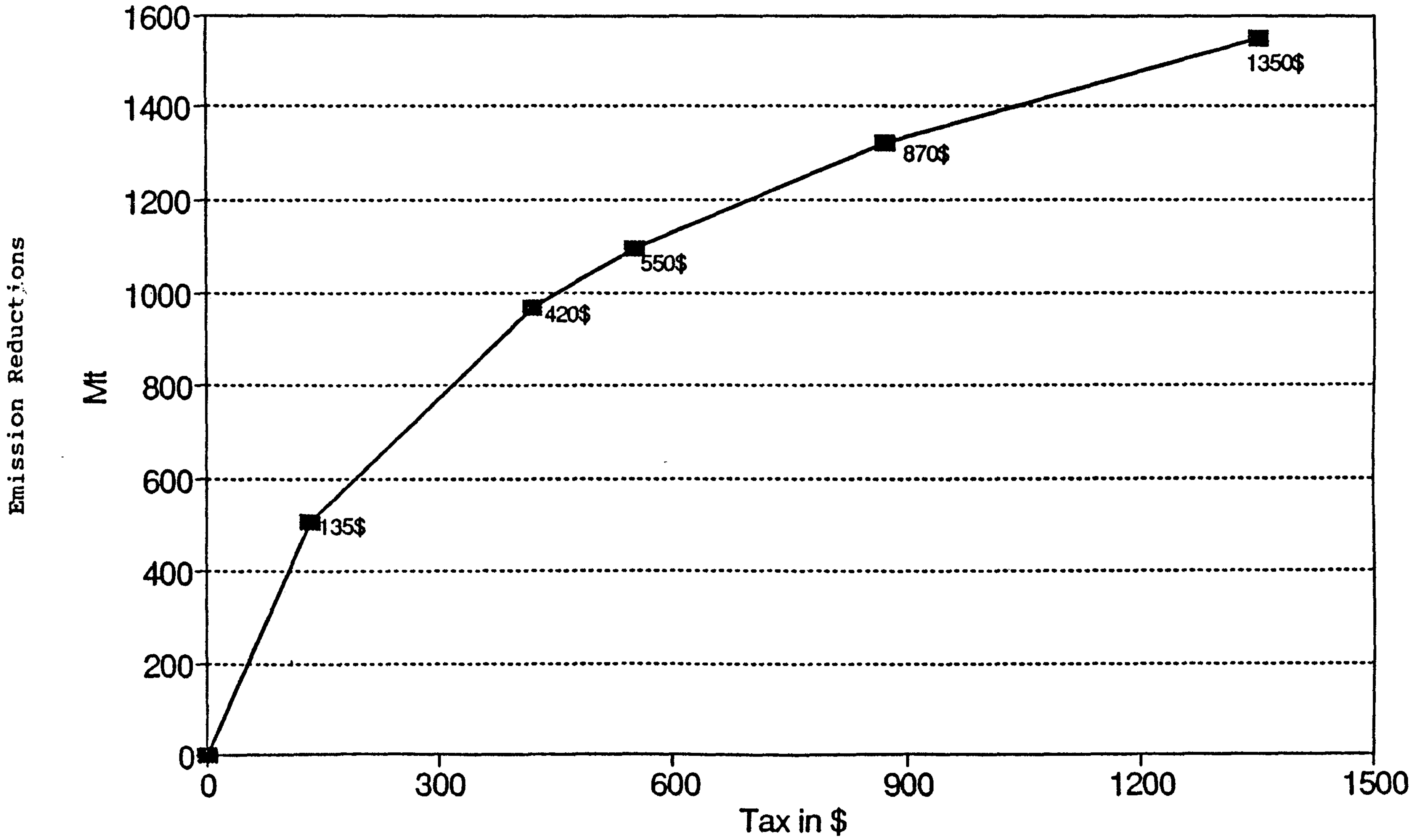


TABLE 6 :EMISSION REDUCTION DUE TO SUBSTITUTION

TOTAL OECD	1990	1995	2000	2005
	REFERENCE CASE			
Energy (MTOE)	4184.6	4508.1	4776.3	5011.1
Emissions (M. tons carbon)	3043.0	3274.7	3466.5	3631.9
	ONE PER CENT REDUCTION CASE			
Energy	4184.6	4327.3	4428.0	4520.9
Emissions	3043.0	3091.5	3113.1	3138.8
reduction in emissions %		-5.8	-10.8	-14.6
reduction in energy %		-4.1	-7.6	-10.3
substitution %		1.7	3.2	4.3
as % of total reduction		28.9	29.6	29.4
	TWO PER CENT REDUCTION CASE			
Energy	4184.6	4145.9	4088.2	4070.0
Emissions	3043.0	2923.1	2803.0	2736.3
reduction in emissions %		-11.4	-21.2	-28.3
reduction in energy %		-8.4	-15.6	-20.8
substitution %		3.0	5.7	7.5
as % of total reduction		26.3	26.8	26.5
	THREE PER CENT REDUCTION CASE			
Energy	4184.6	3859.1	3717.3	3657.1
Emissions	3043.0	2668.8	2480.7	2384.6
reduction in emissions %		-20.5	-33.5	-42.1
reduction in energy %		-15.5	-25.1	-31.5
substitution %		4.9	8.4	10.6
as % of total reduction		24.0	25.1	25.1
	STABILISATION CASE			
Energy	4184.6	4251.4	4333.6	4417.2
Emissions	3043.0	3019.7	3023.9	3043.2
reduction in emissions %		-8.1	-13.7	-17.7
reduction in energy %		-5.9	-9.7	-12.6
substitution %		2.2	3.9	5.1
as % of total reduction		27.7	28.8	28.7

However, certain other features would also suggest that there would be a tendency for the model to overestimate required taxes in the long run and for cases of very high taxes. The exogeneity of GDP would become an important weakness, especially in a case like the 3 per cent reduction, which only seems achievable, in the medium term, through reduced economic growth (although the redistribution of revenues would reduce the impact of GDP greatly when compared to historical experience). What may be a more significant weakness is the constancy of the industrial structure. While the model does allow for reduced energy intensity, in the various industrial sectors it covers, as a result of higher prices, it does not allow for reduced weighting in the energy-intensive industries as prices rise. Clearly, in the more extreme cases, a significant amount of restructuring could take place even within the model's time period.

Similarly, the assumption of fixed non-CO2 emitting power generation seems reasonable, for a period of 15 years, given the time lags involved. However, it seems likely that when a very high carbon tax is imposed, more marginal hydro projects could come on-stream towards the end of the period and the pressure for more nuclear power generation would increase. With a carbon tax of $1 000 even currently exotic energies could make a more than marginal contribution in 15 years' time.

V. Conclusions

The IEA model is strongest at simulating the impact of carbon taxes on energy markets over the short to medium term. Its strengths include, (a) the detailed modelling of end-use consumer prices and their link to primary prices, and (b) the incorporation of many of the rigidities in the current energy system of OECD regions. The semi-exogeneity of the macroeconomy and the industrial structure are unlikely to lead to significant overestimation of the carbon taxes required except in the case of very severe emissions targets and towards the end of the period[4].

The model's results suggest that the 1 per cent reduction and the stabilisation scenarios, are feasible but would require high carbon taxes. The 2 per cent reduction scenario would require extremely high taxes and it is doubtful that it could be implemented as assumed over the next ten years. The most severe scenario is impossible to examine through the present version of the model in a satisfactory way. On the basis of historical precedent, even for the next five years, its application would only seem possible through a very severe and lasting recession.

The fundamental conclusion is that, in the short to medium term, any reduction in emissions is likely to originate far more from a reduction in energy than from substitution in favour of less polluting fuels. The model suggests that reducing emissions from current levels would require the imposition of implausibly high taxes and historical experience would suggest that this is likely to be very costly. Thus, even if a very severe emission target is necessary, the model results suggest that its imposition should not be immediate and should include a substantial period of adjustment. A gradually rising tax to achieve an increasingly more severe target would seem more likely to be the "optimal" way of introducing an emissions target.

Notes

1. For a more detailed description of the model the interested reader should consult The IEA Medium Term Model Presentation -- an IEA document available on request.

2. For more information on likely energy trends for the period to 2005, the interested reader is referred to the IEA's Energy Outlook, published in Energy Policies of IEA Countries, 1990 Review, OECD/IEA, Paris, 1991.

3. The growth and population assumptions are the same as those laid down for the EMF12 project; they are fully described in the overview paper for the OECD's global model comparisons exercise (forthcoming ESD Working Paper).

4. The quantitative significance of changes in the industrial structure is one of the issues that, it is hoped, the new substantially-revised version of the model will be able to examine. Other issues, relevant to this paper, that are also currently under consideration include the incorporation of more information on the characteristics of energy-using capital stock and its turnover and, subject to the incorporation of more technological assumptions, the extension of the model's projection horizon.

Table A1

EMF BASE CASE
NON-OECD PRIMARY ENERGY REQUIREMENTS
AND CO2 EMISSIONS

	average annual per cent change	share - per cent -	
	1990-2005	1990	2005
USSR/Eastern Europe			
Oil	1.2	27.7	25.8
Natural gas	3.1	34.7	42.4
Solid fuels	-0.1	30.6	23.3
Nuclear	4.5	3.4	5.1
Hydro and other	1.6	3.5	3.5
TOTAL	1.7	100.0	100.0
Developing countries			
Oil	3.0	40.9	34.9
Natural gas	7.1	11.4	17.8
Solid fuels	3.8	37.6	36.4
Nuclear	2.3	1.2	1.0
Hydro and other	4.8	8.8	9.9
TOTAL	4.0	100.0	100.0
World			
Oil	1.4	39.0	34.8
Natural gas	3.5	20.6	25.0
Solid fuels	2.1	28.6	28.1
Nuclear	1.7	5.5	5.1
Hydro and other	3.0	6.3	7.1
TOTAL	2.2	100.0	100.0
CO2 EMISSIONS			
OECD	1.2	44.6	39.8
USSR/Eastern Europe	1.3	23.4	21.1
Developing countries	3.4	31.9	39.1
World	2.0	100.0	100.0

TABLE A2. ONE PERCENT REDUCTION CASE ENERGY REQUIREMENTS AND EMISSIONS

	1990	1995	2000	2005	Annual % change 1990-200	2005 Compared to ref	Shares % in 2005 Ref	Shares % in 2005 Current
	MTOE							
OECD North America								
Oil	885.9	915.6	903.6	899.5	0.1	0.9	36.6	37.0
Natural Gas	494.4	570.2	645.4	676.1	2.1	1.0	24.6	27.8
Solid Fuels	562.4	554.0	529.9	515.2	-0.6	0.7	26.1	21.2
Nuclear	160.2	163.7	160.1	163.2	0.1	1.0	6.1	6.7
Hydro and other	141.5	149.7	164.2	178.9	1.6	1.0	6.7	7.4
TOTAL	2244.4	2353.2	2403.2	2432.9	0.5	0.9	100.0	100.0
EMISSIONS (M. tons carbon)	1652.4	1716.7	1728.8	1729.2	0.3	0.9		
CARBON TAX $	0.0	53.0	88.0	123.0				
OTHER OECD								
Oil	927.6	907.1	885.7	878.9	-0.4	0.9	42.4	42.1
Natural Gas	289.2	336.5	387.9	419.1	2.5	1.0	18.1	20.1
Solid Fuels	393.0	366.8	361.7	371.6	-0.4	0.7	21.5	17.8
Nuclear	208.4	229.6	246.9	261.1	1.5	1.0	11.2	12.5
Hydro and other	122.0	134.1	142.6	157.3	1.7	1.0	6.8	7.5
TOTAL	1940.2	1974.1	2024.8	2088.0	0.5	0.9	100.0	100.0
EMISSIONS (M. tons carbon)	1390.6	1374.8	1384.3	1409.6	0.1	0.9		
CARBON TAX $	0.0	91.0	161.0	231.0				
OECD TOTAL								
Oil	1813.5	1822.7	1789.3	1778.4	-0.1	0.9	39.3	39.3
Natural Gas	783.6	906.7	1033.3	1095.2	2.3	1.0	21.6	24.2
Solid Fuels	955.4	920.8	891.6	886.8	-0.5	0.7	24.0	19.6
Nuclear	368.6	393.3	407.0	424.3	0.9	1.0	8.5	9.4
Hydro and other	263.5	283.8	306.8	336.2	1.6	1.0	6.7	7.4
TOTAL	4184.6	4327.3	4428.0	4520.9	0.5	0.9	100.0	100.0
EMISSIONS (M. tons carbon)	3043.0	3091.5	3113.1	3138.8	0.2	0.9		

A3. TWO PERCENT REDUCTION CASE ENERGY REQUIREMENTS AND EMISSIONS

		1995	2000	2005	Annual % change 1990-200	2005 Compared to ref	Shares % in 2005 Ref	Current
		--MTOE--						
					OECD NA			
Oil		886.0	825.8	786.2	-0.8	0.8	36.6	36.6
Natural		553.3	610.5	612.7	1.4	0.9	24.6	28.6
Solid Fuels		503.8	437.0	404.5	-2.2	0.6	26.1	18.9
Nuclear	.2	163.7	160.1	163.2	0.1	1.0	6.1	7.6
Hydro and other	.5	149.7	164.2	178.9	1.6	1.0	6.7	8.3
TOTAL	44.4	2256.5	2197.6	2145.5	-0.3	0.8	100.0	100.0
EMISSIONS (M. tons	1652.4	1626.8	1540.7	1473.8	-0.8	0.7		
CARBON TAX $	0.0	136.0	256.0	376.0				
OTHER OECD								
Oil	927.6	861.3	804.8	781.6	-1.1	0.8	42.4	40.6
Natural Gas	289.2	330.1	377.3	402.0	2.2	1.0	18.1	20.9
Solid Fuels	393.0	334.3	319.0	322.5	-1.3	0.6	21.5	16.8
Nuclear	208.4	229.6	246.9	261.1	1.5	1.0	11.2	13.6
Hydro and other	122.0	134.1	142.6	157.3	1.7	1.0	6.8	8.2
TOTAL	1940.2	1889.4	1890.6	1924.5	-0.1	0.8	100.0	100.0
EMISSIONS (M. tons carbon)	1390.6	1296.3	1262.3	1262.5	-0.6	0.8		
CARBON TAX $	0.0	228.0	388.0	548.0				
OECD TOTAL								
Oil	1813.5	1747.3	1630.6	1567.8	-1.0	0.8	39.3	38.5
Natural Gas	783.6	883.4	987.8	1014.7	1.7	0.9	21.6	24.9
Solid Fuels	955.4	838.1	756.0	727.0	-1.8	0.6	24.0	17.9
Nuclear	368.6	393.3	407.0	424.3	0.9	1.0	8.5	10.4
Hydro and other	263.5	283.8	306.8	336.2	1.6	1.0	6.7	8.3
TOTAL	4184.6	4145.9	4088.2	4070.0	-0.2	0.8	100.0	100.0
EMISSIONS (M. tons carbon)	3043.0	2923.1	2803.0	2736.3	-0.7	0.8		

TABLE A4. THREE PERCENT REDUCTION CASE ENERGY REQUIREMENTS AND EMISSIONS

	1990	1995	2000	2005	Annual % change 1990-200	2005 Compared to ref	------- Shares ------- % in 2005 Ref	Current
	-----------------	MTOE	-----------------					
OECD North America								
Oil	885.9	821.3	731.7	689.4	-1.7	0.7	36.6	36.0
Natural Gas	494.4	506.1	555.5	540.0	0.6	0.8	24.6	28.2
Solid Fuels	562.4	431.3	371.7	346.0	-3.2	0.5	26.1	18.0
Nuclear	160.2	163.7	160.1	163.2	0.1	1.0	6.1	8.5
Hydro and other	141.5	149.7	164.2	178.9	1.6	1.0	6.7	9.3
TOTAL	2244.4	2072.1	1983.2	1917.5	-1.0	0.7	100.0	100.0
EMISSIONS (M. tons carbon)	1652.4	1464.0	1356.1	1282.7	-1.7	0.6		
CARBON TAX $	0.0	300.0	500.0	700.0				
OTHER OECD								
Oil	927.6	800.8	705.7	666.4	-2.2	0.7	42.4	38.3
Natural Gas	289.2	318.2	357.9	375.0	1.7	0.9	18.1	21.6
Solid Fuels	393.0	304.3	281.0	279.8	-2.2	0.6	21.5	16.1
Nuclear	208.4	229.6	246.9	261.1	1.5	1.0	11.2	15.0
Hydro and other	122.0	134.1	142.6	157.3	1.7	1.0	6.8	9.0
TOTAL	1940.2	1787.0	1734.1	1739.6	-0.7	0.7	100.0	100.0
EMISSIONS (M. tons carbon)	1390.6	1204.8	1124.6	1101.9	-1.5	0.7		
CARBON TAX $	0.0	492.0	857.0	1222.0				
OECD TOTAL								
Oil	1813.5	1622.1	1437.4	1355.8	-1.9	0.7	39.3	37.1
Natural Gas	783.6	824.3	913.4	915.0	1.0	0.8	21.6	25.0
Solid Fuels	955.4	735.6	652.7	625.8	-2.8	0.5	24.0	17.1
Nuclear	368.6	393.3	407.0	424.3	0.9	1.0	8.5	11.6
Hydro and other	263.5	283.8	306.8	336.2	1.6	1.0	6.7	9.2
TOTAL	4184.6	3859.1	3717.3	3657.1	-0.9	0.7	100.0	100.0
EMISSIONS (M. tons carbon)	3043.0	2668.8	2480.7	2384.6	-1.6	0.7		

TABLE A5. STABILISATION CASE ENERGY REQUIREMENTS AND EMISSIONS

	1990	1995	2000	2005	Annual % change 1990-200	2005 Compared to ref	Shares % in 2005 Ref	Shares % in 2005 Current
	MTOE							
OECD North America								
Oil	885.9	898.2	874.4	866.4	-0.1	0.9	36.6	36.9
Natural Gas	494.4	561.2	639.1	664.6	2.0	1.0	24.6	28.3
Solid Fuels	562.4	520.6	491.2	477.1	-1.1	0.7	26.1	20.3
Nuclear	160.2	163.7	160.1	163.2	0.1	1.0	6.1	6.9
Hydro and other	141.5	149.7	164.2	178.9	1.6	1.0	6.7	7.6
TOTAL	2244.4	2293.4	2329.0	2350.2	0.3	0.9	100.0	100.0
EMISSIONS (M. tons carbon)	1652.4	1660.3	1658.4	1652.8	0.0	0.8		
CARBON TAX $	0.0	86.0	131.0	176.0				
OTHER OECD								
Oil	927.6	898.9	873.8	866.9	-0.5	0.9	42.4	41.9
Natural Gas	289.2	335.8	386.9	417.4	2.5	1.0	18.1	20.2
Solid Fuels	393.0	359.6	354.4	364.3	-0.5	0.7	21.5	17.6
Nuclear	208.4	229.6	246.9	261.1	1.5	1.0	11.2	12.6
Hydro and other	122.0	134.1	142.6	157.3	1.7	1.0	6.8	7.6
TOTAL	1940.2	1958.0	2004.6	2067.0	0.4	0.9	100.0	100.0
EMISSIONS (M. tons carbon)	1390.6	1359.4	1365.5	1390.4	-0.0	0.8		
CARBON TAX $	0.0	110.0	185.0	260.0				
OECD TOTAL								
Oil	1813.5	1797.1	1748.2	1733.3	-0.3	0.9	39.3	39.2
Natural Gas	783.6	897.0	1026.0	1082.0	2.2	1.0	21.6	24.5
Solid Fuels	955.4	880.2	845.6	841.4	-0.8	0.7	24.0	19.0
Nuclear	368.6	393.3	407.0	424.3	0.9	1.0	8.5	9.6
Hydro and other	263.5	283.8	306.8	336.2	1.6	1.0	6.7	7.6
TOTAL	4184.6	4251.4	4333.6	4417.2	0.4	0.9	100.0	100.0
EMISSIONS (M. tons carbon)	3043.0	3019.7	3023.9	3043.2	0.0	0.8		

ECONOMICS DEPARTMENT

WORKING PAPERS

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