GLOBAL TRADE INTERDEPENDENCE AND THE CO$_2$-EMISSION ELASTICITY WITH RESPECT TO ECONOMIC GROWTH IN JAPAN, THE UNITED STATES AND WESTERN EUROPE

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RESUMEN

Los autores presentan una estimación de la elasticidad de las emisiones de CO$_2$ frente al crecimiento en los bloques económicos más importantes en la economía mundial. Simulan un crecimiento adicional en los bloques económicos con el ARCA World Model y estiman los efectos sobre las emisiones de CO$_2$ fuera de estos bloques, utilizando un modelo satélite que establece la relación entre las variables energéticas en el modelo y las emisiones de CO$_2$ fuera del modelo. Según sus cálculos, la elasticidad total de las emisiones en el "Norte" industrializado estaría debajo pero cerca de uno; la correspondiente elasticidad directa estaría ligeramente encima de uno. Los tres mayores jugadores en la economía mundial muestran elasticidades directas más altos, pero elasticidades indirectas y totales más bajas. Europa Occidental tiene la elasticidad directa más baja; Japón tiene la elasticidad total más baja.

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ABSTRAC

The authors estimate the CO_2*-emission elasticity with respect to economic growth in the major economic blocks in the world economy. They simulate additional growth in the economic blocks with the ARCA World Model and estimate the effects on the* CO_2*-emissions outside the blocks, making use of a satellite model which establishes the link between the energy variables in the model and the* CO_2*-emissions outside the model. According to their calculations, the total emission elasticity for the industrialised "North" would be less but close to unity; the corresponding direct elasticity would be slightly above unity. The three major players in the world economy show higher direct elasticities, but lower indirect and total elasticities. Western Europe has the lowest direct elasticity; Japan has the lowest total elasticity.*

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INTRODUCTION

There is a growing and justified concern about the so-called greenhouse effect due to increasing and cumulative CO_2-emissions (fossile fuels), CH_4-emissions (from more intensive methods in agriculture), and N_2O-emissions (from industrial processes and traffic) which disturb the radiation balance in the atmosphere. A still growing body of literature has been devoted to the management of this problem (McDonald, 1987; Blok, Hendriks & Turkenburg, 1989; Kats, 1990; Nordhaus, 1991; Morgenstern, 1991; Cline, 1992; and others).

In this paper we would like to contribute to this multi-disciplinary discussion from an economic perspective by attempting to estimate the carbon content of additional CO_2-emissions (i.e. the most important greenhouse gas) caused by a percentage additional economic growth in the major economic blocks in the world economy.[3] For this purpose we will link an existing empirical world trade and income model with a satellite model establishing the relationships between the energy variables in the model and emission variables outside the model.

THE ECONOMICS OF THE GREENHOUSE EFFECT

In a number of areas in economics, relevant contributions related to the problem of gas emissions, have been presented.

These contributions are ranging from theoretical contributions on the micro-economic level (e.g. the inclusion of emission variables in optimization models, see : Hartl & Luptácik,1992; Feichtinger & Luptácik,1987; etc.) to applied studies on the macro-economic level.

The introduction of energy variables in macro-economic models, stimulated by the occurrence of the energy crises in the seventies, should especially be mentioned. Be it that these studies gave rather rise to a discussion of problems of exhaustion of stocks of natural resources than to a discussion of problems of pollution (incl. emissions).

From a methodological and empirical point of view, the attempts to link environmental variables to input-output models have been fruitful. We might refer to Leontief & Ford (1972), Pearson (1989), and Suslov (1993).

Important research areas are also: cost-benefit analyses of CO_2 reduction policies (see e.g. Nordhaus,1991, Cline,1992, Grubb,1993, and Wilson & Swisher,1993 on the use of policy models), and that in which effective and efficient ways to combat gas emissions are searched for. Three ways can be distinguished here: quantitative emission restrictions, tradable emission permits, and emission taxes. We refer to Morgenstern (1991), Cline (1992), and Oates & Portney (1992), and also Bertram (1992) on the economics of tradable emission permits and Manne & Richels (1993) on the effects of combined carbon and energy taxes.

A derived area of study is that of establishing ecological statistics in addition to economic statistics and correcting economic statistics for ecological effects. These corrected variables can then be used as inputs in macro-economic models. We might refer to Ahmad, El Serafy & Lutz (1990), Comolet & Weber (1990), Levin (1990), Repetto (1990), and Bartelmus, Stahmer & Van Tongeren (1991) for a discussion of how to correct national accounts for environmental effects or how to establish satellite accounts.

AN ESTIMATION OF THE ADDITIONAL CO_2-EMISSION AS A RESULT OF A PERCENTAGE ADDITIONAL GROWTH : THE MODEL

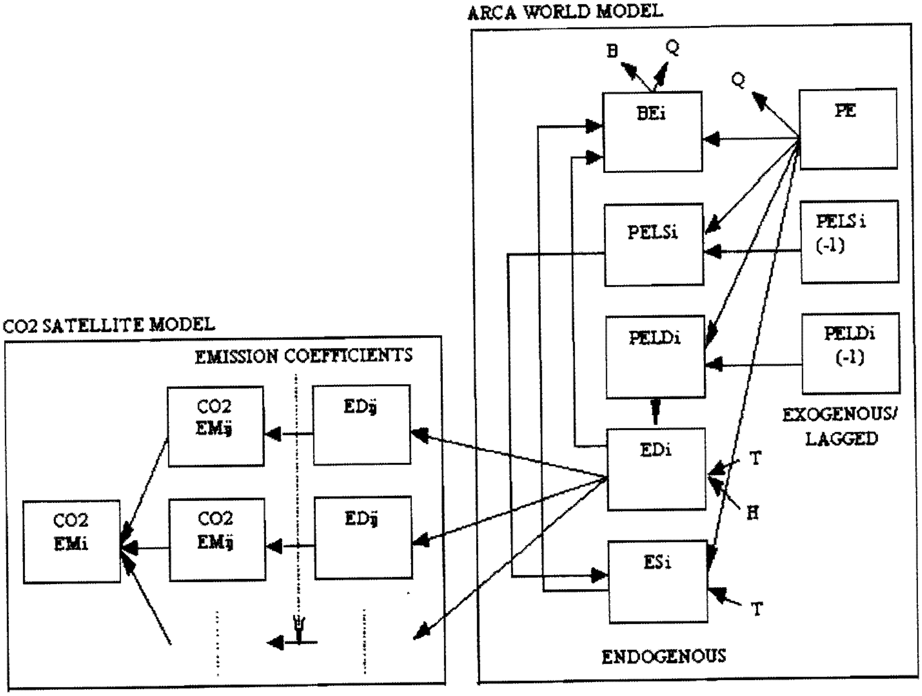
In order to estimate the carbon content of additional CO_2 output as a result of an additional percentage point regional and global economic growth we link emission variables to an empirical world trade and income model: the ARCA World Model. This model is an updated and disaggregated version of the Cambridge Economic Policy Group and FERE world models, developed at he University of Cambridge. It is a real trade and income model of Keynesian and Kaldorian inspiration, especially designed for the macro-economic analysis of the energy markets (see e.g. Cuyvers,1986).

The model describes the interactions between 12 trading blocks, following UN statistical groupings: the US, Japan, Germany, the Rest of Western Europe, Other Developed Market Economies (Canada, Australia, New Zealand, South Africa, and Israel), East-Central Europe, the Commonwealth of Independent States (CIS), China, Asia, the Middle East, Africa, and Latin America. The model counts 315 equations and is semi-econometric. The historical series start in 1961 and are regularly updated; the data sources are: the UN, the OECD, and the IMF. For our calculations, we used an available baseline scenario from the ARCA working group with forecasts until the year 2005. For more details on the specification of the model and some applications, we refer to: Atkinson e.a. (1980), Cuyvers, Karl & Leithauser (1984), Cripps & Ward (1987), Wolleb (1990), Fuller (1990), Buelens & De Lombaerde (1991), De Lombaerde (1992,1993).

As energy appears as a separate product category (besides manufactures and raw materials), the model allows for indirectly linking macro-economic variables to environmental variables (emissions, etc.) via the energy variables which are related to the economic variables within the model. In Figure 1 these interactions are shown. The energy variables in the model are expressed in oil-equivalents.

Figure 1

The Economy-Energy-Environment Interaction in and between the ARCA World Model and the CO2 Satellite Model



H = real spending (1975 USD); Q = output,GDP (id.); B = total balance of trade (id.); PE = real world energy export price (in terms of world manufactures energy price); PELS = real long-run supply price of energy (id.); PELD = real long-run demand price of energy (id.); ES = energy supply (millions of tons of oil equivalents); ED = energy demand (id.); T = time; i = 1..12 (referring to the different trade blocks); j = particular energy source.

The energy demand in each block can be related to the carbon content of the gas emissions, which requires the application of emission coefficients.

In our study we simulated a percentage point additional growth in the US, Japan, Western Europe, and the industrialized world as a whole. We targeted percentage point deviations from growth figures in the base scenario and chose internal spending as instruments à-la-Tinbergen. This additional growth in a particular block results in a directly stimulated energy demand in that block, on the one hand, but also in more growth and energy demand in other blocks because of external multiplier effects via trade linkages, on the other hand. Total energy demand will have to be met by total energy supply, so that the shock will also be reflected in energy production (per block) and energy prices, assuming that no major geographical shifts in the distribution of supply appear.

In this paper we are particularly interested in the degree to which more energy consumption (demand) gives rise to more CO_2 and carbon emissions. Therefore, the macro-energy variable has to be split in its components according to energy source, and the relevant emission coefficients have to be applied.

We assumed that the effects on energy demand do not alter relative energy prices and therefore do not result in substitution effects. It will be clear that in dynamic studies this assumption will have to be left.

AN ESTIMATION OF THE ADDITIONAL CO_2-EMISSION AS A RESULT OF A PERCENTAGE ADDITIONAL GROWTH : THE EMISSION COEFFICIENTS

The choice of the relevant emission coefficients related to the combustion of fossile fuels is not self-evident. Different sources and methodologies (resulting in different emission coefficients) exist.

Systematically separate values were given for solids, liquids and gaseous fossile fuels. We considered values from five sources (Table 1). Because the carbon emissions were expressed in different units, a direct comparison of the sources, however, was not possible. In order to check the correspondence between these emission-coefficients, conversion factors had to be applied to the values to obtain common units.

Table 1

CO_2 and Carbon Emission Coefficients

		Emission coefficients	
Sources	Solids	Liquids	Gaseous
Edmonds & Darmstädter (1990:6)	23.8 gC/MJ	19.2 gC/MJ	13.8 gC/MJ
Cohen & Collette (1991:138)	0.001155 GtonC/10^6 mtoe	0.0008663 Gton/10^6 mtoe	0.0006432 Gton/10^6 mtoe
Decoster, Proost & Schokkaert (1992:24)	90 ton CO2/TJ	70 ton COS/TJ	53 ton CO2/TJ
Okken (1987:155)	87.3 gCO2/MJ	70.4 gCO2/MJ	50.2 gCO2/MJ
OECD (1991:18)	25.8 kgC/GJ	20.0 kgC/GJ	15.3 kgC/GJ

Remarks : J = Joule (unit of energy); mtoe = metric tons oil equivalents; gC/MJ = grams of carbon emission per Mega Joule (1 MJ = 10^6J); GtonC/10^6 mtoe = Giga tons of carbon emission per million ton oil-equivalents (1 Giga Joule = 10^9 Joule); ton CO_2/TJ = tons of carbon dioxide per Terra Joule (1 TJ = 10^{12} J).

From Table 1 follows that the emission-coefficients for carbon, from the combustion of fossile fuels, are expressed as a quantity of carbon dioxide per energy-unit or a quantity of carbon per energy-unit.

We established the relationship between both ways of expression, starting from the atom masses for oxygen (O) and carbon (C) in Mendeljev's table :

O : 15.9994 g/mol
C : 12.011 g/mol

Consider now the reaction equation for the combustion of carbon:

$$\begin{array}{lllll} C & + & O_2 & \longrightarrow & CO_2 \\ 1\ \text{mol} & & 1\ \text{mol} & & 1\ \text{mol} \end{array}$$

A CO_2-molecule consists therefore of 1 carbon-atom and 2 oxygen-atoms. Taking into account the atom masses, we may write :

$$12.011g \quad + \quad \underset{(2 * 15.9994)}{31.9988g} \longrightarrow 44.0098g$$

From this follows that 1 gram of carbon dioxide consists of :

31.9988 / 44.0098 = 0.7270835 grams of oxygen,

and :

12.011 / 44.0098 = 0.2729165 grams of carbon

The conversion factor therefore is : 1g CO_2 = 0.2729165g C

Knowing that :

1mtoe = 44.76 * 10^9 J (The Carbon Dioxide Information Analysis Centre, 1990:44),

and that: 1MJ = 10^6 J , 1GJ = 10^9 J , 1TJ = 10^{12} J

the data now could be recalculated in terms of a common unit, i.e. : gC/MJ. The results of these calculations are shown in Table 2.

Table 2
Emission Coefficients, Recalculated in Terms of gC/MJ

		Emission coefficients	
Sources	Solids	Liquids	Gaseous
Edmonds & Darmstädter (1990:6)	23.8 gC/MJ	19.2 gC/MJ	13.8 gC/MJ
Cohen & Collette (1991:138)	25.8 gC/MJ	19.4 gC/MJ	14.4 gC/MJ
Decoster, Proost & Schokkaert (1992:24)	24.6 gC/MJ	19.1 gC/MJ	14.5 gC/MJ
Okken (1987:155)	23.8 gC/MJ	19.2 gC/MJ	13.7 gC/MJ
OECD (1991:18)	25.8 gC/MJ	20.0 gC/MJ	15.3 gC/MJ

When comparing the values in the Table, large differences do not seem to occur. Note, however, that Okken (1987) systematically reports the lowest emission coefficients for all three categories, whereas the OECD (1991) shows the highest carbon emissions. These small differences can probably partly be attributed to changes in the composition of the fuels in each category. EUROSTAT is aiming at establishing standard emission-coefficients in the near future, so as to make environmental data more comparable across countries.

Rather than calculating an average, we chose to apply the emission-coefficients from the OECD in the calculations below. In our opinion, this choice is justified because the coefficients of the OECD prepared for the Intergovernmental Panel on Climate Change are -according to several specialists in the field- considered as standard.

One should however be aware of the fact that average values are considered here. The OECD also published more detailed coefficients, i.e. emission values for each kind of fuel within the categories of solids, liquids and gaseous fuels. These coefficients can be found in Table 3.[4]

Table 3
Detailed Emission Coefficients According to the OECD

Type of energy		Emission coefficient gC/MJ
LIQUIDS	Crude Oil	20.0
	N. Gas Liquids	NA
	Gasoline	18.9
	Kerosene	19.5
	Jet Fuel	NA
	Gas/Diesel Oil - Bunkers	20.2
	Residual Oil - Bunkers	21.1
	LPG	17.2
	Naphta	NA
	Petroleum Coke	NA
	Refinery F-Stocks	NA
	Other Oil - Bunkers	NA
SOLIDS	Coking Coal	25.8
	Steam Coal	25.8
	Subbit. Coal	26.1
	Lignite	27.6
	Peat	28.9
	Coke	NA
	Other Solids	NA
GASEOUS FUELS	Natural Gas (Dry)	15.3

Source : OECD (1991:18).

AN ESTIMATION OF THE ADDITIONAL CO_2-EMISSION AS A RESULT OF A PERCENTAGE ADDITIONAL GROWTH: THE SIMULATION RESULTS

In order to analyse our simulation results, we defined the following elasticity coefficients :

- The direct CO_2-emission elasticity with respect to economic growth :

$$e_D = \frac{\dfrac{CO2^*_{i,t} - CO2_{i,t-1}}{CO2_{i,t-1}} - \dfrac{CO2_{i,t} - CO2_{i,t-1}}{CO2_{i,t-1}}}{\dfrac{Y^*_{i,t} - Y_{i,t-1}}{Y_{i,t-1}} - \dfrac{Y_{i,t} - Y_{i,t-1}}{Y_{i,t-1}}}$$

$$= \frac{\dfrac{CO2^{*}_{i,t} - CO2_{i,t}}{CO2_{i,t-1}}}{\dfrac{Y^{*}_{i,t} - Y_{i,t}}{Y_{i,t-1}}}$$

and we know :

$$\begin{cases} Y^{*}_{t} > Y_{t} \\ CO2^{*}_{t} > CO2_{t} \\ Y^{*}_{t} \Rightarrow CO2^{*}_{t} \\ Y^{*}_{t} = Y_{t} + \Delta Y_{t} \Leftrightarrow \dfrac{Y^{*}_{t} - Y_{t}}{Y_{t-1}} = 0.01 \end{cases}$$

- The indirect CO_2-emission elasticity with respect to economic growth

$$e_{I} = \frac{\dfrac{\sum\limits_{j\neq i} CO2^{*}_{j,t} - \sum\limits_{j\neq i} CO2_{j,t}}{\sum\limits_{j\neq i} CO2_{j,t-1}}}{\dfrac{Y^{*}_{i,t} - Y_{i,t}}{Y_{i,t-1}}}$$

where : j = 1,..,i,..12

- The total CO_2-emission elasticity with respect to economic growth

$$e_T = \frac{\dfrac{\sum_j C^{*}_{j,t} - \sum_j C_{j,t}}{\sum_j C_{j,t-1}}}{\dfrac{Y^{*}_{i,t} - Y_{i,t}}{Y_{i,t-1}}}$$

In Table 4 the values for e_D and e_T are given, along with the proportion e_i/s_D. The higher this proportion, the more a country (block) is able to shift growth-related pollution to other countries. We added two other interesting indicators, namely: the proportion of energy consumption to energy production (ED/ES, cfr. Figure 1 for the notations), and the proportion of CO_2-emissions (i.e. the carbon content of the emissions) to energy consumption (CO2/ED). The first proportion indicates the extent to which the energy demand in a country (block), due to more growth, gives rise to more exploitation of energy sources outside the country (block). The second proportion indicates the degree of pollution per unit energy consumption (in oil equivalents); the variation comes from the fact that the countries have a different energy input-mix (for geographical, economical, political, etc. reasons).

All indicators are defined in such a way that relatively high values have a rather “negative” connotation.

Table 4
Summary Simulation Results

	ED_i/ES_i	C_i/ED_i	e_D	e_T	e_i/e_D
Western Europe	1.7120	$8.4219 \cdot 10^8$	1.190	0.330	0.1443
Japan	7.0935	$8.6089 \cdot 10^8$	1.238	1.238	0.0347
United States	1.2360	$8.7500 \cdot 10^8$	1.326	0.521	0.2320
"North"	1.2145	$8.6438 \cdot 10^8$	1.020	0.971	0.8238

As far as the proportion of enèrgy consumption on energy production per block is concerned (first column), the case of Japan leaps to the eye. Indeed, Japan has practically no coal, oil or gas supplies. In 1990, 77.3% of the own energy production was based on electricity generation from non-fossile energy sources, mainly nuclear energy and hydraulic energy (resp. 67% and 32% of non-thermical electricity production) (UN, 1992:66,444). Japan's own energy production covers only a small part of the energy demand: according to the base scenario only 14% of the total energy consumption. In the other blocks, energy demand and supply are more balanced but no industrialized block (considered here) is self-sufficient.

The figures on the pollution intensity of energy consumption (second column), indicate that -on average- one ton of oil-equivalent energy consumption results in an emission of 860 tons of carbon. The (relatively small) differences in the values for the different blocks are due to differences in terms of energy input mix. The US have the highest carbon exhaust per unit of energy, which can be attributed to the fact that only 4.4% of the energy consumption is coming from non-fossile fuels (UN, 1992:58). This is low in comparison with Japan and Western Europe (7.2% and 8.6% resp., UN, 1992:44,70), resulting in lower carbon pollution per unit of energy consumption.

The direct emission elasticities with respect to economic growth (third column) are all larger than one, leading to the conclusion that, with a constant energy input-mix of 1990, one percent additional economic growth in the industrialized North will result in more than one percent extra carbon exhaust. This might be interpreted in the sense that extra growth is likely to take place in more-than-average energy intensive activities. The additional energy needs are expected to be covered for over 90% by fossile fuels. A cross-country comparison again indicates a high figure for the U.S., which is not surprising, however, given the unfavorable energy input-mix. The fact that the score for the industrialized North does not lay in the interval set by the three countries, is to an important extent due to the presence of East-Europe and the CIS in this country grouping.

The relatively high indirect emission elasticity for the U.S. (i.e. growth in the U.S. gives rise to relatively important carbon emissions outside the U.S.) enforces its "first" rank, also in terms of the total elasticity coefficient. The relatively low non-resource import dependence of Japanese growth is reflected in a relatively low indirect emission elasticity, in turn underlining Japan's low score on the direct elasticity coefficient in terms of the total elasticity coefficient. This means that of the three actors we considered (the U.S., Japan, and West-Europe), a percentage point additional growth in Japan causes the relatively smallest negative atmospheric effects in terms of carbon emissions.

CONCLUSIONS

According to our calculations, the "total" CO_2-emission elasticity with respect to economic growth for the industrialized "North" would be less but close to unity; the direct emission elasticity would be slightly above unity. The three major players in the world economy show "lower" total and indirect emission elasticities but higher direct elasticities than the industrialized world as a whole.

Japan is clearly exhausting relatively most external energy sources but the functioning of its production apparatus leads to relatively few external carbon emission effects (Japan shows the lowest indirect emission elasticities). The contrary is true for the U.S.

The most "environment-friendly" economy of the three is that of West-Europe, where the carbon output per unit energy consumption is the lowest, making abstraction of any external emission effects. The most polluting and energy-intensive economy is the economy of the U.S.

REFERENCES

AHMAD, Y.J., EL SERAFY, S. & LUTZ, E. (Eds.) (1990), Environmental Accounting for Sustainable Development, The World Bank, Washington D.C.

ATKINSON, P., BEGG, I., CRIPPS, F., ANYADIKE-DANES, M. & GUDGIN, G. (1980), "World Trade and Finance : Prospects for the 1980s", Cambridge Economic Policy Review, Vol.6,No.3,pp.1-50.

BARTELMUS, P., STAHMER, C. & VAN TONGEREN, J. (1991), "Integrated Environmental and Economic Accounting : Framework for a SNA Satellite System", The Review of Income and Wealth, Vol.37,No.2,pp.111-148.

BERTRAM, G. (1992), "Tradeable Emission Permits and the Control of Greenhouse Gases", The Journal of Development Studies, Vol.28,No.3,pp.423-446.

BLOK, K., HENDRIKS, C. & TURKENBURG, W. (1989), "The Role of Carbon Dioxide Removal in the Reduction of the Greenhouse Effect", in: IEA, Energy Technologies for Reducing Emissions of Greenhouse Gases, International Energy Agency, Paris, April 12-14th, Vol.II,pp.135-156.

BUELENS, F. & DE LOMBAERDE, P. (1991), "A Simulation of the United States Trade Policy Measures Against Japan in a Retaliation Scenario", Hitotsubashi Journal of Economics, Vol.32,No.2,pp.91-101.

CLINE, W.R. (1992), The Economics of Global Warming, Longman, Harlow.

COMOLET & WEBER (1990), "Un instrument de connaissance et d'aide à la décision: le système de comptes du patrimoine naturel français", Revue Economique, Vol.41,No.2,pp.243-267.

CRIPPS, F. & WARD, T. (Eds.) (1987), Europe in the World Economy, Commissariat Général du Plan, Paris.

CUYVERS, L., KARL, G. & LEITHAUSER, G. (1984), "A European Reflation Strategy for the World Economy : Simulations with the Cambridge Economic Policy Group World Economy Model", RUCA Working Paper, No.84/12.

CUYVERS, L. (1986), "Scenarios of Falling Oil Prices. Simulations with the FERE World Model", Economic Forecasts, Vol.3,No.10,pp.23-28.

DE KIMPE, A. (1993), Relatie tussen Economische Groei, Verbruik van Fossiele Brandstoffen en CO_2-Emissies, Universiteit Antwerpen (RUCA), Antwerpen.

DE LOMBAERDE, P. (1992), "Modelling a Trade Conflict as a Game: The One-Round Two-Period Case", Czechoslovak Journal for Operations Research, Vol.1,No.3,pp.219-224.

DE LOMBAERDE, P. (1993a), "Taking Up the Locomotive Role in an International Non-Cooperative Context and the Problem of Time Inconsistency of Relative Locomotive Power", International Review of Economics and Business, Vol.XL.

DE LOMBAERDE, P. (1993b), The Bilateral Manufactures Balance of Trade Between the U.S. and Japan, Protectionism, Game Theory, and "The Free Trade Domain", Economia Internazionale, XLVI(2-3):180-200.

FEICHTINGER, G. & LUPTÁCIK, M. (1987), "Optimal Production and Abatement Policies of a Firm", European Journal of Operational Research, Vol.29,No.3,pp.274-285.

FULLER, A. (1990), "The ARCA World Model", Paper presented at the Conference : The European Economy and the Environment in the 1990s, Sep.20-24th, Archimede Informatics in Progress & Scuola Internazionale di Scienze Umane, Palermo (Italy).

GRUBB, M. (1993), "Viewpoint : Policy Modelling for Climate Change - The Missing Models", Energy Policy, Vol.21,No.3,pp.203-208.

HARTL, R.F. & LUPTÁCIK, M. (1992), "Environmental Constraints and Choice of Technology: A Dynamic Activity Analysis", Czechoslovak Journal for Operations Research, Vol.1,No.2,pp.107-125.

KATS, G.H. (1990), "Slowing Global Warming and Sustaining Development", Energy Policy, No.1,pp.25-33.

LEVIN, J. (1990), "The Economy and the Environment: Revising the National Accounts", IMF Survey, Vol.19,No.11,pp.161-169.

MANNE, A.S. & RICHELS, R.G. (1993), "The EC Proposal for Combining Carbon and Energy Taxes - The Implications for Future CO2 Emissions", Energy Policy, Vol.21,No.1,pp.5-12.

McDONALD, G.J. (1987), "Impact of Energy Use on Global Climate Change", Paper presented at the XVth Energy Technology Conference, Washington.

MORGENSTERN, R.D. (1991), "Towards a Comprehensive Approach to Global Climate Change Mitigation", American Economic Review, Vol.81,No.2,pp.140-145.

NORDHAUS, W.D. (1991), "A Sketch of the Economics of the Greenhouse Effect", American Economic Review, Vol.81,No.2,pp.146-150.

OATES, W.E. & PORTNEY, P.R. (1992), "Economic Incentives and the Containment of Global Warming", Eastern Economic Journal, Vol.18,No.1,pp.85-98.

OECD (1991), "Estimation of Greenhouse Gas Emissions and Sinks", Report Prepared for the Intergovernmental Panel on Climate Change, OECD, Paris, (Aug.).

REPETTO, R. (1990), "The Case for Natural Resource Accounting", Economic Impact, No.2,pp.41-46.

THE CARBON DIOXIDE INFORMATION ANALYSIS CENTRE (1990), Glossary Carbon Dioxide and Climate, Oak Ridge National Laboratory, Oak Ridge, No.3532.

UN (1992), 1990 Energy Statistics Yearbook, Department of Economic and Social Development, Statistical Office, New York.

VERBRUGGEN, A. (1990), Broeikaseffect en CO_2, SESO, University of Antwerp.

WILSON, D. & SWISHER, J. (1993), "Exploring the Gap - Top-Down Versus Bottom-Up Analyses of the Cost of Mitigating Global Warming", Energy Policy, Vol.21,No.3,pp.249-263.

WOLLEB, G. (Ed.) (1990), Una Politica Europea "Cooperativa". Effetti Reali e Finanziari sullo Sviluppo dell'Economia Mondiale, ISMERI, Roma.

NOTAS

[3] In this paper, we will follow common practise in the literature and express CO_2 emissions in terms of the carbon content of these emissions. However, it is easy to recalculate the results in terms of real CO_2 emissions using the following equation: 1g CO_2 = 0.273g C

[4] On the basis of these detailed values, and combining them with detailed statistics on the consumption in each block of specific fuels, a more exact analysis of the CO_2 emissions per block would seem to be possible. A weighted average of these values should then correspond with the OECD values (1991:63). We did not elaborate this possibility however, because -as might be observed in Table 3- for a considerable number of fuel categories the emission coefficients are not available (and cannot easily be estimated).