RICHER AND CLEANER?
A STUDY ON CARBON DIOXIDE EMISSIONS
IN DEVELOPING COUNTRIES

by

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Abstract. The Climate Change debate has drawn attention to the problem of greenhouse gases emissions into the atmosphere. One of the most important issues in the policy debate is the role that should be played by developing countries in joining the commitment of developed countries to reduce GHG emissions, and particularly CO_2 emissions. This debate calls into play the relationship between energy consumption, CO_2 emissions and economic development. In this paper we use a panel data model for 110 world countries to estimate the relationship between CO_2 emissions and GDP and to produce emission forecast. The paper contains three major results: (i) the empirical relationship between carbon dioxide and income is well described by non linear Gamma and Weibull specifications as opposed to more usual linear and log-linear functional forms; (ii) our single equation reduced form model is comparable in terms of forecasted emissions with other more complex, less data driven models; (iii) despite the decreasing marginal propensity to pollute, our forecasts show that future global emissions will rise. The average world growth of CO_2 emissions between 2000 and 2020 is about 2.2% per year, while that of Non Annex 1 countries is posted at 3.3% per year.

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1. Introduction

The threat of climate change due to global warming is an issue whose relevance is by now widely recognised by all experts, governments, and public opinions throughout the world. The Earth Summit held in Rio de Janeiro in 1992 and the 1997 Kyoto Summit have called the international attention upon the negative consequences of a heating of the planet as well as upon the potential instruments to cope with this problem.

One of the most important issues in the policy debate is related to the role that should be played by developing countries. The Kyoto Protocol contains a specific commitment taken by industrialised and transition economies (Annex I countries, in the Protocol's jargon and hereafter) to reduce CO_2 emissions over the period 2008-2012 down to the level attained in 1990. No such commitment has however been taken by developing countries (non Annex I, hereafter): the usual argument in favour of this position is that the industrialisation and development process should be subject to no constraints, particularly for energy production and consumption. One possible rationale for this position is the presumption that, while pollution increases with GDP growth, there comes a point after which pollution goes down.

This tenet calls for a careful analysis of the relationship between economic growth and pollution. This link is obviously very complex. It depends on many different factors such as: (i) the size of the economy; (ii) the sectoral structure, including the composition of the energy demand; (iii) the vintage of the technology; (iv) the demand for environmental quality; (v) the level (and quality) of environmental protection expenditures. All these aspects are clearly interrelated. For example, countries with the same composition of output may have a different level of emissions if their capital stocks are different in terms of technological vintage.

On the basis of these considerations, there have been in the last few years several studies dealing with the relationship between the scale of economic activity and the level of pollution (see the survey articles by Stern, 1996; Stern, Common, and Barbier, 1996; Barbier, 1997; Ekins, 1997; Mc Connell, 1997).

Despite the complexity of the issue, if we concentrate on local pollutants, typically measures of air and water quality, in several cases a number of empirical studies have identified a bell shaped curve for the pollution intensity of GDP (Shafik and Bandyopadyay, 1992; Shafik, 1994; Selden and Song, 1994; Grossman, 1995; Grossman and Krueger, 1995; Panayotou, 1997). Moreover, the global nature as a pollutant and its crucial role as a major determinant of the greenhouse effect attribute to the case of CO_2 emissions special interest. A number of empirical studies have looked for an inverted-U curve in this case (Shafik and Bandyopadyay, 1992; Holtz-Eakin and Selden, 1995; Tucker, 1995; Cole, Rayner, and Bates, 1997; Moomaw and Unruh, 1997; Roberts and Grimes, 1997; Schmalensee, Stoker, and Judson, 1998).

The bell shape of the relationship implies that, starting from low (per capita) income levels, (per capita) emissions or concentrations tend to increase but at a slower pace. After a certain level of income (which typically differs across pollutants) – the "turning point" - emissions or concentrations start to decline as income further increases. In the 1940s Simon Kuznets empirically identified an inverted-U historic relationship between income distribution and income growth, which was then termed "Kuznets Curve" after him. Given the obvious analogy, the bell shaped relationship between per capita income and pollution has been dubbed "Environmental Kuznets Curve" (EKC hereafter).

Concentrating our attention on CO_2 emissions we note that nearly all the mentioned studies share the following features:

(i) The relationship consists of a reduced-form equation relating per capita CO_2 emissions to per capita income. In general, and with the possible exception of the time trend, no extra explanatory variables are included.

(ii) The analysis is usually conducted on a panel data set of individual countries around the world. Moreover, the data for CO_2 emissions almost invariably have come from a single source, namely the Oak Ridge National Laboratory.[1]

(iii) The functional relationship considered is either linear or log-linear one, with a few studies considering both (Holt-Eakin and Selden, 1995; Cole, Rayner, and Bates, 1997).

[1] The data for real per capita GDP are typically drawn from the Penn World Table and are on a PPP basis.

(iv) Due to the almost complete coverage of world countries, the estimation technique is typically the least square dummy variable method, allowing for both fixed country and time effects.

In a previous paper (Galeotti and Lanza, 1999) we noted that, while the bulk of the literature has focused upon the empirical emergence of the EKC and has typically discussed its implications with special reference to the value of the income turning point, the problem of the robustness of the basic findings does not appear to have been a major concern. In particular, the issue of the functional form appears to be critical for the emergence of a "well-behaved" EKC and for the crucial policy implications that could be drawn from such an empirical finding.[2] As a matter of fact, while many researchers warn that a reduced-form relationship is ill-suited for drawing policy prescriptions, it cannot be denied that an inverted-U relationship for CO_2 emissions intensity suggests that pollution reduction might be expected to occur as a natural by-product of economic development. Indeed, such considerations might have well underlied the position held by non Annex 1 countries at the Kyoto meeting.

In our previous paper we studied the relationship between a country GDP and the CO_2 emissions by first fitting a "standard" linear relationship, both in levels and in logarithms, but using an alternative, possibly better, data set. Then we considered the issue of the shape of the estimated environmental Kuznets relationship by conducting a series of non-nested tests across alternative functional forms. In so doing, we proposed and estimated two alternative non-linear functional forms, Gamma and Weibull, which were also contrasted with the usual ones and found superior in terms of theoretical properties and empirical performance.

The present paper takes our previous analysis a step forward and presents forecasts for CO_2 emissions based on the above mentioned econometric strategy. It is well known that a major problem in forecasting emissions, particularly for non-Annex I countries, is related to the poor quality of the available data. In this respect reduced-form equation models can

[2] The only noticeable effort in that direction has been the explicit consideration of a third-order, rather than just a second-order polynomial for the linear or log-linear models.

provide a good benchmark for forecasting CO_2 emissions on a country-by-country level since the only information needed are the projections of per capita GDP. The exclusion from the CO_2-GDP relationship of potentially relevant explanatory variables other than per capita GDP (and not directly related to it) is one of the most relevant issues related to the specification of reduced-form equations and the results they produce. This fact has spurred criticism by several recent papers (see Ekins, 1997, for a summary). However, it is also a feature that makes CO_2 emission forecasting a conceptually easy task (see also Selden and Song, 1994; Holtz-Eakin and Selden, 1995; Schmalensee, Stoker, and Judson, 1998).

The paper is organised as follows. Section 2 describes our data and model specification. Section 3 presents our estimation results. Section 4 describes the resulting projections, particularly for non-Annex I countries. Issues to pursue in future research and concluding remarks are presented in the last section.

2. Data and Model Specification

Our analysis exploits a data set recently developed by IEA (International Energy Agency, 1998a). It covers the period between 1960 to 1996 for the Annex II countries of the United Nations Framework Convention on Climate Change (Rio de Janeiro, 1992) and between 1971 to 1996 for all the other countries. In order to avoid the complications related to the use of an unbalanced sample and because the most relevant period for our purposes pertains to the last thirty years, we employ data that cover the 1971 to 1996 period for 110 countries. In 1996 these accounted for 88% of the CO_2 emissions generated by fuel combustion.[3] The series for Gross Domestic Product (GDP) and population of the OECD countries (with the exception of Czech Republic, Hungary, Poland and the Republic of Korea) come from the OECD Main Economic Indicators. The corresponding series for the other countries have been obtained from the World Bank.[4]

[3] A few countries have been omitted from the original data set. Kuwait, Luxembourg and Netherlands Antilles were excluded, being clear outliers in either per capita emissions or per capita GDP dimensions or both (see also, for instance, Holtz-Eakin and Selden, 1995).

[4] GDP data for the Czech Republic from 1990 onwards come from the OECD and from 1971 to 1989 are IEA estimates.

On the whole, the sample consists of 2,860 observations. However, in order to account for the different stage of economic development, position relative to the technological frontier, and other structural differences, we have also considered and analysed the sub-samples of Annex I and non-Annex I countries. These two groups of countries were also considered separately in order to provide as sound emission forecasts as possible. Annex I countries include 30 nations for 780 observations, whilst the non-Annex I group includes 80 countries for a total of 2,080 observations.

Galeotti and Lanza (1999) provided a detailed discussion of different specification strategies in modelling the EKC. Basically all the papers in the literature assume that the empirical reduced-form relationship between per capita CO_2 emissions and GDP can be adequately described by a polynomial function of income. Being linear in parameters, such relationship can be estimated using standard econometric techniques. The choice between alternative specifications, and particularly between linear and log-linear models, has been the subject of several contributions to the econometric literature (see, for instance, McAleer, 1994). Using the theory of non-nested hypothesis testing (see Kobayashi and McAleer, 1999, for a very recent contribution), our previous paper used a few non-nested tests and discrimination criteria finding that the log-linear specification is to be preferred to the linear one, albeit not decisively so. Moreover, certain difficulties which nevertheless remain with the log-linear specification prompted us to search for alternative functional forms possibly satisfying three criteria: to perform better econometrically, not to restrain a priori the range of possible shapes which can characterise the relationship under study, and to outperform the log-linear specification on statistical testing grounds. We considered the following non-linear functional forms:

$$y = \frac{1}{\beta\Gamma(\alpha)}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\exp\left[-\left(\frac{x-\gamma}{\beta}\right)\right] \quad (1)$$

$$y = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\exp\left[-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right] \quad (2)$$

In the statistical literature expressions (1) and (2) are know as three-parameter Gamma and Weibull functions. They have also been used in applied environmental and ecological economics (Bai, Jakeman, and McAleer, 1992). One advantage of these functional relationships is the interpretability of the parameters. In fact, α, β, and γ are associated with "shape", "scale", and "shift" of the function: depending upon the values they take on, the relationship can assume a variety of different behaviours. Furthermore, the income turning point could be easily determined analytically using the estimated parameters, while in standard specifications a closed-form expression for the turning point often does not exist. On the basis of non-nested hypothesis tests we found that the proposed Gamma and Weibull specifications better described the data on the CO_2 emission intensity and outperformed the widely employed log-linear model.[5]

3. Estimation Results

For the three samples mentioned above we estimate (1) and (2) after allowing for multiplicative country and time fixed effects and after taking logs, so that the regression models become:[6]

$$\log CO2_{it} = \varphi_i + \varphi_t + (\alpha - 1)\log\left(\frac{GDP_{it} - \gamma}{\beta}\right) - \left(\frac{GDP_{it} - \gamma}{\beta}\right) + \varepsilon_{it} \qquad (3)$$

$$\log CO2_{it} = \psi_i + \psi_t + (\alpha - 1)\log\left(\frac{GDP_{it} - \gamma}{\beta}\right) - \left(\frac{GDP_{it} - \gamma}{\beta}\right)^{\alpha} + \omega_{it} \qquad (4)$$

with i=1,…110 and t=1971,…1996. We use a standard least squares dummy variable estimator for (3) and (4) which produces the results reported in Table 1. The fit is satisfactory in all cases, and the parameters are always strongly significant with the exception of γ in the

[5] It was remarkable that the non-nested tests yielded an unambiguous outcome in that the log-linear model is rejected by both Gamma and Weibull functional forms. The data, however, did not allow to discriminate clearly between Gamma and Weibull.

[6] Note that the constant terms corresponding to (1) and (2) are absorbed into the coefficients of the fixed effects.

Annex I countries sample for the Weibull functional form. While it is difficult to judge the relative merits of the two specifications on the basis of this evidence alone, we note that the parameters are not stable across samples, thus providing support to the need for estimating separate regressions for the two groups of countries.

Figure 1 shows that all our estimated relationships display a bell shaped curve, which leads to conclude that a “well-behaved” EKC is supported by our data. In the figure the value of the income turning point is reported. The existence and the level of the income turning point has attracted the attention of a number of studies. While, for instance, Shafik and Bandyopadyay (1992) and Shafik (1994) find that per capita CO_2 emissions increase monotonically with income growth, Holtz-Eakin and Selden (1995) in their quadratic specification generate an out-of-sample income turning point of $35,428 per capita (in 1986 prices), suggesting that substantial economic growth would be required before CO_2 emissions began to decline. While present, the estimated turning point is disturbingly high. Sengupta (1996) finds a much lower income turning point of $8,740 per capita (in PPP 1985 dollars), but also a tendency to positive emissions elasticities beyond $15,300, thus indicating that emissions decline over a mid-range of incomes before re-establishing an upward trend with GDP growth. Cole, Rayner, and Bates (1997) using a sample of seven world regions set the turning points at $62,700 in the quadratic logs model and at $25,100 in the quadratic levels specification (values in 1985 dollars). Moomaw and Unruh (1997) consider a linear-in-variables cubic model obtaining an N-shaped relationship with a first turning point at $12,813 and a second one at $18,133, implying a very narrow income range for CO_2 declines. Our own evidence points to very reasonable values, ranging between $15,073 and $21,757 depending on different specifications and samples.

Interestingly, Figure 1 displays curves that are strongly asymmetrical with a steep increase at low income levels and a slow decline afterwards. The reduction in emissions appears however to be faster for Annex I than non Annex I countries, and this fact appears to be of interest in itself.

The finding that per-capita CO_2 emissions might eventually decline as income increases is not a new result. However, in terms of policy implications an important message that emerges is that, the U-shape of the EKC relationship notwithstanding, future economic growth will nevertheless cause an increase in carbon emissions, particularly for non-Annex I countries. This fact has to do with the skewed distribution of global income. A large proportion of population is experiencing the most rapid growth in terms of per capita income. These countries have a (declining) but still positive marginal propensity to emit. As these countries' share in total emissions grows, the result is growth in total emissions. In summary, while the U-shape of the estimated emissions-income relationship "gives hopes that one could eventually outgrow the emissions problems, as a practical matter (…) this effect does not come into play in the next future" (Holtz-Eakin and Selden, 1995, p.94).

4. Carbon Dioxide Emissions Forecasts

Forecasts based on Environmental Kuznets Curves possess advantages and disadvantages which both depend upon the same feature: their simplicity. In fact, given projections for income and population, it is relatively easy to compute forecasts of aggregate emissions for all the countries considered.

Table 2 presents the outcome for global and regional carbon dioxide emissions. As a term of reference for our exercise we selected two well-known multi-equation models and considered their emission forecasts. The first is the World Energy Model (WEM) developed by IEA (International Energy Agency, 1998b), while the second is the NEMS (National Energy Modelling Systems) operated by the U.S. Department of Energy (Energy Information Administration). For our scenario we use projections on the growth of GDP and of population provided by the WEM. In particular GDP projections are based on OECD (1997). The business as usual scenario predicts the following average annual growth rates over the period 1995 to 2020: OECD North America 2.1; OECD Europe 2.0; OECD Pacific 1.8; Transition Economies 3.3; China 5.5; East Asia 4.5; South Asia 4.2; Latin America 3.3; Africa 2.5; Middle East 2.7. Projections for world population are based from the United Nations and are in line with those of OECD (1997). For the same time period the following growth rates are expected: OECD North America 0.79; OECD Europe 1; OECD Pacific 0.14; Transition

Economies 1; China 0.79; East Asia 1.16; South Asia 1.54; Latin America 1.29; Africa 2.41; Middle East 2.47.

An advantage of our approach relates to the possibility to generate forecasts on a country-by-country basis. This is not always possible when using other methodologies or estimation techniques. For example, Integrated Assessment and Computable General Equilibrium models usually adopt regional breakdowns rather than a country detail. On the other hand, time series models are difficult to estimate, particularly for non-Annex I countries, due to the lack of suitable data.

The results reported in Table 2 show that our forecasts are in line with those of the chosen terms of reference, although in many cases our projections predict a lower level of total emissions. Comparisons can be made both for levels and for average annual growth rates. Results for China and India are also shown, because they are the most important non Annex I countries in terms of total emissions, representing roughly 50% of the total non Annex I emissions, and because they are the only non-Annex I countries for which a comparison with our reference models is possible.

While country-by-country forecasts for Annex I countries are available from different sources, this is not so for non-Annex I countries. In this respect, the Working Group III of the IPCC has recently completed a comprehensive survey on models and emissions scenarios (Intergovernmental Panel on Climate Change, 1999). The database includes over 400 regional and global scenarios (not only related to CO_2 emissions) from over 150 different sources. Further evidence on the fact that our reduced-form equation approach to forecasting compares well with alternative procedures is provided in Table 3 for Africa and two Latin American countries: Argentina and Brazil. For the sake of completeness, we also report in Table 4 forecast figures for Annex 1 countries. The table clearly shows that our results are in most cases similar to those generated by existing models for individual countries or areas.[7]

Going back to Table 2 it is worth underlining that non-Annex I countries emissions are expected to grow (on average) 3.2% per year from 2000 to 2020 while the same average

[7] Notice that for each model we used, whenever possible, the reference scenario but we were unable to check all the different underlying hypotheses.

growth for Annex I countries is around 1.3%. As a result the share of non-Annex I countries on total emissions will grow from 40% to almost 50%. Not surprisingly we get higher carbon dioxide emissions as a results of faster per capita income growth.

Figure 2 presents an alternative way to consider this point. The histograms represent the total population that corresponds to an income's cluster. Population is measured on the left scale, while on the right one we have per capita carbon dioxide emissions. A very rough extrapolation of per capita carbon dioxide emissions (cluster 3000-6000 per capita US$) would lead us to the dotted line while the current level of per capita carbon dioxide emissions is lower and this is another simple evidence of the Environmental Kuznets effect. However, all available estimates and forecasts point to an increase in emissions. The bell shape notwithstanding, it is clear that most of the countries and most of the world's population are facing the most steeply rising section of the curve.

In summary, non-Annex I countries account for the largest share of the world's population but emit very little carbon dioxide per capita. However they are characterised by income levels such that GDP growth per capita is going to be accompanied by a more than proportional increase in their per capita pollution. Although non-Annex I countries have very low per capita emission rates the corresponding population is very high. Hence, the total level of emissions is very significant.

5. Conclusions

Building on a previous contribution, in this paper we have estimated single equation reduced form EKCs for Annex 1 and Non annex 1 countries. For the latter group of countries we have then produced CO_2 emission forecasts up to 2020. We have then argued that, particularly for developing countries, where data availability and quality is typically a problem, our EKC approach to forecasting is convenient relative to more complex multi-equation models. Not only, but the evidence presented shows that the approach is also useful in that it generates forecasts that are in line with the few others available in the literature. Finally, despite the decreasing marginal propensity to pollute, our forecasts show that future global emissions will rise. The average world growth of CO_2 emissions between 2000 and 2020 is about 2.2% per year, while those of Non Annex 1 countries will grow at a yearly 3.3% rate.

From a policy perspective it follows from our results that actions aimed at reducing CO_2 emissions while there is an increase in per capita income should be taken. Considering that a large number of non-Annex I countries is on the verge of industrialisation, effective technological co-operation should be put in place to reach a sound co-operation between Annex I and Non Annex I countries. In the absence of such policies measures governments of Non Annex I countries will pursue increases in per capita income with the existing technology and this will adversely affect overall CO_2 emissions.

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Table 1: Carbon Dioxide Emissions - GDP Relationship

	All Countries	*Annex I Countries*	*Non Annex I Countries*
		GAMMA Specification	
α	1.746 (41.319)	6.450 (2.442)	1.638 (37.171)
β	22268.6 (10.439)	5070.11 (3.081)	33995.5 (5.085)
γ	33.978 (0.9749)	-9776.61 (-2.0329)	66.757 (2.689)
Adjusted R^2	0.974	0.969	0.964
Number of observations	2860	780	2080
Turning Point	16,646	17,855	21,757
		WEIBULL Specification	
α	1.6404 (57.825)	2.3470 (11.660)	1.5850 (47.8297)
β	26637.3 (19.318)	25826.4 (28.420)	36132.2 (8.3797)
γ	60.406 (2.481)	-2389.7 (-1.954)	74.3969 (3.4561)
Adjusted R^2	0.974	0.926	0.964
Number of observations	2860	780	2080
Turning Point	15,073	17,961	19,340

Notes to the Table:

(1) Dependent variable: carbon dioxide emissions per capita; independent variable: GDP per capita. Estimated coefficients of country and time effects not reported.

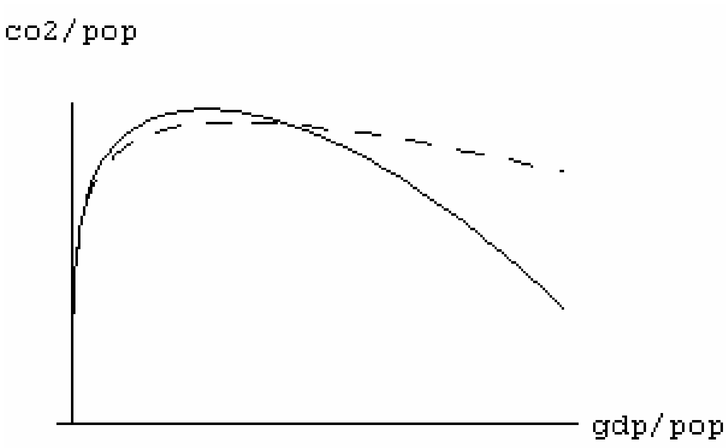
(2) T-statistics in parenthesis.

(3) The turning point is in US$ 1990 PPP.

Figure 1: Estimated Gamma and Weibull Functional Form

(Turning points in Brackets – U.S. 1990 Dollars)

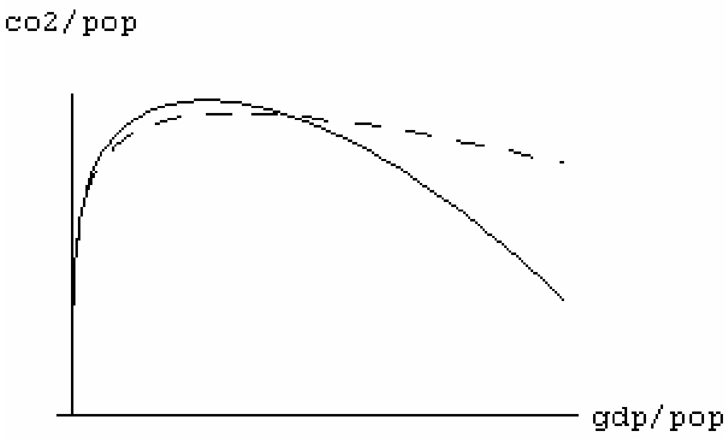
All Countries



Gamma (16,646)

Weibull (15,073)

Annex 1 Countries



Gamma (17,855)

Weibull (17,961)

non-Annex 1 Countries

Gamma (21,757)

Weibull (19,340)

Table 2 - World Carbon Emissions by Region

	Million Metric Tons					% average annual growth rates			
	2000	*2005*	*2010*	*2015*	*2020*	2000-2005	2005-2010	2010-2015	2015-2020
World									
NEMS	6430	7220	8018	8850	9817	2.3	2.1	2.0	2.1
WEM	6647	7482	8330	9083	10111	2.4	2.2	1.7	2.2
EKC	6352	7191	8163	8948	9794	2.5	2.6	1.9	1.8
Annex I									
NEMS	3983	4242	4471	4702	4931	1.3	1.1	1.0	1.0
WEM	4050	4400	4698	4854	5150	1.7	1.3	0.7	1.2
EKC	3906	4240	4607	4874	5148	1.7	1.7	1.1	1.1
Non - Annex I									
NEMS	2447	2978	3547	4148	4886	4.0	3.6	3.2	3.3
WEM	2597	3082	3632	4229	4961	3.5	3.3	3.1	3.2
EKC	2446	2951	3555	4074	4646	3.8	3.8	2.8	2.7
China									
NEMS	930	1143	1391	1670	2031	4.2	4.0	3.7	4.0
WEM	1051	1247	1447	1658	1925	3.5	3.0	2.8	3.0
EKC	994	1200	1446	1675	1930	3.8	3.8	3.0	2.9
India									
NEMS	273	331	386	436	494	3.9	3.1	2.5	2.5
WEM	268	332	412	494	590	4.4	4.4	3.7	3.6
EKC	277	342	420	483	555	4.3	4.2	2.8	2.8
Non - Annex I Share on Total Emissions									
NEMS	0.38	0.41	0.44	0.47	0.50				
WEM	0.39	0.41	0.44	0.47	0.49				
EKC	0.39	0.41	0.44	0.46	0.47				

Note: EKC are our own forecasts

Table 3: Carbon Emissions Forecasts: Selected Non Annex 1 Regions and Countries

Source	*Scenario*	*Region*	*1990*	*2000*	*2010*	*2020*
IIASA	A1	Africa	126	184	277	391
IIASA	A2	Africa	126	183	251	315
IIASA	A3	Africa	126	159	187	214
IIASA	B	Africa	126	179	246	320
IIASA	C1	Africa	126	180	260	342
IIASAC	C2	Africa	126	180	260	344
NEMS	Ref	Africa	178	214	270	325
WEM	Ref	Africa	170	216	278	351
EKC	Ref	Africa	178	212	296	371
IEEBF	Ref	Argentina	25	30	36	
EKC	Ref	Argentina	27	42	59	77
GREEN	Ref	Brazil	96	132	162	207
NEMS	Ref	Brazil	57	73	121	187
EKC	Ref	Brazil	57	90	128	172

Notes to the Table:

(1) Million metric tons.

(2) Source: IPCC (1999).

(3) Legend: IIASA. This model considers 6 different scenarios: A1, High Growth (high); A2, High Growth(moderate), (A3) High Growth (low); (B) Non intervention; (C1) Ecologically Driven 1; (C2) Ecologically Driven 2. IEEBF: Institute of Energy Economics, Bariloche Foundation. GREEN: OECD GREEN model.

Table 4: Carbon Emissions Forecasts: Selected Annex 1 Countries
(Million Metric tons)

Source	*Scenario*	*Region*	*1990*	*2000*	*2010*	*2020*
ABARE	Ref	Australia	83	100	112	
EKC	Ref	Australia	72	87	97	109
IER/AU&GE	Ref	Austria	16	17	17	17
EKC	Ref	Austria	16	18	21	24
IEA&ETSAP	Ref	Belgium	29	31	31	31
EKC	Ref	Belgium	30	36	41	47
AMOCO	High	Canada	130	160	185	
AMOCO	Low	Canada	130	150	177	
NEMS	Ref	Canada	126	151	162	182
EKC	Ref	Canada	117	135	155	176
IGER	Ref	Czech Rep.	44	33	36	37
EKC	Ref	Czech Rep.	39	35	40	46
NEMS	Ref	France	103	103	109	124
EKC	Ref	France	103	111	127	146
IER/AU&GE	Ref	Germany	274	229	212	213
NEMS	Ref	Germany	267	244	265	286
EKC	Ref	Germany	268	261	299	342
NEMS	Ref	Italy	113	122	138	153
EKC	Ref	Italy	111	121	139	159
GOTO	Ref	Japan	300	360	408	
GREEN	Ref	Japan	333	461	477	565
IEA&ETSAP	Ref	Japan	306	335	357	386
IIASA/GECCP	Ref	Japan	336	355	332	280
NEMS	Ref	Japan	274	273	322	358
EKC	Ref	Japan	289	335	373	385

Table 4: Carbon Emissions Forecasts: Selected Annex 1 Countries (cont'd)
(Million Metric tons)

Source	*Scenario*	*Region*	*1990*	*2000*	*2010*	*2020*
NEMS	Ref	Netherlands	59	62	67	71
EKC	Ref	Netherlands	59	62	63	71
IER/POL	Ref	Poland	126	128	147	159
EKC	Ref	Poland	95	109	135	168
IIASA	Ref	Romania	44	50	52	
EKC	Ref	Romania	46	37	46	58
CUTEC	Ref	Sweden	17	18	23	29
EKC	Ref	Sweden	14	17	20	22
IEA&ETSAP	Ref	Switzerland	12	12	13	13
EKC	Ref	Switzerland	12	12	14	16
CECO	Ref	UK	158	147		
ECCO	Ref	UK	157	192	238	
NEMS	Ref	UK	167	156	170	181
EKC	Ref	UK	160	168	193	221
AIM	Ref	USA	1417	1677	1803	2125
AMOCO	High	USA	1416	1669	1914	
AMOCO	Low	USA	1416	1550	1637	
BNL	Ref	USA	1348	1487	1601	1847
GLOBAL2100	Ref	USA	1430	1638	1849	2081
GREEN	Ref	USA	1350	1547	1732	1951
GRI	Ref	USA	1356	1459	1644	
NEMS	Ref	USA	1346	1585	1790	1975
EKC	Ref	USA	1329	1534	1758	1910

Legend:

ABARE	Australian Bureau of Agriculture and Resource Economics
AIM	Asian-Pacific Integrated Model (AIM)
AMOCO	Amoco Corporation
BNL	Brookhaven National Laboratory, Photovoltaic Energy Impacts on U.S. CO2 emissions, June 1995.

CECO	M. Slesser, Edinburgh University
CUTEC	Long-Term Strategies for Mitigating Global Warming, 1994 Chalmers University of Technology
ECCO	Cambridge Econometrics – UK-ECCO model, M. Slesser, Edinburgh University, 1994
GLOBAL2100	Harmonized Conventional CHALLENGE Scenario by Alan Manne and Leo Schrattenholzer, April 1993
GOTO	Institute of General Energy Research, Macroeconomic and Sectoral Impacts of Carbon Taxation
GRI	Gas Research Institute GRI Baseline Projection of U.S. Energy Supply and Demand to 2010, 1994 edition, December 1993
IEA&ETSAP	IEA-ETSAP/Annex IV
IEEBF	Institute of Energy Economics, Bariloche Foundation
IER/AU&GE	Balandynowicz H. W., The Cost of CO_2 Emissions Reduction: Case Study for Austria, Stuttgart University, 1995.
IER/POL	Balandynowicz, H.W. et al. (1992), " CO_2 Reduction Strategies for Poland"
IGER	Institute of General Energy Research

Figure 2

Population, Carbon Dioxide and GDP: a world overview