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KYOTO COMMITMENT AND EMISSIONS TRADING: A EUROPEAN UNION PERSPECTIVE

Abstract

This paper presents an estimation of the cost of reducing CO_2 emissions as agreed in Kyoto by Annex I countries. Unlike most of the existing literature, this paper focuses on European Union countries abatement costs and, using a simple model, estimates the role of each EU country within a EU market as well as an Annex 1 market. As a major result, marginal (and total) abatement costs for each EU country (as well as the EU total cost) are presented. Some conclusions on the redistribution of income among market participants related to the trading system are also shown.

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1. Introduction

Annex 1 countries signed the Kyoto Protocol in 1997. These countries agreed to reach a fixed level of greenhouse gas emissions by 2008-2012 (see Table 1). Most countries accepted a substantial emission reduction, some an emission stabilisation. Few countries are allowed to increase their emissions up to the agreed quantity.

The emission reduction is clearly expected to involve costs, at least for some countries: reducing emissions requires either the implementation of appropriate technological changes in energy consumption or the reduction of the energy consumption itself; in any case, reducing emissions involves a social and economic price to be paid.

The Kyoto Protocol allows for the use of flexibility mechanisms, whereby countries mitigate their compliance costs.

This work focuses on emission trading. Different scenarios corresponding to the participants in the market (EU (European Union), Annex 1 without the FSU (Former Soviet Union), Annex 1 with the FSU) and the limitations in using emission trading are presented. For each scenario the market price of one ton of carbon as well as the total abatement cost each country has to pay is obtained. While the Kyoto Protocol considers six different greenhouse gases this paper is limited to the most relevant emission i.e. CO_2 (Carbon dioxide).

The economic literature has discussed and presented the issue of determining abatement costs implied by the Protocol, with and without emission trading and the other flexibility mechanisms. Some of this literature is examined in section 2. However, in existing literature either EU is treated as a single entity within an Annex 1 market or, as in the isolated case of Bader (2000), EU countries are considered separately, but the market is limited to Europe. The aim of this paper is to consider each European country as a different subject within the EU market but also within an Annex 1 market. Section 3 and 4 present the methodology adopted and other major numerical results.

2. The market for emission permits

The Kyoto-related cost for a single country is obtained considering two different scenarios and their difference in terms of cost. The first scenario is the Business as Usual (BAU) forecasted emission level which represents a zero-cost scenario. On the other hand, an alternative scenario is required with a target in terms of forecasted emissions. In this context total abatement means the difference between BAU emissions and Kyoto requirement emissions and the year 2010, which is central to the period considered in the protocol, is used as a reference year.

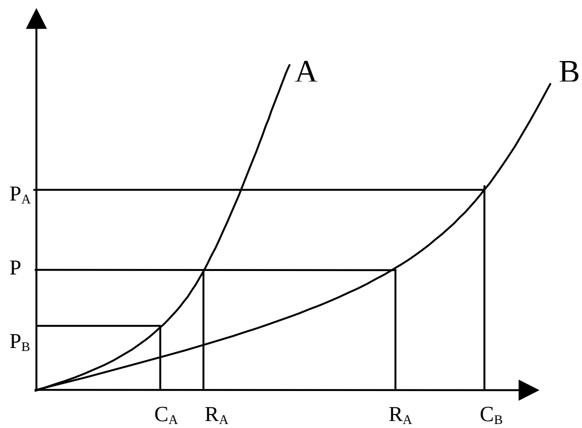
The cost of emission reduction is described by the marginal abatement cost (MAC). Using MAC curves, demand and supply of emission permits can be derived. In principle, in order to minimise costs, each country s reduction will be such that the MAC corresponding to that reduction will be equal to the price of the permits. If the reduction so obtained is higher than the requirement, the country will sell permits, contributing to the supply in the permits market. Conversely, if the reduction is lower than that required, the country will contribute to the demand of permits (see figure 1). The market-clearing condition determines the market price of emission permits.

3. Review of the literature

Different authors have discussed the issue of determining MAC curves using various strategies and the main solutions that have been proposed can be briefly outlined. Results vary widely depending on the methodology. However, most of the papers use MAC curves derived from detailed technological (bottom up model) or macroeconomic models.

Ellerman and Decaux (2000) analyse the impact of permit trading using estimated MAC curves. derived for each macroregion (EU, USA, Japan, other OECD countries, Former Soviet Union Countries and Eastern Europe) by means of the Massachusetts Institute of Technology s Emission Predictions and Policy Analysis EPPA model.

Figure 1: At price P, country A will reduce by R_A, whereas country B by R_B. Since the commitment of country A is lower than R_A (the price P_A is lower than P), Country A will be a supplier of permits. Vicevesa Country B will demand permit. The market involving A and B will be in equilibrium for a price P such that $(R_A\text{-}C_A)+(R_B\text{-}C_B)=0$.



EPPA is a multiregional general equilibrium model of economic activity, energy consumption and carbon emissions. MAC curves are drawn by plotting together shadow prices of carbon and corresponding percentages of carbon reduction. Ellerman and Decaux also provide a quadratic interpolation of the curves in order to obtain the total cost by integration; and to perform, for each MAC curve, a robustness test to MAC changes in other regions. Empirical results show that a trade permit system within the OECD countries should produce a total saving (with respect to the autarkic solution) of US$13 billion, and a carbon market price of 240 $/tC. In this context the European Union (as a whole) and Japan would buy permits, while USA and other OECD countries would sell them. A trade permits system within all Annex 1 countries determines a lower market price (127 $/tC), and a total cost reduction of about 47% always with respect to the autarkic solution; in this system only the FSU countries are permit sellers but, if trading of *hot air* [1] is not permitted, the price will rise to 150 $/tC, cost reduction is about 40% and permit sellers are FSU and Eastern Europe countries. Ellerman and Decaux also provide a simulation of the effects of a 1/3 ceiling on permit demand; in order words only 1/3 of the potential demand from each country can be satisfied using the trading system. This ceiling would lower the price of a ton of carbon to US$114 with a substantial gain reduction especially for Japan and selling countries.

Edmonds and Scott (1999) show the magnitude of savings that may accrue from international emission trading. Their paper does not focus on the Kyoto Protocol but evaluates the costs of stabilising emissions at the 1990 level by 2010. MAC curves are derived from a Second Generation Model (SGM) that links a detailed technological model of the energy sector with a Computable General Equilibrium (CGE) economic model. As usual estimated MACs vary widely among the countries involved: Japan (304 $/tC), Canada (249 $/tC), Western Europe (154 $/tC), Australia (147 $/tC), USA (139 $/tC) and FSU (0 $/tC). Total costs amount to US$57,7 billion but drop to US$37,5 billion when a trading system is considered (equilibrium price is 106 $/tC).

Finally Bader (2000) tries to evaluate the cost of the Kyoto protocol for EU countries with and without a trading system. Bader adopts a methodology that does not require any complex CGE (Computable General Equilibrium) model. In his approach MAC curves are derived from a carbon demand curve and this methodology relies on the assumption that it is easier to abate emissions for countries that have higher price elasticity of Carbon Demand. MAC curves are derived using a cross country approach and this is a major limitation of Bader analysis since estimated parameters are not stable over time and applying the same

[1] In all BAU scenarios, the FSU is assumed to reach an emissions level lower than that of 1990 by 2010. The difference between projected emissions and the 1990 level is the amount of the so called hot air . The fall in emissions level is a consequence of two factors: the slow growth of the economy and the reduction of energy subsidies.

methodology to data from different years gives very different results. However, Bader estimates, which use 1995 data, yield interesting results: the introduction of a tradable permit system would reduce total cost of compliance with the Kyoto protocol for EU countries by about 50%, with Belgium, France, Ireland and the Netherlands selling permits at a market price of 82 $/tC.

The Energy Information Administration (EIA, 1999) provides a comparison of costs of the Kyoto Protocol for the United States and the cost reduction by Annex I trading, as estimated by using several CGE models. It provides a useful comparison of our results with other estimates of USA MACs and the market price of permits. Estimates of MAC for USA are between US$221 and US$348 $ per ton of carbon while market price of permits is estimated to be between 100 and 177 $/tC for Annex I countries.

The OECD report Economic modelling of climate change, shows the results obtained with different models and is useful to compare different studies on the implementation of the Kyoto protocol. Two of the models used in the articles are predominantly bottom-up technological models, whereas other models are top-down economic models. The authors analyse the cost of implementing the Kyoto Protocol with autarkic measures and with a system of tradable permits. The ranking of MACs for OECD countries is relatively uniform in all the papers with Japan at the top, followed by Europe and then by the United States. The two bottom-up technological models (MERGE and POLES) provide different MACs for the United States, US$274 and US$82, respectively. The remaining models (SGM, G-Cubed, GTEM, WorldScan, Green, AIM), which are all top-down economic models, show a large variance (?) in the results, ranging from $38 to $375 for the US, $78 to $773 for Europe and $77 to $751 for Japan. Model results demonstrate that permit trading, through its mechanism of equalising MACs across countries, leads to significant declines in the overall cost of abatement among the OECD countries. The range of permit prices is $20 (WorldScan) to $123 (GTEM). Results obtained by the two bottom up models show a significant coincidence ($112 for POLES and $114 for

MERGE), top-down models give, in general, lower permit prices, but significant variation among the results.

Most of the models show that, since the FSU has the lower MAC, this region will be the main supplier of permits. In 2010 every OECD region will be a net buyer of permits. Results also indicate that the size of the market will vary from model to model and that, in general, the United States would meet (?) a lower percentage of its emissions from trading than would Japan and the European Union.

Finally, the importance of the hot air issue is underlined by all the models. The existence of a hot air bubble would affect the overall cost and efficiency of emission reduction with a higher level of emissions for Annex I countries under a tradable emission scheme than under an autarkic system.

4. Estimating abatement costs

For all countries other than those of the FSU, the approach of this paper follows Bader (2000). First, a carbon demand function is estimated for each country. Since neither the market (trade) nor the price of Carbon are clear, it is essential to preliminarily estimate quantities and price of this virtual market. The way these quantities are obtained is explained in the appendix. In short: carbon demand is a function of carbon price calculated as the ratio of the total expenditure of carbon fuels and their total carbon content. The time series of carbon prices shown in figure 2. The difference between prices in different countries is due both to different prices of specific fuels and to the different composition of fuel demand. Thus it should be noted that these series are not genuine collected time series but estimates and so they contribute to the uncertainty of the results. The extent to which these data are reliable is examined in the appendix: the key issue is the percentage of emissions covered by the fuel considered in determining the price.

The estimated carbon demand function has the form

$$\left(\frac{C_t}{GDP_t}\right) = q(p_t)^b \, (EN_t)^g \qquad (1),$$

where EN is the share of Total Primary Energy Supply (TPES) covered by carbon-free energy sources; C_t the Carbon emission; GDP_t the gross domestic product and p_t the price of Carbon (P_c in the appendix). Since our aim is to estimate the demand for carbon as a function of price and, when appropriate, of other variables.

For each country the following regression has been estimated

$$\log\left(\frac{C_t}{GDP_t}\right) = a + b \log(p_t) + g \log(EN_t) \qquad (2)$$

including or excluding as appropriate EN in order to avoid multicollinearity with prices or the inclusion of a non relevant variable. The estimates are obtained either by Ordinary Least Squares (OLS) or by Johansen or Engle-Granger cointegration procedure, according to stationarity and order of integration of the series. In some cases, a reduced sample has been used, in particular when on the whole sample a non linear relation could be detected. Details on estimates can be found in Table 2.

Since the aim of this paper is to investigate the cost of carbon abatement we simply ignore those countries for which the coverage of emissions is not satisfactory such as Luxembourg. Moreover, we excluded from the analysis those countries for which carbon turns out to be a Giffen good (Portugal, Greece and New Zealand, see figure 7) since the positive relationship between price and quantity of carbon would lead to negative abatement costs. [2]

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[2] A possible explanation for the positive slope of these demand curves could be the fast industrialisation of the countries mentioned above during the period analysed. In such a phase of transition, the share of Industry production on GDP became bigger, and Carbon consumption has grown quickly because Industry production requires more Carbon emission per unit of GDP than agriculture production does.

The main problems in estimating regression functions were the non linearity of the relationship and the non stationarity of dependent variables and regressors. We could eliminate some of the non-linearity problems simply by reducing the sample used for some countries or by introducing dummy variables. In fact, by examining the graphs of price and emissions, we observed that non linearity was due to a sudden change in the behaviour of the two series, usually related to a change in the behaviour of Log(EN). In those cases we allow only for the more recent structure, dropping the first years or estimating different regression parameters for the different periods (technically this was achieved by introducing a dummy) and keeping those estimates with those from the more recent years. Non stationarity of dependent variables and covariates must be allowed for in almost all regressions (see Table 2 where the results of stationarity tests are summed up). Two different situations must be distinguished according to the characteristics of the dependent variable: I(0) or I(1). If the dependent variable is I(1), given that the price series is always I(1), a cointegrating equation between at least Log(C) and Log(PC) must be found. Johansen or Engle and Granger procedures were used and Log(EN) was added as a regressor whenever possible: it must be I(1), non multicollinear and, of course, significant. If the dependent variable is I(0) the estimation is straightforward, the theory states that OLS estimates are superconsistent and so the usual procedure can be used. Again, suitable regressors are chosen. Residuals of regression or cointegrating equations have been used to assess the accuracy of the models. In particular, stationarity of residuals has been checked by Augmented Dickey-Fuller (ADF) tests and autocorrelation functions have been examined.

Furthermore, in order to evaluate the stability of the estimated parameters of OLS regressions, two tests have been performed: the Cumulated Sum of residuals (CUSUM) test and the CUSUM of Squares test. Some countries (Italy, Belgium and Finland) show positive results in both tests. Other countries (Germany, Denmark and Ireland), give positive responses to the CUSUM test, but fail the Square of CUSUM test at a 5% significance (but they do not fail at 10% significance). In some cases (United Kingdom, Spain, Sweden), the CUSUM test shows instability of parameters at 5% significance (but not at 10%) while the CUSUM of Squares test does not. The results seem to be quite good: none of the regressions both tests at a confidence level of 5%, so, for each country, stability of parameters cannot be rejected. In order to investigate the effects of global emission trading, carbon demand functions for the most important non EU Annex I countries (Australia, Canada, Japan, USA) have been evaluated. The results are reported in Table 3 below. Stability analysis on the estimated parameters has been performed CUSUM and CUSUM of Squares test. (non capisco il senso della frase precedente) Results show that the parameters for the United States and Australia give positive responses to both tests at 5% significance, whereas parameters for Canada give positive responses only at 10% significance.

Parameters of the estimated demand curves have been used in order to calculate Marginal Abatement Cost (MAC) curves.

Marginal abatement cost is defined, for a fixed abatement, as the price variation needed to obtain a further reduction of one ton of C. It is the tax which would produce a reduction in carbon demand by 1 ton. From (2) we obtain

$$p_c = \left(e^a\right)^{1/b}\left(\frac{C}{GDP}\right)^{1/b} EN^{-g/b} \qquad (3)$$

and so the MAC corresponding to an abatement of r % starting from the level Co/GDPo and ignoring covariates different from price[3], is given by

$$MAC(r) = p_c^{\,rid} - p_c^{\,0} = \left(e^{-a}\right)^{1/b}\left[\left(\frac{C_0}{GDP_0}\left(1-\frac{r}{100}\right)\right)^{1/b} - \left(\frac{C_0}{GDP_0}\right)^{1/b}\right] \qquad (4).$$

As stated above the abatement is defined with respect to BAU zero cost level, so C_0 and GDP_0 are BAU forecasts for 2010. The

[3] Actually they can be considered. In this case the formula for MAC will differ from (4) and the estimation procedure will also be slightly different.

integral of the MAC curve in the interval [0,r] is the cost to abate r% of the emissions.

The MAC curve for the FSU could not be estimated in this way because price data were missing . To consider the FSU in our simulation we simply quote the MAC obtained by Ellerman (2000). We note that BAU forecasted emissions for the FSU are lower than the commitment by 111 Mton, in a MAC curve this is zero for an abatement of less than 111 Mton.

5. Emission trading and abatement costs

Estimated MAC curves are shown in figure 3 as a function of the percentage of abatement. Some important differences (even within EU countries) should be observed. As expected from previous literature Japan and Italy have uniformly higher MAC curves, whereas the USA and Australia have MAC curves lower than those of the other developed countries. The MAC curve for FSU, as already anticipated, is zero for an abatement less than 111 Mton (the *hot air* effect) and then grows sharply for abatement above this amount. By comparing these curves we get the cost of emission reduction and not the cost of Kyoto requirements. These are compared in Table 1 where MAC and total abatement costs corresponding to Kyoto compliance are reported. Table 1 shows that Denmark is by far the Annex 1 country with the highest marginal Kyoto cost, due to a substantial commitment (almost 29% of BAU forecasts). In contrast France and Belgium show marginal costs lower than those of the USA, despite uniformly higher MAC curves, because of their relatively small commitments. Analogous considerations apply to the total abatement costs as a percentage of GDP. MAC curves define a supply and a demand curve of emission permits and so they can be used to determine the equilibrium price of permits and, consequently, the number of permits each country would sell or buy at equilibrium price. This analysis has been performed under various hypotheses on the countries that participate in the market and on the limitations of the market itself.

Let us consider first a EU market, closed to non-EU countries. The market price obtained using this hypothesis is US$211 TC, whereas the total abatement cost is 10 bln$, saving approximately 12 bln$ with respect to the no trading case. Figure 4 illustrates a comparison of the cost distribution among EU. Denmark s share of cost is dramatically reduced (from US$6.7 billion, corresponding to 31% of total EU expenditure, to US$894 million, corresponding to 9.4%), in fact, in the unlimited trading case Denmark buys permits to cover 86% of the commitment. In contrast, France and Belgium show a negative cost; thanks to their low MACs and commitments, they are able to obtain a net income by selling permits. Spain shows negative abatement cost because its commitment is higher than BAU forecast and can obtain a net income by selling permits. The limited trading case shows clearly that an unlimited market in not needed to dramatically reduce abatement costs of In fact if purchases are limited, for each country, to 20% of its commitment, the market price will become US$160 /tC and the total abatement cost 13.8 bln$, less than 5 bln$ more than the unlimited trading case. On the other hand, if the sales of each country are limited to 20% of its commitment, then the market price increases to 462 $/tC, but the total abatement cost is 13,3 bln$, still much lower than the no-trading case. Of course the earnings of Belgium and France would now be greatly reduced.

Only in Bader (2000) is there a similar case, but the comparison between the results of this paper and Bader s is difficult due to a different methodology: Bader estimates the parameters of the MAC curve for the whole of Europe, so that the same shape applies to all EU countries. This means that differences in the MAC are given only by differences in the commitments and in the starting value of the ratio C/GDP. Nevertheless, following a different approach this paper agrees with Bader s ranking of countries. Ultimately, the market price determined by Bader is 81$/tC, much less than our estimation, and the same can be said of total abatement costs. However the percentage cost reduction due to the market is, according to both Bader s and our calculations, around 50%.

Opening the market to non-European countries such as Australia, USA, Canada and Japan results in a market price of 142.6 $/tC (in the unrestricted market case). This further reduction is mainly due to the United States, which has a low MAC and so can cover at low cost 66% of the total abatement and is the main supplier of permits (57% of the total supply). The other big suppliers are Australia, which provides 24% of the total supply of permits, and France (13%). Belgium, Spain and Ireland together provide less than 6%. All the other countries demand permits. The US commitment accounts for 72% of the total commitment of the countries considered. If trading is unlimited the United States will sell 52 Mton of C, corresponding to approximately 7% of the total reduction. This lowers the total abatement cost from 81 bln$ to 42 bln$, more than half of which is spent by the USA as can be seen in figure 5. Other suppliers of permits are Australia, Ireland, Spain, Belgium and France, that, because of their relatively low commitment, gain a net income from trading. Japan and Denmark, being the two countries that benefit most from trading, reduce their expenses to 20% and 10% of the no-market case. Costs relative to limited trade scenarios are compared in figure 5 (columns (C) (D) (E)) which illustrates that limitations up to 20% of the commitments still allow a dramatic reduction in abatement costs. The highest total cost is incurred with a 20% of purchase limitation: 60.2 bln$. Finally, we evaluate a market open also to the FSU, whose commitment is higher than BAU forecasted emissions. For this reason, the MAC of the FSU is zero for abatement below the difference between commitment and BAU emissions. In practice, a supply of 111 Mton is introduced, leading to an important reduction of costs as can be seen in figure 5: the FSU earns US$13.1 billion from trading and the USA buy permits.

In figure 6 the results of the Annex 1 permits market with and without the FSU for each country are illustrated in more detail. Price estimates for the Annex 1 market are easier to find in literature, and our results are similar to the values obtained by other authors quoted in section 2. Adequate consideration should be given to the different methodologies used, because some models consider the European Union as a single area and do not analyse European countries separately.

6. Conclusions

The empirical part of this paper shows that, without transaction costs, a market of permits (vive should) help to reduce the individual and total costs of emission abatement. Clearly, the higher the ceiling on sales and purchase, the smaller the cost reduction.

According to economic theory, a trading permit scheme should help to attain an efficient allocation, but it should be (?) completely neutral with respect to any equity consideration. In fact, a country would be a buyer or a seller of permits depending on its endowment, that is, on its initial commitments. Since commitments are basically political agreements, it is useful to underline that they should be defined carefully: the definition of commitments may produce a redistribution of income (via tradable permits) from countries that have adopted mitigation measures to countries that have not. In fact, probably, the latter can still implement cheaper measures whereas the former have only expensive options to reduce emissions. In this sense, Kyoto commitments seem to lead to a paradox: countries with lower levels of emissions per GDP and emissions per capita pay (through the purchase of permits) developed countries that have significantly higher levels of emissions per capita and per GDP. The result of a tradable market system, in fact, is that Japan and the EU buy permits from the United States if commerce takes place among OECD countries, or from Russia if commerce is open to Annex I countries, where the USA and Russia have the highest ratios of emissions per unit of GDP and per capita (see table 4).

Country	**Japan**	**EU**	**USA**	**Russia**
CO_2 / GDP	0,45	0,5	0,83	2.09
CO_2 / Population	9,29	8,58	20,5	9,89

Tab. 4: Emissions Indicators for some Annex I countries (1997). Source: IEA.

It should be noted that these indicators can be misleading and must be broken down on a sectoral level. Indicators are, in fact, influenced by the productive specialisation of a country and the structure of the economy affects the levels of emissions. When sectors that are intrinsically polluting represent a high share of GDP, aggregate indicators are influenced by their effect even if sectoral indicators show optimal performance. Moreover, the geographical aspects of each country must be taken into account. For instance, countries with low population density will register high levels of emissions per capita in the transportation sector because of the distance that workers, goods and raw materials are forced to travel. Temperature also influences the level of emissions.

Sectoral indicators confirm the results showed by aggregate ratios of the countries considered. With the exception of the Russian transportation sector, per-capita emissions are always higher in the USA and Russia than in Europe and Japan.

Further lines of research include: a specific study on the role of the FSU. Its market position suggests that it may act as a monopolist, and so its aim might not be to minimise costs, as in this model. For example, the FSU could wait until the deadline fixed by the Kyoto Protocol to sell permits at a higher price to countries at risk of non compliance. It is also true that the FSU comprises a number of countries and this may mitigate the monopoly, but there is a reasonable possibility that they may still act as a group. The absence of transaction costs is a second main defect of this model and a market with transaction costs would allow less savings than the no friction market we assumed.

Appendix: price and quantities of the carbon market.

As discussed in section 3, an index of fuel prices should be used as the price of Carbon in a virtual carbon market.

Following Bader (2000), carbon price is defined as

$$P_c = \frac{\sum_i F_i P_i}{\sum_i F_i c_i} \tag{A1}$$

depending on the consumption of the different fossil fuels Fi, on fuel prices Pi and on the carbon content of each fuel (C_i). Interpreting (A1) as the price of carbon seems reasonable since this model considers the total expenditure for fuels containing carbon by the total carbon content of the fuels themselves. Carbon contents of fuels are quoted from Bader.

Historical data (1970-1997) for F_i and P_i for each of the EU-15 countries are provided by the International Energy Agency. For each of the countries involved in the calculation, fuel consumption and price data are divided into three sectors by end use and a possible selection of fuels has been considered for each of these.

Price data are always end user prices and contain energy or CO_2 taxes, set at different levels in each country. They are expressed in terms of US$ PPP in order to even out the differences in the general price level of EU countries.

Fuel consumption data by sector were extracted from the IEA database. The fuel classification by type considered in this database is less refined than the one used for prices.

In particular, all gasoline and diesel for motors are grouped in the household sector, and high-sulphur fuel oil (HSFO) and low-sulphur fuel oil (LSFO) are grouped in the industrial sector. The aggregate fuel oil consumption for households has been split into diesel and gasoline according to the observed ratios of gasoline/diesel consumption derived from Energy Statistics of IEA Countries . That is, DIESEL consumption is $\alpha\times$(TOTAL MOTOR FUELS) where α is the share of diesel consumed as motor gasoline as well as diesel used in households. GASOLINE is calculated in the same way. Furthermore, we equally subdivided the figure for aggregate gasoline in LEADPREM, LEADREG; UNPREM95; UNPREM98 and UNREG.

While quantities in the original databases are in different units (litres, tons of oil equivalent, cal), all quantities from this model are expressed in Mtoe. Conversion factors are provided by CO_2 Emissions from Fuel Combustion edited by the IEA. Prices in the database are in US$ PPP relative to various units of fuels. The carbon price we calculated is expressed in US$ PPP per tonne of Carbon. As mentioned above, P_C depends on the prices of fossil fuels as well as their market shares.

This paper does not consider the total fossil fuel consumption, but a share (in broad terms, the percentage of fossil fuels for which corresponding price and quantities are available), and, moreover, this share varies over time. The fuels considered in the P_C calculation represent a share of total consumption[4] of about 60%, starting from a minimum value of 40% for Luxembourg, to a level of about 80% for France, Italy, and Denmark. The total coverage is relatively stable from 1978 to 1997. In fact, in many countries the quantities recorded in the original database are constant over a number of years, which is a clear sign of their reliability. Besides the share of consumption covered by the fuels, the share of carbon emissions covered by our selection can be considered. This is the ratio of carbon emissions by each fuel (expressed as $\Sigma C_i F_i$) and total carbon emissions as recorded in CO_2 Emissions from Fuel Combustion (2000). The average share of Carbon emissions covered is about 70%, starting from a minimum coverage of about 40% for Luxembourg, to levels near 80% for France, Denmark, Belgium and Italy.

If we examine the coverage level of carbon emissions and the coverage level of consumption for Italy we see again that the level is quite stable over the past 20 years and also observe that the coverage level of carbon emissions is uniformly higher. In other words 75% of the fuel consumed in Italy produces 85% of carbon

[4] As reported in Energy Statistics for OECD countries, IEA, 2000.

emissions, meaning that we tend not to use the less carbon-intensive fuels.

The lowest consumption coverage levels are registered by Sweden and France. Both countries have a percentage of TPES covered by hydro and nuclear close to 46% In both cases a significant amount of end-use demand is not considered in our calculation, but its contribution to carbon emissions is near zero.

Analogously, the lowest emission coverage levels are registered by Germany and Greece. Both countries show 25% to 35% of TPES covered by brown coal. Figure 2 reports the time series of Carbon price for EU-15 countries.

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Table 1: Kyoto commitments and costs for Annex 1 countries (autarkic solution).

	EMISS. BAU (MtC)	ABATEMENT (Emiss. BAU Commitment) (MtC)	% tot EU	% tot	% BAU	*MAC*	ABATEMENT COST Billion $	% tot EU	% tot	%o GDP
A	17,455	2.773	2.5%	0.4%	15.9%	594	724	3%	1%	4.8
B	30.273	986	0.9%	0.1%	3.3%	49	24	0%	0%	0.1
DE	15.818	4.555	4.2%	0.6%	28.8%	4.364	6.721	27%	7%	58.8
FI	20.182	5.509	5.0%	0.7%	27.3%	471	1.040	4%	1%	11.7
FR	107.182	243	0.2%	0.0%	0.2%	7	1	0%	0%	0.0
D	265.091	46.587	42.6%	6.0%	17.6%	189	4.043	16%	4%	2.8
SW	26.182	10.456	9.6%	1.3%	39.9%	710	2.517	10%	3%	15.8
IR	9.818	351	0.3%	0.0%	3.6%	20	3.420	14%	4%	5.3
IT	125.727	13.106	12.0%	1.7%	10.4%	609	3.360	13%	4%	3.3
NL	46.091	4.724	4.3%	0.6%	10.2%	653	1.378	6%	2%	4.7
UK	166.636	20.119	18.4%	2.6%	12.1%	197	1.827	7%	2%	1.7
Tot EU	*830.455*	*109.410*	-	-	*13.2%*	-	*25.054*	100%	28%	*4.46*
AUS	105.491	28.025	-	3.6%	26.6%	0.91	4.971	-	6%	0.01
CAN	150.136	40.541	-	5.2%	27.0%	318	5.292	-	6%	9
J	310.309	38.102	-	4.9%	12.3%	1.706	26.811	-	30%	10.3
USA	1,800.464	564.392	-	72.3%	31.3%	117	27.908	-	31%	4.2
Tot	*3,196.855*	*780.470*	-	-	*24.4%*	-	*90.037*	-	100%	*5.1*

A Austria; B Belgium; DE Denmark; FI Finland; FR France; D Germany; SW Sweden; IR Ireland; IT Italy; NL the Netherlands; UK United Kingdom; Aus Australia; CAN Canada; J Japan; USA United States.

Figure 2: Price of Carbon for EU countries.

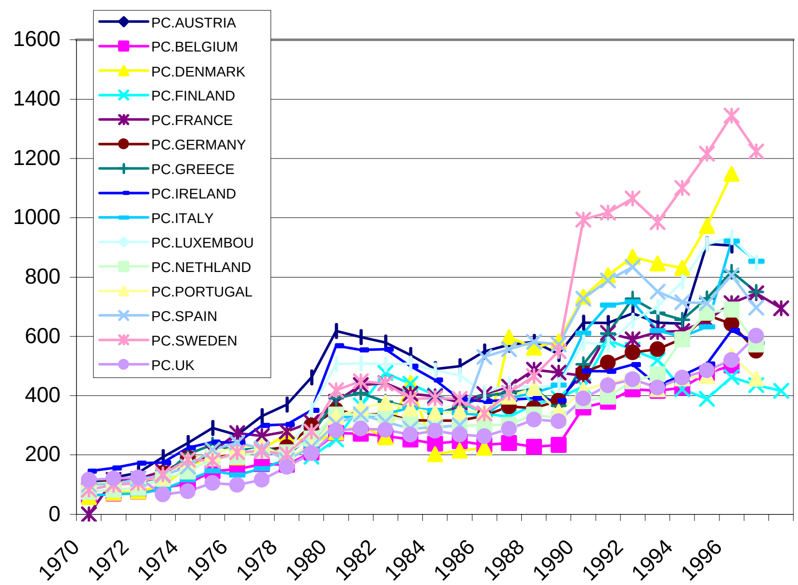

Figure 3: **MAC curves for Annex 1 countries.**

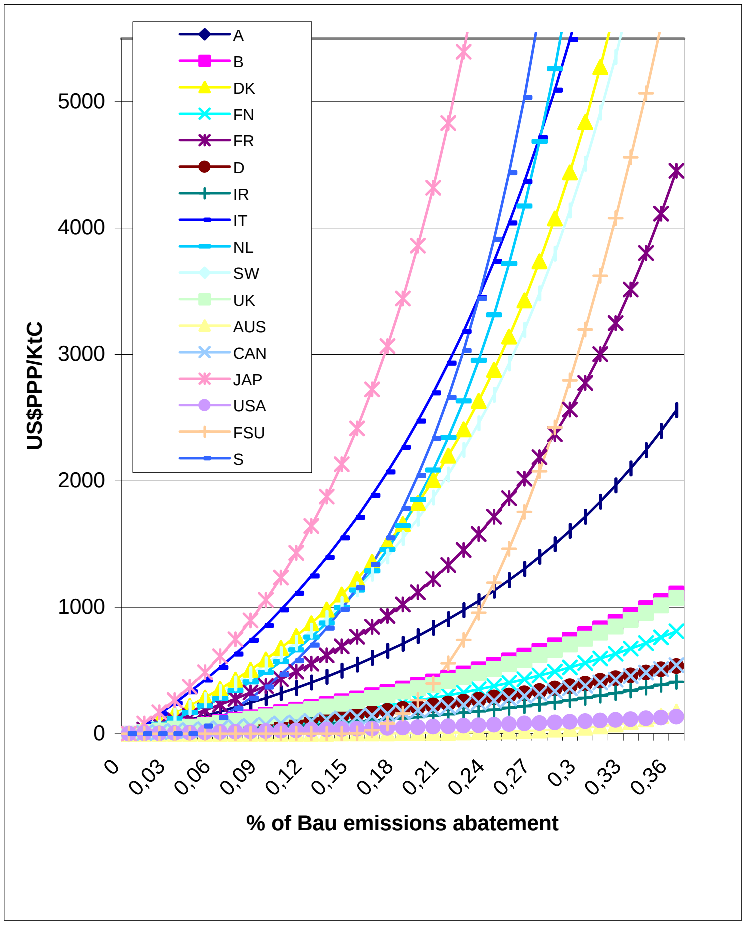

Figure 4: Abatement cost for EU with no trade (A); unrestricted trade (B); trade with purchases restricted to 20% of commitment (C) and sales restricted to 20% of max sale (D).

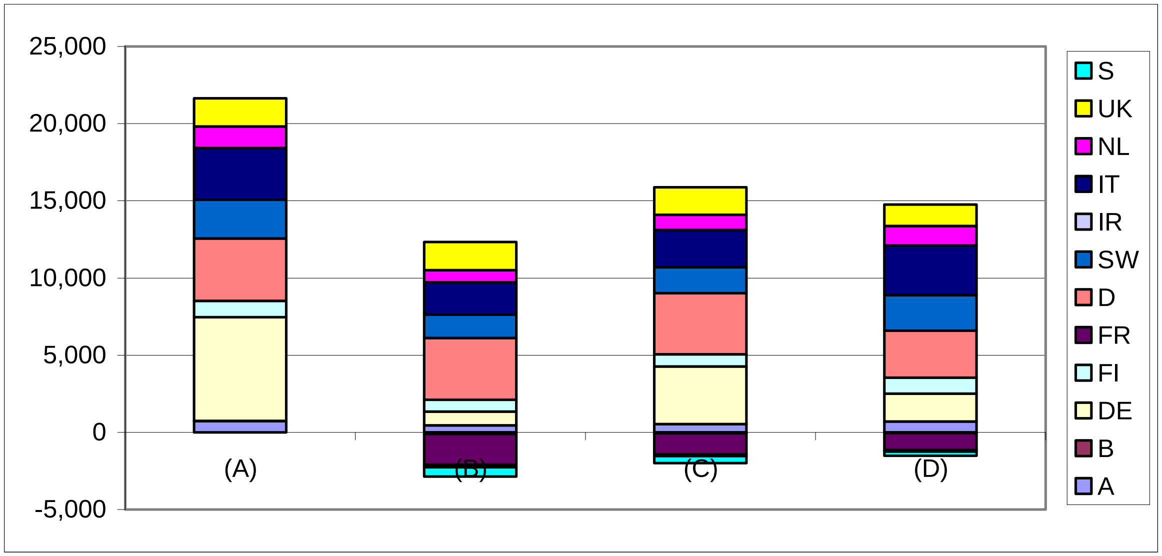

Figure 5: Abatement cost for Annex 1 without FSU assuming: no trade (A); unrestricted trade (B); trade with sales restricted to 50% of maximum sale (C); sales restricted to 20% of max sale (D); purchases restricted to 20% of commitment (E). Abatement cost with FSU assuming: no hot air (F) and hot air (G).

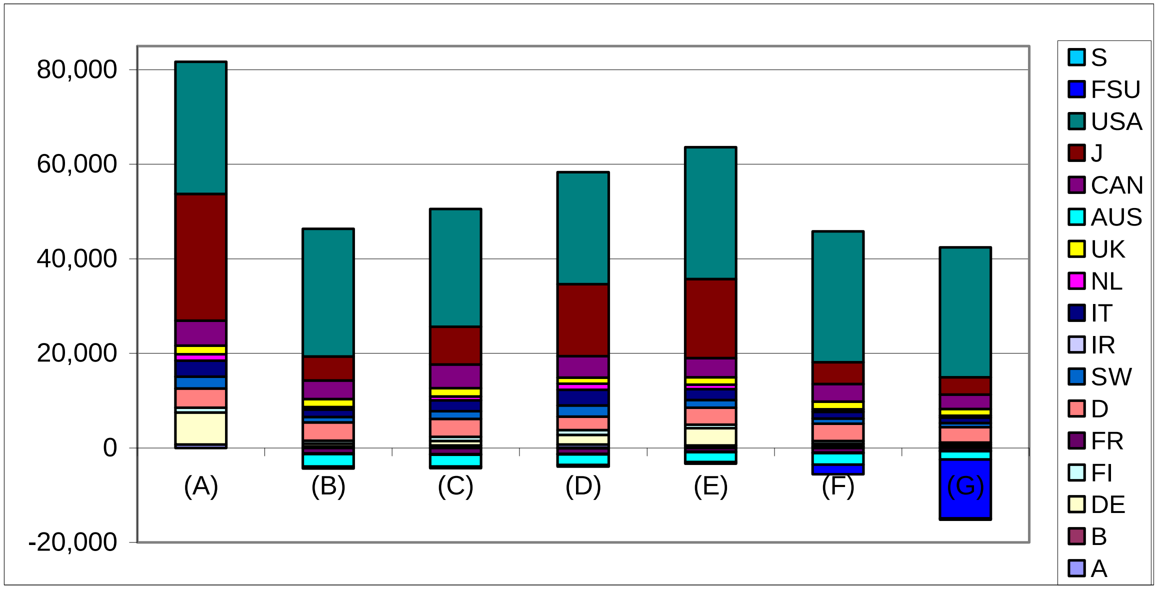

Figure 6: Abatement costs for scenarios: no trade (A); unrestricted trade without FSU (B); unrestricted trade with FSU and hot air (G).

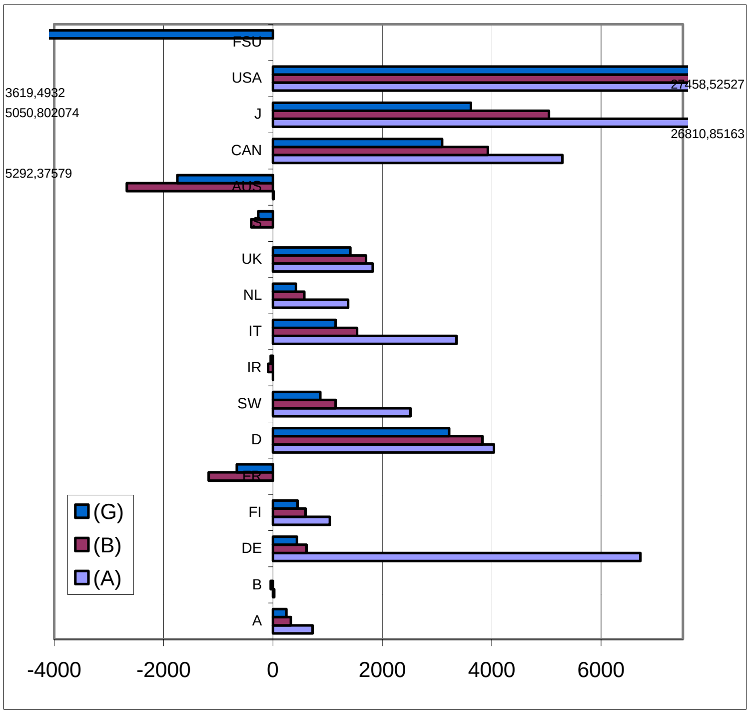

Figure 7: Scatter plot of carbon demand against price for countries which showed a Giffen good behaviour for Carbon.

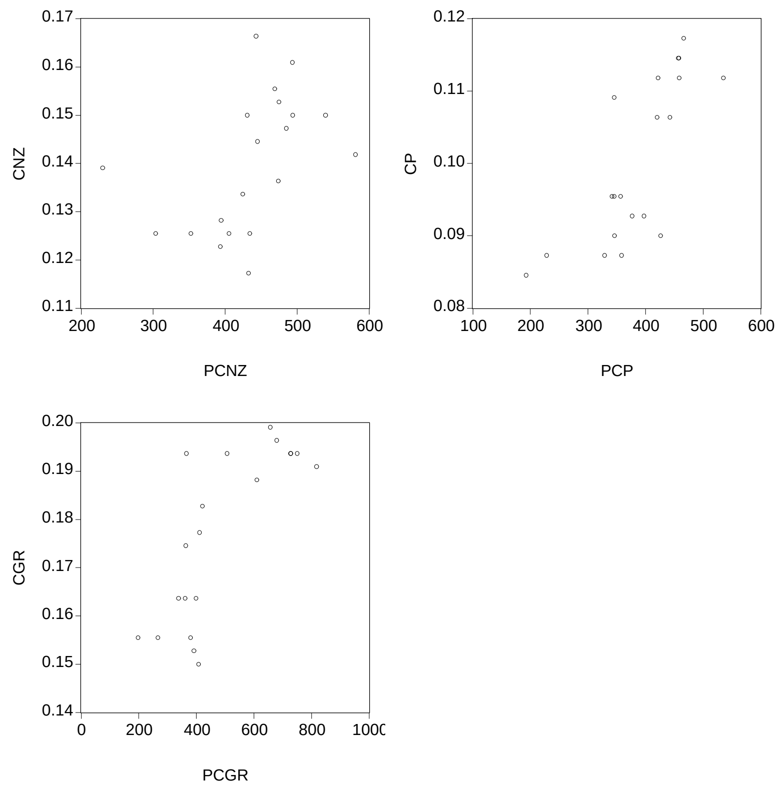

Table 2: Final estimates for EU countries (Johansen tests results: the numbers in parentheses are the critical values at 5% and 1% levels).

Country	**Sample**	**Order of Integration of seriesinvolved and of residuals (when applicable to the method)**	**Method used in estimating demand equation.**	**Demand equation: final estimate (standard deviations in parentheses)**
Austria (A)	78-97	LP=I(1) LC=I(1)	Johansen H0=None: 37.7 (29.7; 35.6) H0= At most 1: 15 (15.4; 20)	LC=-0.08-0.311*LP (0.05)
Belgium (B)	78-97	LP=I(1) LC=I(0) Residuals=I(0) (not spurious)	OLS With dummy variables	LC=1.4*(1-dummyb)*LP-0.4*dummyb*LP + (0.2) (0.04) +0.9*dummyb- 9.3*(1-dummyb) (0.2) (1.3) R-squared=0.89
Denmark (DK)	78-97	LP=I(1) LC=I(1) Residuals=I(0) (not spurious	OLS With dummy variables	LC=-0.19*LP-0.56*dummydk-0.57 (0.06) (1.9) (0.3) R-squared=0.51
Finland (FN)	84-97	LP=I(1) LC=I(0) Residuals=I(0) (not spurious)	OLS	LC=0.609-0.365*LP (0.508) (0.084) R-squared=0.50
France (FR)	78-97	LP=I(1) LC=I(1) LEN=I(1)	Johansen H0=None: 44 (29.7; 35.7) H0= At most 1: 19 ((15.4; 20)	LC=-0.806-0.235*LP-0.435*LEN (0.060) (0.057)

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Germany (D)	78-97	LC=I(1) LP=I(1) Residuals =I(0)	OLS ADF on residuals (Cointegration by Engle and Granger)	LC=2.19 - 0.614*LP (0.287) (0.047) Johansen: LC=2.55-0.67LP LR test indicates 4 c.e. at 5% significance
Ireland (IR)	89-97	LC=I(1) LP=I(1) Residuals =I(0)	OLS ADF on residuals (Cointegration by Engle and Granger)	LC=-0.15*LEN - 0.37*LP (0.04) (0.03) R-squared=0.80
Italy (IT)	78-97	LP=I(1) LC=I(0) Residuals=I(0) (not spurious)	OLS	LC=-1.293-0.133*LP (0.120) (0.019) R-squared=0.71
Netherlands (NL)	78-97	LC=I(1) LP=I(1)	Johansen H0=None: 16.6 (15.4; 20) H0= At most 1: 2.4 (3.7; 6.6)	LC=-0.489-0.197*LP (0.035)
Spain (S)	78-97	LC=I(1) LP=I(1) Residuals=I(0)	OLS ADF on residuals (Cointegration by Engle and Granger)	LC=-1.30-0.11*LP (0.13) (0.02) Rsquared=0.61
Sweden (SW)	78-97	LC=I(1) LP=I(1) Residuals=I(0)	OLS ADF on residuals (Cointegration by Engle and Granger)	LC=-0.33*LP (0.00) R-squared=0.69
United Kingdom (UK)	78-97	LC=I(1) LP=I(1) Residuals =I(0)	OLS ADF on residuals (Cointegration by Engle and Granger)	LC=0.578-0.390*LP (0.261) (0.044) R-squared=0.80

Table 3: Final estimates for non- EU countries (Johansen tests results: the numbers in parentheses are the critical values at 5% and 1% levels).

Country	Sample	Order of Integration of series involved and of residuals (when applicable to the method)	Method used in estimating demand equation.	Demand equation: final estimate (standard deviations in parentheses)
Australia (AUS)	78-97	LP=I(1) LC=I(1) LEN=I(1) Residuals=I(0) (not spurious)	OLS dummy variables	LC= -1.50 0.07*dummyaus*LP + (0.32) (0.016) 0.10*(1-refaus)*LP 0.94*(1-refaus) + 0.29*LEN (0.12) (0.64) (0.14) R-squared=0.71
Canada (CAN)	78-97	LP=I(1) LC=I(0) Residuals=I(0) (not spurious)	OLS	LC=0.93 - 0.41 *LP (0.16) (0.02) R-squared=0.91
Japan (J)	78-97	LP=I(1) LC=I(1) LEN=I(1)	Johansen H0=None: 90 (47; 54) H0= At most 1: 45 (29; 35) H0= At most 2: 16 (15; 20)	LC=-0.14*LP+1.15 (0.08)
United States (USA)	86-97	LP=I(1) LC=I(0) Residuals=I(0) (not spurious)	OLS	LC=2.14 - 0.69*LP (0.68) (0.13) R-squared=0.73
Dummyaus is a dummy variable that is 0 between 1984 and 1987 and 1 elsewhere.				

Table 4 Domestic abatement and total abatement cost for Italy in different trading scenarios.

	Domestic abatement (MtC)	TAC (Billion US$)
Autarkic	13.105	3.359
Unlimited EU	5.452	4.74
Unlimited Annex I	4.154	2.66
Unlimited Annex I with FSU	3.191	1.53

Table 5 Market price of permits when ceilings on purchases and sales are imposed. The limits are expressed as a percentage of the commitment for purchases, as a percentage of the sale in unrestricted case for sales.

	Purchase		**Sale**	
Limits (%)	Price (US$/tC)	TAC (bil Us$)	Price (US$/tC)	TAC (bil US$)
10	-	63.354	535	52.860
20	39	48.507	277	44.574
30	84	41.342	190	40.257
40	89	36.176	146.4	37.215
50	93	32.473	123	35.039
60	96	29.943	118	33.083
70	97	28.339	113	31.235
80	98.9	27.478	108.7	29.503
90	99.9	27.103	104.2	27.940
100	99.9	27.189	99.9	27.189

Table 6 Market price of permits and total abatement cost for different choices of market participants.

	Price (US$/tC)	**TAC** (billion US$)
EU	218	10(1)
Annex I FSU	147	42
Annex I + FSU no H.A.	130	40
Annex I +FSU + H.A.	100	27
(1) only EU countries		

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