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Market Instruments and CO2 Mitigation:
A General Equilibrium Analysis for Spain

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Market Instruments and CO2 Mitigation:
A General Equilibrium Analysis for Spain

Mikel González Ruiz de Eguino[1]

Market instruments are a core element of policies to mitigate climate change. Choosing and designing the right instruments can help to minimise mitigation costs. This paper seeks to analyse various market instruments for CO2 mitigation from the viewpoint of cost-effectiveness, using an AGE (applied general equilibrium) model for the case of Spain. A distinction is drawn between (1) quantity instruments, which represent different extents of a market for emission permits; and (2) price instruments, which represent different types of tax. The analysis quantifies the importance of making the right choice as to which sectors are excluded from the permit market, and of targeting taxes correctly.

Keywords: Environmental policy instruments, general equilibrium analysis, Spain

JEL Classification: D58, H21, Q58

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1. Introduction

Concern about climate change has led many countries to begin to take steps to control emissions of the greenhouse gases (GHG) that cause it, particularly CO2 from the burning of fossil fuels. Although there is considerable technological potential, CO2 mitigation policies can be expected to be expensive in the short term in comparison with other environmental policies (IPCC 2007). Choosing the right instruments is essential if mitigation costs are to be kept to the minimum, and so that more ambitious climate-related objectives can be pursued in the future.

There are various types of pollution control instrument available, all of which are useful in different circumstances. In the past few decades, economists (Hahn 1989, 2000) have defended the use of market instruments or economic incentives, such as taxes or tradeable emission permits together with direct "command and control" (CAC) methods such as the setting of regulations and technological standards. CAC instruments are usually simpler to apply, and can prove effective when the policy to be introduced affects specific sectors or facilities, but when a policy affects many different sectors the cost of enforcing them can be very high.

Economic incentives have therefore been gaining ground in environmental policy. Countries such as Sweden, Norway and Germany have introduced environmental taxes and even environmental tax reform programmes that enable other, traditional taxes to be lowered (OCDE 1999). The EU-ETS (European Union Emission Trading System) has been up and running in the European Union since 2005, covering around 10,000 facilities and around 50% of CO2 emissions.

There are numerous recent papers in the relevant literature (Austin and Dinan 2005; Newel and Stavins 2003, Palmer and Burtaw 2005) which have compared the costs of reaching environmental objectives with market instruments and with CAC instruments. Most of them agree that CAC instruments may be suitable in many circumstances but can significantly increase costs. In this regard, Tietenberg (2006) analyses 14 studies covering different pollutants and regions, and concludes that mitigation costs can be reduced by 40-95% using market instruments.

This paper seeks to analyse CO2 mitigation costs by comparing different types of market instrument. On the one hand we analyse the introduction of a tradeable emission permit system in various sectors, and on the other hand the setting of taxes on CO2, energy, oil, coal and electricity. This analysis enables us to quantify the costs of the exclusion of some sectors from the market and of different taxes "close to" CO2. In practice, this will serve to assess whether the costs incurred can offset other costs inherent in each instrument (e.g. transaction and enforcement costs), thus complementing other major selection criteria such as equity and political feasibility (Goulder and Parry 2008).

Instruments are compared using an AGE (Applied General Equilibrium) model .applied to the case of Spain. It is fundamental that a general equilibrium viewpoint be taken in analysing policies related to energy and climate change, because all sectors of the economy give rise to CO2 emissions, even though in some cases they do so indirectly through electricity consumption. Pre-existing taxes (the "second best setting") are considered to capture any interactions between taxes (Bovenberg and Goulder 1996, Goulder et al 1999).

The rest of the paper is structured as follows: Section 2 briefly introduces the link between market instruments and cost effectiveness. Section 3 presents the model used, and Section 4 details the instruments to be analysed. Section 5 sets out the main results of our analysis, and Section 6 lists some limitations of the study, presents conclusions and suggests future directions for work.

2. Market Instruments and Cost-Effectiveness

One of the classical principles of environmental economics is the so-called “Pigovian tax”, under which the cost of pollution is incorporated into prices in accordance with the externality that it generates, thus bringing pollution down to efficient levels. CO2 also generates an externality, since its production produces future damage that agents do not consider in decision-making processes. These externalities are not easy to estimate, so when choosing between instruments rather than between objectives cost-efficiency is used as a criterion close to efficiency per se. An instrument is cost-effective when it is capable of bringing the cost of reducing emissions down to a target level, whether that level is efficient or not. This happens when the marginal cost of reducing emissions is the same for all agents and they all have to pay the same price for each additional unit that they emit (Baumol and Oates 1971). In these circumstances, each agent has an incentive to use the best mitigation options at his disposal (substitution of inputs, changes in patterns of consumption, capital investment to reduce emissions, downscaling of economic activity, etc) so that the marginal cost of reducing pollution by one additional unit is the same as the price of that unit.

Market instruments allow a price to be set on emissions, albeit through different channels. There are basically two types of market instrument: (1) negotiable emission permits; and (2) taxes or subsidies. Unlike regulatory of CAC instruments, both types are flexible in the way in which objectives are to be reached. In theory CAC instruments can also be cost-effective, but in practice this is more unlikely given the amount of information needed by the regulator.

Tradable emission permits are "quantity" instruments which limit the number of permits, thus creating a shortage and indirectly setting a price for emissions. Ideally, if the market were perfectly competitive and covered all agents and their emissions, there would be a single price and emission reduction would be cost-effective, since all mitigation options could be exploited. By contrast, the smaller the market is the higher costs tend to be. For example, the European Union Emission Trading Scheme (EU-ETS) currently covers Energy Intensive Industries (EII), but leaves out the mitigation options that exist in other sectors.

Taxes and subsidies are "price" instruments, which directly set the price of emissions. Here also, a tax could ideally be cost-effective provided that the object taxed is the actual externality. But in practice it is customary to tax events close to emissions rather than emissions themselves because of the diffuse, shifting nature of many sources and sectors (services, residential, transport). The bigger the gap between the object of taxation and the externality, the higher the cost of controlling pollution becomes. For example a tax on electricity can bring down emissions but clearly fails to make use of all the possibilities for mitigation that involve possible changes in the energy/technology mix.

3. The Model

To estimate mitigation costs we use an Applied General Equilibrium Model (AGE). AGEs are empirical versions of a Walrasian model which enable interdependencies between different economic agents to be taken into consideration (Shoven and Whalley 1992, Ginsburgh and Keyzer 1997). They are useful for analysing policies such as CO2 mitigation, which generate significant direct and indirect impacts.

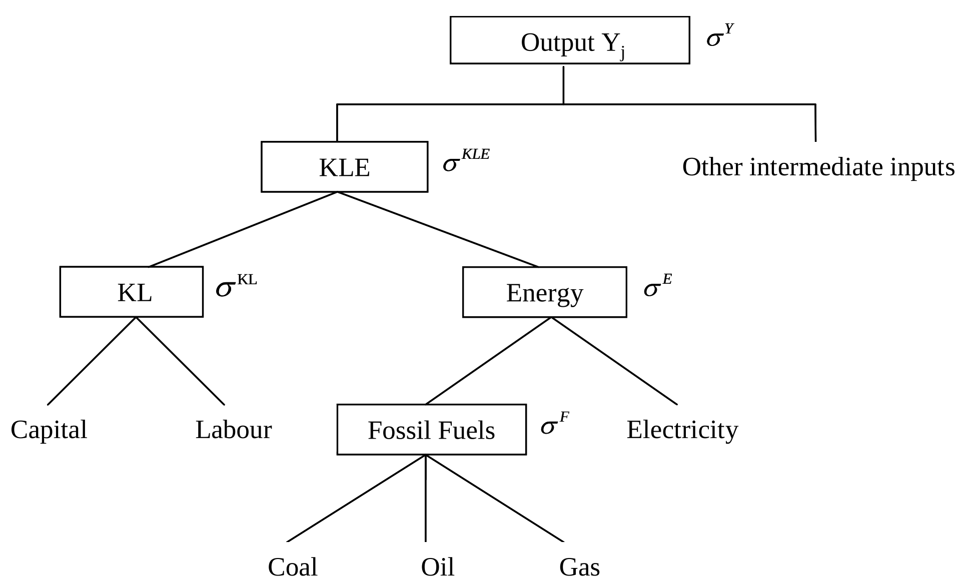
The model comprises (1) 22 production sectors; (2) a representative consumer; (3) a government which collects taxes, supplies goods and services and controls CO2 emissions through the different instruments proposed; and (4) the "Rest of the World", an aggregate that brings together the foreign sector. Production sectors are broken down into energy sectors (coal, oil, natural gas and electricity), major emitters (industry and transport) and other sectors with major economic weight (public and private services).

3.1. Producers

Each production sector $j=1,...J$ produces a homogenous good with a technology characterised by nested CES functions. The output of each sector (Y_j) is obtained by combining the intermediate inputs ($Y^{II}_{1,j}$), capital (K_j) and labour (L_j). Equation 1 shows a simplified form of this output function, and Figure 1 depicts its structure in graphic form. The sigma parameters (σ) of the function represent the elasticities of substitution between different inputs (see appendices).

$$Y_j = f\left(Y^{II}_{1,j},...,Y^{II}_{J,j};K_j;L_j:\sigma\right),\forall j \in (1,...,\mathrm{J})^{2} \quad (1)$$

Figure 1: Output function structure



[2] Equation 1 depicts these functions in a shortened form, via inputs and elasticities. For instance, a CES function for a case with two levels of nesting and two inputs takes the following form: on the first level: $Y = CES(X_1, X_2;\sigma) = (a_1 X_1^{\sigma-1/\sigma} + a_2 X_2^{\sigma-1/\sigma})^{\sigma/\sigma-1}$ and on the second level: $X_2 = CES(X_3, X_4;\psi) = (a_3 X_3^{\psi-1/\psi} + a_4 X_4^{\psi-1/\psi})^{\psi/\psi-1}$, where a_1, a_2, a_3, a_4 are parameters and σ, ψ represent the elasticities of substitutions between the inputs. By substituting X_2 in function Y we can envisage the length of the output functions proposed.

Producers maximise profit, subject to the technological constraints. At equilibrium, net profit after tax would be zero, i.e. the value of the output from each sector would be the same as the sum total value of the inputs. This condition is reflected in equation 2, where P_j is the price of the output from sector *j*, P_K is the price of capital and P_L is the price of labour. Finally, τ_j^K and τ_j^L are the sectoral tax rates on capital and labour.

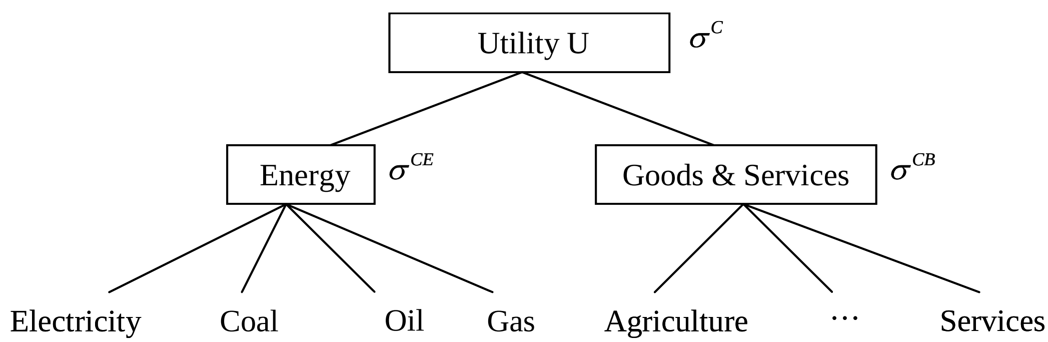
$$P_j \cdot Y_{jj,j}^{ID} + (P_K + \tau_j^K) \cdot K_j + (P_L + \tau_j^L) \cdot L_j = P_j \cdot Y_j \quad , \forall j \in (1, ..., \mathrm{J}) \qquad (2)$$

3.2. Consumers

The model considers a representative consumer, who owns the production factors. Consumer preferences are defined by a utility function from among the various consumer goods *j* ($C_{1,t}$) and their corresponding elasticities of substitution (see Eq. 3 and Figure 2).

$$U = CES(C_1, ..., C_J : \sigma) \qquad (3)$$

Figure 2: Utility function structure



The consumer maximises his total utility subject to his budgetary constraints. As shown in Equation 4, the income obtained from labour, capital and direct transfers from the government (T) is equal to consumption (C_j), tax payments associated with consumption (τ_j^C) and savings (S). The savings of the representative consumer (see Section 3.7) are what enable investments and the foreign trade deficit to be financed.

$$P_K \cdot K + P_L \cdot L + T = \sum_{j=1}^{J} (P_j + \tau_j^C) \cdot C_j + S \qquad (4)$$

3.3. The Government

The government obtains its income through taxes on capital, labour and consumption. That income enables it to provide public goods and services G_j and make direct transfers to consumers (T). The preferences of the government are modelled via a Leontief function that enables the structure of public spending to be considered as fixed (see Equation 5).

$$\bar{G} = Leontief\,(G_1,...,G_J) \tag{5}$$

$$\sum_{j=1}^{J}(\tau_j^L \cdot L_j + \tau_j^K \cdot L_j + \tau_j^C \cdot C_j) = \sum_{j=1}^{J} P_j \cdot \bar{G}_j + T \tag{6}$$

The additional income collected by the government from controls on CO2 emissions is transferred directly (T) to consumers, so that the level of public spending remains constant (see Equation 6).

3.4. The Foreign Sector

To reflect trade with surrounding areas, we group all other countries into a single aggregate item referred to as the "Rest of the World". Out of all the flows that exist, we consider imports and exports of goods and services.

Two assumptions habitually made in AGEs are used here. The first is the small economy assumption, which establishes that (a) the domestic economy is too small to influence world-wide prices; and (b) import and export requirements can be met by trade with the Rest of the World. The second is the Armington assumption, which assumes that domestic and imported/exported goods are imperfect substitutes (Armington 1969). In practice, this means modelling total supply (Y_j^{TS}) as a CES function (see Equation 7) which aggregates domestic output (Y_j) and imports (M_j); and total demand (Y_j^{TD}), equal to total supply, by means of a transformation function or CET function (see Equation 8), which breaks down that aggregate into domestic demand (Y_j^D) and exports (X_j).

$$Y_j^{TS} = CES\left(Y_j, M_j\right)\ ,\forall j \in (1,...,\mathrm{J}) \tag{7}$$

$$Y_j^{TD} = CET(Y_j^D, X_j)\ ,\forall j \in (1,...,\mathrm{J}) \tag{8}$$

Finally, as a "closure rule" (see Equation 9), we assume that the trade deficit (XD), i.e. imports minus total exports, is constant, with P_X being the adjustment variable.

$$\sum_{j=1}^{J} P_X (M_j - X_j) = \overline{XD} \quad (9)$$

3.5. CO2 Emissions

CO_2 emissions are calculated by using coefficients (α_e, λ_e) applied to consumption of coal, oil and natural gas. The representative consumer also generates emissions (heating, gasoline and diesel) so the total emissions (E) are the sum of the emissions from the production sectors $j\,(E^P)$ and those of the representative consumer (E^C)

$$E = E^P + E^C = \sum_{j=1}^{J} \sum_{e=1}^{3} \alpha_e \cdot Y_{e,j}^{ID} + \sum_{e=1}^{3} \lambda_e \cdot C_e \quad (10)$$

The potential for emission reduction is limited, because burning fossil fuels inevitably generates CO_2. However, in the context of this model, emissions can be reduced in an induced fashion (see Dellink 2005). When emissions are limited the relative prices of the factors vary, resulting in changes (i) in the energy mix, with CO2 intensive fossil fuels being replaced by less intensive fuels; (ii) in the output and utility functions, with energy use being replaced by other inputs; and (iii) in the economic structure, with patterns of consumption shifting towards low-carbon products and services. Finally, once all the possibilities of substitution have been exploited, the alternative that remains is to reduce the level of economic activity in some sectors.

3.6. Supply of Capital and Labour

The total supply of labour is considered to be exogenous and constant. It is also important to specify investment and capital flows: the level of investment in an economy depends on interest rates, on the capital stock and on depreciation. These points cannot be incorporated into a static context, so we assume that the initial capital stock is adjusted over the years of the simulation in line with the following condition: the price of investment (P_I) in equilibrium must be equal to the price of capital (P_K).In this way (cf. Hayashi 1982), investment decisions are at least consistent with the return required by capital.

3.7. Equilibrium and Solution

The conventional Walrasian concept of equilibrium is used: the quantities supplied are equal to the quantities demanded, prices act as adjustment variables and all agents comply with their optimisation plans. In our case, that means equilibrium in the goods and services markets (Equation 11), in the labour and capital markets (Equations 12 and 13) and between savings and investment (Equation 14)[3].

[3] In the case of instruments that use a tradeable emission permit market there is also equilibrium between the permits granted or offered by the government and those demanded by agents, achieved by setting a price for those permits.

$$Y_j^D = \sum_{jj=1}^{J}\left[Y_{j,jj}^{ID} + C_j + G_j + I_j + (M_j - X_j)\right], \forall j \in (1,...,\mathrm{J}) \tag{11}$$

$$\sum_{j=1}^{J} L_j = \overline{L} \tag{12}$$

$$\sum_{j=1}^{J} K_j = \overline{K} \tag{13}$$

$$S = \sum_{j=1}^{J} P_j \cdot I_j + \overline{XD} \tag{14}$$

Finding equilibrium solutions means resolving a system of non-linear equations. The model is programmed using GAMS/MPSGE language and resolved with the PATH algorithm (Dirkse and Ferris 1995).

3.8. Calibration and Data

The initial equilibrium data come from an SAM drawn up by integrating[4] the data from the Symmetric Input Output Table (INE 2002) and the data from sectoral energy balance sheets (Eurostat 2005). The integration of these two tables reveals the underlying energy flows in the IOT, so that CO2 emissions can then be calculated.[5] The reaction of agents to changes is reflected through elasticities of substitution (Babiker et al 2001, see appendices) and emissions are calculated via the standard coefficients[6] for coal, oil and natural gas.

4. Instruments Analysed

The instruments analysed are grouped into "quantity" and "price” instruments. In the case of quantity instruments a tradeable emission permit market is simulated (González and Dellink 2007). The government sets the number of permits for each period and allows them to be traded freely on the market. Permits are just one more production factor (linked directly to CO2 emissions) that reaches an equilibrium price - via supply and demand – that increases when their number decreases. For price instruments the simulation process is based on an iterative process in which taxes are increased gradually until the desired level of emission reductions is achieved.

[4] Energy data are integrated by introducing new rows into the IO Table for demand for energy goods (crude oil, coal, oil, natural gas and electricity) originating from the multiplication of the physical data and prices for energy balance sheets using the procedure described in Rutherford and Paltsev (2000).
[5] The database used to draw up the SAM is the symmetric IO Table of the INE (Spanish National Statistics Office), so the data are valued at basic prices. Tax on consumption includes VAT and the tax on labour includes social security contributions payable by workers. All remaining taxes are grouped under tax on capital.
[6] Eurostat (2005): tonnes of CO2 per Ktoe for coal (4.104), oil (2.851) and gas (2.187).

4.1. Quantity Instruments

i. **"Complete market":** this is the cost-effective instrument from the viewpoint of quantity instruments. It comprises a market for tradeable emission permits that extends to all agents (production sectors plus the representative consumer) and covers all emissions of CO2.

ii. **"EII market":** this comprises a tradeable emission permit market restricted to Energy Intensive Industries[7] (EII). These account for around 60% of total CO2 emissions and around 18% of output. This is an approximation of their extent under the EU-ETS.

iii. **"Industry market":** this covers all industries, not just EII. It accounts for 67% of emissions and 45% of output.

iv. **"Industry + transport market":** this comprises a tradeable emission permit market that includes industry and the transport sector, the latter being responsible for 8.5% of total emissions. It does not extend to emissions from the residential sector (15.4%), services (3.5%), agriculture (5.5%) or the extractive sector (0.5%).

v. **"Non-EII market":** this comprises an emission permit market that includes all sectors except EII. It covers 40% of emissions, 82% of output and 90% of final consumption.

4.2. Price Instruments

vi. **"CO_2 Tax":** this is the cost-effective instrument from the viewpoint of price instruments. It entails a tax on CO2 emissions and covers all agents (producers plus the representative consumer).

vii. **"Energy Tax":** this is a tax on consumption (intermediate and final) of coal, oil and gas. It does not take into account the different carbon contents of each fossil fuel, so the rate is the same for all three.

viii. **"Oil Tax":** this is a tax on consumption (intermediate and final) of oil, including gasoline and diesel used in the transport and residential sectors. Oil accounts for 65% of total CO2 emissions.

ix. **"Coal Tax":** this is a tax on consumption (intermediate and final) of coal. Coal is the most emission-intensive fossil fuel, accounting for 24% of total CO2 emissions.

x. **"Electricity Tax":** this is a tax on consumption (intermediate and final) of electricity. Although the consumption of electricity does not directly emit CO2, its production is fossil-fuel intensive, and accounts for 22.7% of total CO2 emissions. Electricity imports total just 1% of domestic total output, so the electricity produced is practically the same as that consumed.

5. Results

5.1. Analysis of Results

This section presents the results of the various emission reduction simulations. To analyse the performance of the instruments, identical reductions in CO2 emissions are simulated and compared. We

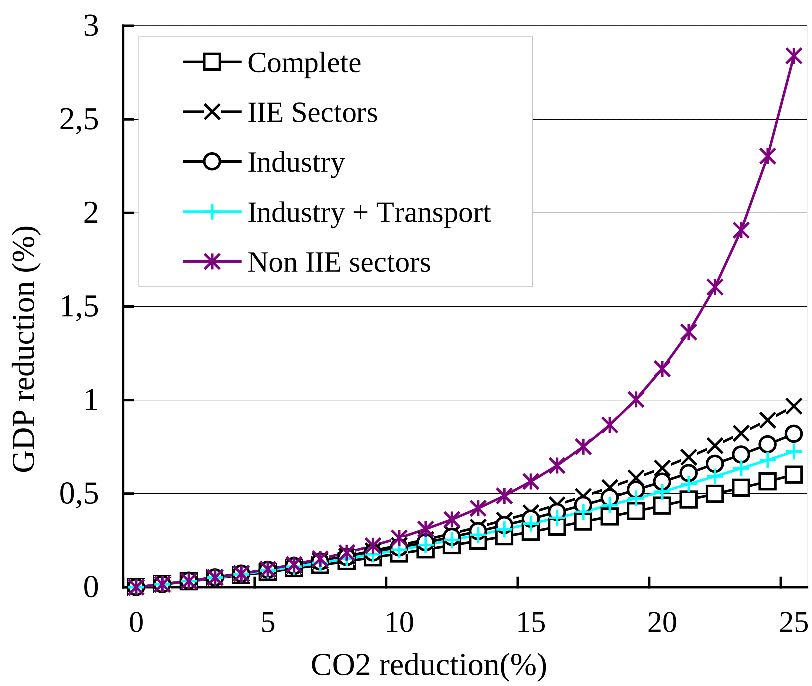
[7] These include the following industries (see Appendix): wood and paper, oil refining, chemicals, metal, electricity, natural gas and "other industries".

first analyse the macroeconomic effect of each instrument for the various CO2 reduction target levels, then compare them in terms of cost-effectiveness. Finally, we study the distribution of the impacts by sectors.

5.2. General Results: Quantity Instruments

Figure 3 shows the link between CO2 reduction and gross domestic product (GDP) for the various quantity instruments listed in Section 4. The main result shown in this figure is that reducing CO2 emissions has a cost in terms of GDP when compared to the option of emitting without constraints and without charge. Moreover, the (convex) form of this function indicates that those costs will increase disproportionately as the level of reductions increases and the best mitigation options are exhausted.

Figure 3: Mitigation costs for quantity instruments



The "complete market” instrument is the benchmark option, and as such it reveals the minimum cost of reducing CO2: a 25% cut in emissions means a 0.6% drop in GDP. The drop in GDP for the "EII market” instrument is 0.96%, though this policy covers the most energy-intensive industries its costs are higher because it leaves out many others. In general, mitigation costs tend to fall as the market, and with it the mitigation options, is extended. For instance, extending the market for emission permits to all industries ("industry market”) and to the transport sector ("industry + transport market”) brings costs down to 0.81% and 0.72% respectively.

The size or extent of the market for emission permits is a relevant variable, but it is also important to consider what sectors are included in the market. If it were decided to set up an emission permit market for non-energy-intensive industries *("Non-EII")*, the cost would rocket and the drop in GDP would be 2.84%, even though this market covers 80% of output and 40% of emissions. This is because the cheapest mitigation options, i.e. those which should be implemented first, would have to be ruled out. Moreover, the industries affected (mainly transport and services) have major indirect impacts which feed back into the general, negative effect on the economy as a whole. Selecting the right industries can therefore help reduce mitigation costs.

Table 1 shows the general results broken down according to different variables (general, sectoral and energy-related) for a CO2 reduction of 15%. As can be seen from the table, a 15% overall reduction in emissions requires a greater reduction in emissions from those sectors included in the emission permit market, i.e. those that actually cut their emissions. For example, emissions in the "EII market" (and therefore the number of emission trading permits granted in the market) would have to drop by 27.9% in order for overall emission levels to drop by 15%. For the "Non-EII" market the drop in permits/emissions would have to be 42.2%.

Table 1: Impact of 15% reduction in CO_2 with quantity instruments

	Complete	EII	Industry	Ind.+Trans.	Non-EII
General %)					
Utility	-0.22	-0.29	-0.26	-0.23	-0.52
GDP	-0.30	-0.40	-0.37	-0.34	-0.56
Private sector consumption	-0.19	-0.28	-0.25	-0.22	-0.51
Investment	-0.62	-0.83	-0.79	-0.74	-0.97
Sectoral % output)					
Agriculture	-0.59	-0.61	-0.62	-0.65	-1.63
Industry	-1.01	-1.07	-1.08	-1.07	-1.83
Transport	-0.57	-0.94	-0.89	-0.95	-0.17
Services	-0.18	-0.35	-0.32	-0.27	-0.34
Energy % consumption)					
Coal	-26.37	-37.14	-33.45	-30.02	-5.42
Oil	-10.07	-6.80	-7.62	-8.18	-15.71
Natural Gas	-5.34	-5.62	-6.30	-5.61	-10.35
Electricity	-3.03	-5.16	-4.58	-4.12	-3.41
Emissions %)					
Sectoral Emissions	-15.00	-27.90	-22.94	20.29	-42.23
Total Emissions	-15.00	-15.00	-15.00	-15.00	-15.00

The results show that utility, GDP, consumption and investment all fall, regardless of which instruments are used. Utility drops by 0.22% with the cost-effective instrument, and by between 0.23% and 0.52% with the others. Although utility is the best indicator of loss of welfare in this case, it must be stressed that the future benefits of mitigation policies are not taken into account.

The drop in GDP for a 15% reduction in CO2 emissions is between 0.30% and 0.56%. This reflects trends in consumption and investment, since public spending and the foreign trade deficit are constant. The fall in investment is due to a drop in the prices of the capital factor and of labour relative to energy prices (and CO2 permits). Lower returns or capital prices lead to a reduction in the flow of investment. On the other hand, although the drop in GDP is greater than that in utility it must be pointed out that in a static model it is not possible to reflect how future economic growth will be affected by lower levels of investment.

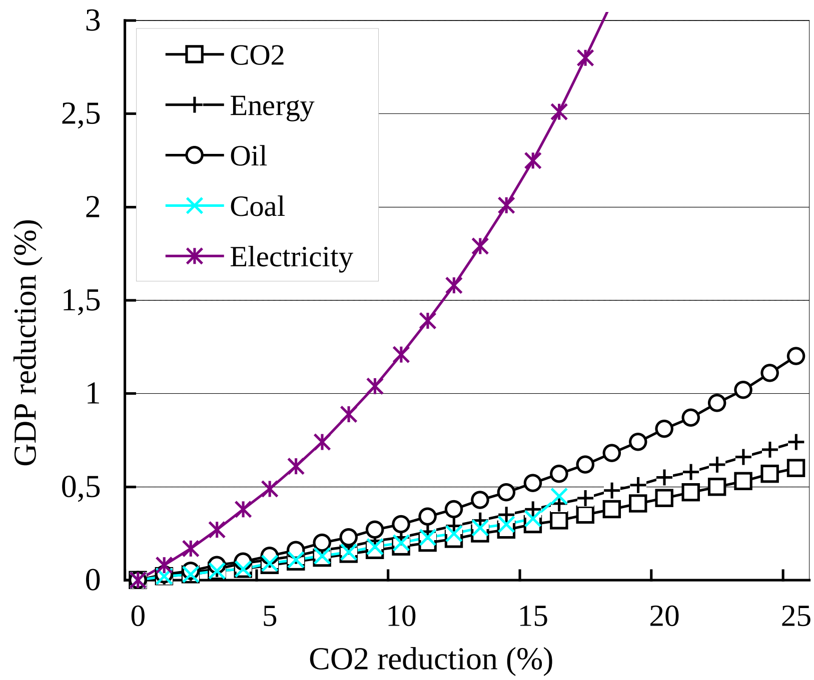
Table 1 also reveals effects on the economic structure, with the data aggregated under Agriculture, Industry, Transport and Services. The results show a shift towards the service sector in the economy for all instruments. That shift is most pronounced for the instruments with the biggest overall impact, because of the possibilities of substitution in the output and utility functions, which enable economic activity to be channelled towards less CO2 emission-intensive sectors. The service sector has a lower impact, and its economic weight is enormous (accounting for 65% of consumption and 45% of output), so the general reduction in the other macroeconomic variables is partly offset.

Another significant point of difference between instruments is their impact on energy consumption. The "complete market" instrument induces a change that is to some extent proportional to the carbon content of each fuel used for energy: coal consumption is reduced by 26.3%, oil by 10 per cent, gas by 5.3% and electricity by 3%. The further the various instruments are from this "optimum" variation in the energy mix, the more the cost of reduction increases. For example, coal consumption decreases by the substantial figure of 37.8% with the "EII" instrument, since it affects mainly heavier industries and the electricity industry, but the decrease in oil consumption is smaller (7.6%) because the instrument does not include the transport and residential sectors. The "industry + transport" instrument covers a broad emission permit market, but does not include gasoline and diesel consumption in the residential sector, so the consequent reduction in oil consumption (8.6%) is not optimum. The energy mix resulting from the "Non-EII" instrument shows why this policy is so expensive: the drop in the consumption of coal (the "dirtiest" fuel) is just 5.2%, and the brunt of achieving the emission reduction is shouldered by natural gas (10.3%), the cleanest fuel.

5.3. General Results: Price Instruments

Figure 4 shows the results for price instruments. These results can be interpreted similarly to those obtained for quantity instruments. In this case "CO2 Tax" is the cost-effective instrument, so the impact of CO2 reductions with this instrument is identical to that of the "complete market" instrument, because in both cases resources are finally allocated in such a way that the marginal cost of mitigation is the same for all agents or sectors.

Figure 4: Mitigation costs for price instruments



The greater the extent to which CO2 emission taxes are replaced by other, related taxes, the more the mitigation costs increase, because some opportunities for mitigation are not taken into account. For instance, a tax on coal is close to a tax on CO2, because coal is the most CO2-intensive fuel, but the consumption levels involved are not high (because the instrument does not consider oil or gas), so such a tax alone fails to achieve a reduction of more than 15%. A tax on oil consumption could greatly reduce CO2 emissions, but would raise the cost in terms of the fall in GDP to 1.2%. A tax on energy consumption could be a good option as the resulting reduction in GDP would be 0.74%, but the cost associated with a tax on electricity would be a massive 6.05%. This last measure is the most expensive of all those analysed, since it fails to take into account the role that low-carbon technologies can play in producing electricity.

Table 2 breaks down the results obtained for price instruments. To simulate these instruments, the tax introduced is increased until an overall CO2 reduction of 15% is achieved. For the "CO2 tax" instrument, utility falls by 0.22%, while for the other instruments the fall is between 0.29% (for the “energy tax") and 2% (for the "electricity tax"). The behaviour of the macroeconomic variables is similar, and is explained by the same factors as in the case of quantity instruments.

Table 2: Impact of 15% reduction in CO_2 with price instruments

	CO_2	Energy	Oil	Coal	Electricity
General %)					
Utility	-0.22	-0.29	-0.46	-0.42	-2.00
GDP	-0.30	-0.38	-0.52	-0.34	-2.25
Private sector consumption	-0.19	-0.21	-0.30	-0.41	-1.56
Investment	-0.62	-0.76	-0.92	-0.36	-4.03
Sectoral % output)					
Agriculture	-0.59	-0.76	-1.13	-0.18	-1.87
Industry	-1.01	-1.17	-1.42	-1.77	-4.53
Transport	-0.57	-0.87	-1.15	-0.19	-2.28
Services	-0.18	-0.29	-0.42	-0.18	-1.23
Energy % consumption)					
Coal	-26.37	-14.86	6.06	-73.84	-36.94
Oil	-10.07	-14.31	-25.01	2.91	0.74
Natural Gas	-5.34	-16.12	7.21	7.51	-8.24
Electricity	-3.03	-1.52	0.31	-8.42	-49.66
Emissions %)					
Total Emissions	-15.00	-15.00	-15.00	-15.00	-15.00

However, the effect of each tax can be observed very clearly through the energy mix. The CO2 tax also reduces consumption of each fuel by an amount proportional to its carbon content. By contrast, a tax on energy reduces consumption of all three fossil fuels by similar amounts (14.8% for coal, 14.3% for oil and 16.1% for natural gas) and also reduces electricity consumption, albeit by just 1.5%. The figures for the three fossil fuels are not exact, because each sector has its own energy mix and its own possibilities of substitution.

A tax on oil brings oil consumption down by a substantial 25% and transfers energy requirements so that there is an increase in other sources, particularly coal and gas (consumption of which increases by 6% and 7.2% respectively). This tax mainly affects industry, but is also felt by the transport and residential sectors. Indeed, with this tax overall activity in the transport sector drops by 1.15%, compared to 0.57% with a tax on CO2.

Taxing coal brings about a drastic 73.8% reduction in consumption. It is unlikely that CO2 can subsequently be reduced further by increasing this tax. To offset the reduction in coal consumption, there are increases of 2.9% in oil consumption and 7.5% in gas. Consumption of electricity -- the production sector most closely linked to coal consumption -- decreases. In this case the effect on the transport sector is negligible (0.19%), but the effect on industry is much greater at 1.77%.

The option that takes us furthest from the optimum energy mix is the tax on electricity. To reduce CO2 emissions by 15%, electricity consumption needs to fall by 49.6%. Consumption of coal drops by 36% and gas by 8.2%, while oil consumption increases by 0.7%. The reduction in electricity consumption mainly affects the service sector. A comparison of the "CO2 tax" and the "electricity tax" shows that the overall reduction in the service sector goes from 0.18 with the former to 1.23 with the latter (up 6.9 fold), while in industry it goes from 1.01 to 4.53 (up 4.4 fold).

Finally, if we consider quantity and price instruments together, each instrument can be compared with the cost-effective instrument in terms of its loss of utility. Table 3 shows this comparison for different levels of CO2 reduction. The ratios in the table show the quotients for the loss of utility with a cost-effective instrument divided by the loss of utility with each of the other instruments.

Table 3: Cost ratios re. cost-effective instrument for different CO2 reduction levels %)

	5%	10%	15%	20%	25%	30%
Quantity Instruments						
Complete market	1.00	1.00	1.00	1.00	1.00	1.00
EII market	1.12	1.23	1.35	1.48	1.65	1.86
Industry market	1.06	1.12	1.19	1.26	1.34	1.43
Industry + transport market	1.01	1.03	1.07	1.11	1.15	1.19
Non-EII market	1.20	1.71	2.40	3.54	6.29	7.09
Price instruments						
Tax on CO_2	1.00	1.00	1.00	1.00	1.00	1.00
Tax on energy	1.45	1.40	1.37	1.34	1.31	1.29
Tax on oil	1.93	2.03	2.15	2.31	2.52	2.86
Tax on coal	1.03	1.04	1.94	-	-	-
Tax on electricity	5.46	7.35	10.62	12.74	13.68	-

The "complete market" instrument and the "CO2 tax" instrument are cost-effective, so their ratio is always one to one. However, the "EII market" instrument can multiply costs by 1.84 fold, and the "non-EII market" instrument can increase them by up to 7-fold. Although the cost increase due to a tax on coal is low for small reductions in emissions, for a 15% reduction it would be 1.9 fold. A tax on oil could increase costs up to 2.8 times, and a tax on electricity could increase them by up to 13-fold for a 25% reduction in emissions. These results show the enormous differences in costs that can result even between one market instrument and another.

5.4. Sectoral Results: Price and Quantity Instruments

One of the advantages of AGEs is that they allow a sectoral analysis of each instrument to be conducted. This breakdown by sectors is important, because mitigation policies and the instruments through which they are implemented have both micro and macro impacts In an AGE model the inputs are exogenous, so sectoral changes can be understood as a shifting of resources from some sectors to others, which have become more profitable due to an exogenous shock. In general, sectoral impacts can be said to arise from a combination of effects on the supply side (where the most emission-intensive sectors suffer increases in their production costs) and on the demand side (where higher prices for more emission-intensive products cause their consumption to decrease). A number of indirect impacts extending across the whole inter-sectoral chain are also influential. As seen above, these effects take the form of changes in economic structure through which less CO2-intensive goods or services acquire greater economic weight. Finally, each instrument has specific effects on each sector, so it is hard to know before the fact how its impact will be distributed.

Table 4: Impact on sectoral output %) of 15% reduction in CO_2 with quantity instruments

	Complete	EII	Industry	Ind.+Trans.	Non-EII
Agriculture	-0.6	-0.6	-0.6	-0.6	-1.6
Coal mining	-27.6	-38.3	-34.6	-31.4	-7.7
Crude oil & gas extraction	-10.2	-5.3	- 6.2	-6.4	-21.5
Mineral extraction	-0.3	-0.2	-0.2	-0.3	-1.3
Foodstuffs industry	-0.5	-0.4	-0.5	-0.5	-1.6
Textiles & leather industry	-0.5	-0.5	-0.6	-0.6	-1.6
Wood & paper industry	-0.5	-0.6	-0.6	-0.5	-0.9
Oil refining industry	-10.1	-6.8	-7.6	-8.2	-15.9
Chemical industry	-0.5	-0.5	-0.6	-0.6	-1.5
Metal industry	-0.7	-0.6	-0.6	-0.7	-1.7
Machinery industry	-0.4	-0.5	-0.5	-0.5	-0.7
Other industries	-0.8	-0.4	-0.5	-0.7	-2.5
Electricity	-3.1	-5.2	-4.7	-4.2	-3.4
Natural gas	-5.2	-4.9	-6.6	-5.6	-11.7
Water distribution	-0.4	-0.5	-0.5	-0.5	-0.9
Construction	-0.5	-0.7	-0.7	-0.6	-0.8
Land transport	-0.7	-0.7	-0.7	-0.8	-1.6
Maritime transport	1.0	-4.5	-4.3	2.4	28.5
Air transport	-0.8	-1.7	-1.6	-0.6	1.6
Transport ancillary	-0.5	-0.7	-0.7	-0.5	-0.4
Commercial services	-0.3	-0.4	-0.3	-0.3	-0.6
Non commercial services	0.0	0.0	0.0	0.0	0.0

Tables 4 and 5 show the effects of the (quantity and price) market instruments considered here on output in all 22 sectors analysed, for a 15% reduction in total CO2 emissions. In general, the industries most affected are those most closely related to energy: coal mining, crude oil extraction, oil refining, natural gas and electricity. This is because of the increase in the relative prices of fossil fuels, substitution by other inputs and changes in the energy mix, as examined above. In general the impact is less pronounced in the electricity industry, since electricity production is more flexible in terms of its potential for substituting inputs. An exception to this assertion arises in the case of a tax on electricity: taxes on coal, oil and energy are felt mainly by industry, while a tax on electricity mainly affects the service sector (with transport ancillary services down by 1.9%, commercial services by 1.5% and non commercial services by 0.1%).

When the sectoral impact of each instrument is considered, the analysis becomes more diverse and more complex. For instance, in quantity instruments it can be observed that the sectoral impacts of the "EII market" and "industry market" instruments are similar to those of the "complete market" instrument. However, the impact of the "non-EII market" instrument is appreciably greater, especially for the service and transport sectors.

The oil refining industry provides a good example of the importance for each sector of choosing the right instruments and considering indirect impacts. The output of the oil refining industry (see Table 4) decreases by 6.8% with the "EII market" instrument and by 15.9% with the "non-EII market" instrument. The former is an emission permit market that includes the refining industry, but the latter does not include it, so there is no direct mitigation effort.

Table 5: Impact on sectoral output %) of 15% reduction in CO_2 with price instruments

	CO_2	Energy	Oil	Coal	Electricity
Agriculture	-0.6	-0.8	-1.1	-0.2	-1.9
Coal mining	-27.6	-16.9	2.2	-73.8	-38.9
Crude oil & gas extraction	-10.2	-13.8	-23.1	1.8	-0.6
Mineral extraction	-0.3	-0.3	-0.3	-0.4	-3.6
Foodstuffs industry	-0.5	-0.5	-0.8	-0.3	-1.9
Textiles & leather industry	-0.5	-0.7	-1.0	-0.2	-2.1
Wood & paper industry	-0.5	-0.6	-0.7	-0.4	-2.2
Oil refining industry	-10.1	-14.4	-25.1	3.0	1.3
Chemical industry	-0.5	-0.6	-0.8	-0.4	-2.2
Metal industry	-0.7	-0.9	-1.2	-0.1	-3.3
Machinery industry	-0.4	-0.4	-0.5	-0.5	-3.1
Other industries	-0.8	-1.1	-1.6	0.3	-2.3
Electricity	-3.1	-1.5	0.3	-8.6	-49.7
Natural gas	-5.2	-15.5	8.2	6.9	-9.1
Water distribution	-0.4	-0.4	-0.4	-0.6	-4.9
Construction	-0.5	-0.6	-0.8	-0.3	-3.4
Land transport	-0.7	-0.9	-1.3	-0.2	-2.2
Maritime transport	1.0	-1.3	-0.3	0.7	-7.3
Air transport	-0.8	-1.5	-1.9	0.1	-3.3
Transport ancillary	-0.5	-0.7	-1.0	-0.2	-1.9
Commercial services	-0.3	-0.3	-0.4	-0.2	-1.5
Non commercial services	0.0	0.0	0.0	0.0	-0.1

The performance of the transport sector also requires an explanation. For instance, in the case of the "industry + transport market" instrument, all sectors included in the market should, a priori, bear the costs of mitigation to a greater or lesser extent. However the maritime transport industry, which accounts for only a small part of the overall transport sector, ends up indirectly increasing its activities (see Tables 4 and 5). This industry is more CO2 emission-intensive than others, but less so than its nearest substitutes – land and air transport -, which results in its carrying a large proportion of the passenger and freight traffic handled by the sector. This is another good example of the importance of considering indirect impacts of mitigation instruments and policies.

6. Conclusions

Climate change policies can be expected to have a significant effect on economic activity, and choosing the right instruments can help minimise mitigation costs. This study sets out to analyse CO2 mitigation costs for different types of market instrument, broken down into (1) "quantity instruments", which represent different sectors included in an emission permit market; and (2) "price instruments", which represent different taxes on CO2, energy, coal, oil and electricity. To that end we use an applied general equilibrium (AGE) model for Spain.

To put our results in perspective we must first clarify the main characteristics and limitations of our analysis. In the first place, the model is based on perfectly competitive markets and perfectly mobile factors between sectors. Secondly, it considers only the "pure" (direct and indirect) costs of mitigation, which reflect the possibilities for substitution of inputs, and does not include other costs, e.g. transaction and enforcement costs (Heyes 2000). Thirdly, the instruments are analysed on the basis of cost-effectiveness, although other criteria exist, such as equity, political feasibility, the need for information, incentives for innovation, etc. which are also important, and between which there may sometimes be a trade-off. Finally, we do not consider the possibility of obtaining a double dividend by including these instruments in an environmental tax reform (Patuelli et al 2000).

The main conclusion of our study is that mitigation costs can vary considerably from one instrument to another, and increase disproportionately as targets become tougher. Our simulations show that with the market instruments analysed substantial CO2 reductions of up to 30% can be achieved, but CO2 mitigation costs may be up to 13 times higher than with a cost-effective instrument.

The analysis conducted shows how important it is to choose the right sectors for inclusion in an emission trading market. In general, the more sectors there are in the market, the lower mitigation costs will be. However, the wrong choice (the inclusion of industries which are diffuse or are not energy/emission-intensive) can result in costs being substantially higher. Similarly, choosing the right taxes to reduce CO2 is also fundamental. For instance a tax on electricity would give rise to enormous mitigation costs.

For CO2 mitigation one possible solution is to set up a market for emission permits (similar to the EU-ETS) for energy-intensive industries and a tax on CO_2 for the transport and residential sectors. Given the difficulty of monitoring and taxing CO2 in diffuse sectors, it would also be possible to follow Eskeland and Devarajan (1995), who suggest setting a tax on gasoline and diesel and technologically regulating the number of grams of CO2 permitted per km travelled by motor vehicles. A reasonable solution for controlling climate change and for environmental policies in general is probably to use a mixture of the different types of instrument.

Appendices

Indices

Label	*Entries*	*Description*
j, jj	1,...,J	Sectors, Intermediate Inputs or Goods
e	Coal, Oil, Gas	Fossil Fuels

Parameter

Label	*Description*
τ_j^L	Tax rate on labour, sector j
τ_j^P	Tax rate on capital , sector j
τ_j^C	Tax rate on consumption, good j
T	Transfers between consumers and government
α_e	CO_2 emission coefficients for fuel and for producers
γ_e	CO_2 emission coefficients for fuel and for a representative consumer
σ	Elasticity of substitution between inputs

Variables

Nombre	*Descripción*
Y_j	Output of sector j
$Y_{j,jj}^{ID}$	Intermediate demand for input jj in sector j
Y_j^D	Domestic demand for good j
Y_j^{TS}	Total supply of good j

Y_j^{TD}	Total demand for good j
M_j	Imports of good j
X_j	Exports of good j
K_j	Demand for capital of sector j
L_j	Demand for labour of sector j
U	Utility of representative consumer
C_j	Private consumption of good j
G_j	Public consumption of good j
S	Savings
I_j	Investment in sector j
P_j	Equilibrium market price of good j
P_K	Equilibrium market price of capital
P_L	Equilibrium market price of wages
P_X	Equilibrium real exchange rate price of foreign goods)
P_I	Equilibrium market price of investment
E^P	CO_2 emissions by producers
E^C	CO_2 emissions by representative consumer
E	Total CO_2 emissions

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