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Wide and Narrow Approaches in Climate Change Policies: The Case of Spain*

by

Xavier Labandeira**

Miguel Rodríguez**

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** FEDEA and rede,Universidade de Vigo. Xavier Labandeira, FEDEA, Jorge Juan 46, 28001 Madrid (Spain), Tlp: +34 914350401 email: xlabandeira@fedea.es; url: http://webs.uvigo.es/xavier

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Summary

This paper deals with the effects of emissions trading, a standard economic instrument to control greenhouse gas emissions, in a particular country. After distributing the Kyoto-mandated allocation among member states, the European Commission introduced a rather conventional emissions trading scheme in 2005. The extent of application of the market is limited, with only certain sectors being subject to it (mostly industries), and tradable permits are freely allocated. Both facts have important consequences in efficiency and distributional terms, also raising (normative) concerns on the actual and desirable regulatory approximation. The paper mainly focuses on the (positive) efficiency and distributional effects of the EU emissions trading system, with the use of a static general equilibrium model for the Spanish economy, also incorporating some hypothetical simulations (broader scope of the market, carbon taxation). The results indicate that the narrow scope of the EU emission trading market generates efficiency costs and relevant distributional effects.

JEL Codes: D58, L60, Q21

Keywords: markets, global warming, regulation, efficiency, distribution

1. Introduction

Global warming, mainly caused by human emissions of CO_2 (carbon dioxide), is now considered a most pressing environmental problem. Given the global nature of climate change causes and consequences, international coordination is necessary and so the Kyoto Protocol can be interpreted as a first step in this sense. Accepted by the European Commission (EC) in 2002, the Kyoto Protocol-mandated reduction in greenhouse gas emissions (GHG) from the European Union (EU) (8% in 2010-2012 with respect to 1990) was distributed among member states through the so-called burden sharing agreement. Subsequently, in a move to guarantee a cost-effective compliance of those reductions, the EC designed a market scheme for GHG trading (Directive 2003/87/CE) that came into force in 2005.

The EU emissions trading system for greenhouse gases (EUETS) is rather conventional. On the one hand, only certain sectors are subject to it (electric generation, refinement of petroleum, iron and steel, cement, lime, glass, ceramics, brick and tile, paper and paper pulp), representing about 40% of total EU CO_2 emissions. This raises efficiency and equity concerns because cost-effectiveness of any environmental regulation requests a full coverage of emitters if non-subject sectors present low abatement costs and, of course, because any unequal treatment of sectors generates distributional consequences. However, a market limited to main emitters is appealing because it reduces administrative and compliance costs. Furthermore, the presence of a limited number of sectors could also reduce lobbying activities and ease the regulatory path (see e.g. Bovenberg et al. 2005).

Moreover, the EUETS involves grandfathered pollution permits despite the empirical evidence on the superiority of auctioning with revenue recycling in distortionary taxes (e.g. Parry et al. 1999; Fullerton and Metcalf 2001). This is probably explained by the difficulties faced by the EC to get its carbon tax proposals accepted by all member states during the nineties (due to the unanimity rule in fiscal matters). Among other things, this probably responded to industrial pressures to avoid a loss of competitiveness due to increasing (environmental tax) costs, in contrast with the much milder situation with grandfathering of pollution permits.

The EUETS is largely implemented through the National Allocation Plans (NAP), proposed by national EU governments to the EC for approval, which basically set the strategy (combination of measures and instruments) to achieve the burden sharing agreement and include the specific allocation of permits to emitters. There are two phases in the application of the EUETS: the test period (2005-2007), and the compliance period (2008-2012) where environmental objectives must be attained.

This paper is mainly interested in calculating the efficiency and distributional effects associated with the actual application of the EUETS in a particular country, also considering different alternatives within that scheme. We take Spain as a case study for two reasons: the scarce empirical evidence available so far, and the possibility of examining a polar case where large emission reductions will be needed to comply with the mandated objectives. Obviously this will make the efficiency and distributional effects even wider, and will request complementary policies in the sense already indicated by other papers (e.g. McKibbin and Wilcoxen, 1997; Pizer, 2001).

At the time of writing this paper, Spain has increased its 1990 CO_2 emissions by about 50%, far above the 15% rise required by the EU burden sharing agreement. This has mainly to do with the strong path of economic and population (due to immigration) growth seen by Spain since the mid-nineties and with the absence of consistent energy and environmental policies that could improve matters. Therefore, even with the intense use of (project-based) Kyoto flexible mechanisms as contemplated by the current NAP, Spain faces a large reduction of its GHG emissions that explains our interest in this issue.

Despite taking Spain as a case study, the qualitative results are general enough as to be applied to other countries because our main objective is to analyze the effects from the application of a binding emissions reduction with flexible mechanisms (as the EUETS). Moreover, this study should be seen as a contribution to the large and growing literature on the EUETS and burden-sharing agreement [e.g. Böhringer et al. (2005) or Kallbekken (2005)].

The method we employ to calculate the efficiency and distributional effects from the application of the EUETS is a static applied general equilibrium (AGE) model for the Spanish economy. The consumption of energy goods by industries and institutions is broken down as much as possible from national account data, so the model allows agents to substitute between goods and thus increases the reliability of results. In addition, the model simulates the CO_2 emissions associated with the consumption of fossil fuels and incorporates a national market for CO_2.

After calibrating the model, we consider a number of simulations. First, the real market as established by the current Spanish NAP. In this case, the overall effects on the Spanish economy are not important, but the specific effects on the industries subject to the scheme are indeed relevant. A second simulation includes all sectors and, as expected, there are some efficiency gains and the distributional picture is also modified. The final simulation compares the second scenario with a hypothetical policy where permits are auctioned in a way that resembles a carbon tax. In this case, the efficiency costs for the Spanish economy, and for most sectors, are higher.

This article is structured in four sections, including this introduction. In section 2 we contemplate the method, with a description of the theoretical model and its empirical implementation. Section 3 discusses the above-mentioned simulations and presents the efficiency and distributional effects with the use of the model. Finally, section 4 covers the main conclusions and some policy implications.

2. Methodology

2.1 The Applied General Equilibrium Model

To evaluate the efficiency and distributional effects of environmental and energy policies, we use a multi-sectoral static AGE model for an open and small economy such as Spain. This type of model allows a greater breakdown of institutions and sectors, which is essential to take into account the heterogeneity of energy consumption between sectors and to increase the reliability of results (see e.g. Repetto and Austin, 1997; Hawellek et al., 2003). Our model is also good for the analysis of environmental and (efficiency and distributional) economic effects, being close to the procedure followed by Böhringer et al. (1997), Faehn and Holmoy (2003) and Rutherford and Paltsev (2000), among others.

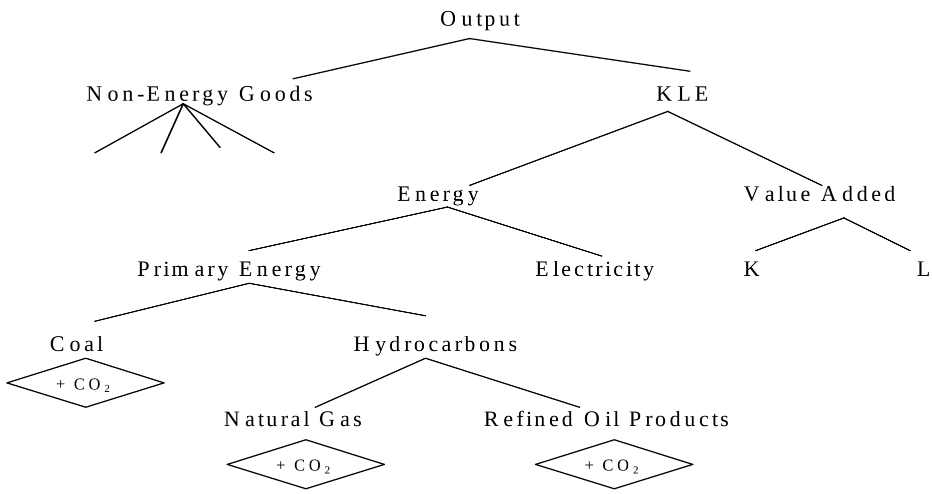
Following Spanish national accounts, there are five institutions in the economy as established by the new European system of accounts (ESA-95): a representative household, the public sector, the foreign sector, non-profit household-serving institutions (NPHSIs)[1] and corporations. In general, they receive capital income, carry out net transfers with other agents and save to balance their budget. Capital endowments and transfers are exogenously determined.

There are 17 productive sectors in the economy and therefore the same number of commodities. Each activity is modeled through a representative firm that minimizes costs subject to null benefits in the equilibrium, as we assume perfect competition and constant returns to scale. The production function is a succession of nested constant elasticity of substitution (CES) functions, as

[1] NPISHs consist of non-profit institutions that are not predominantly financed and controlled by the government (e.g. professional associations, charities, etc.).

illustrated in Figure 1[2]. The energy goods are taken out from the set of intermediate inputs and are included in a lower nest within the production function, thus allowing for more flexibility and substitution possibilities. Therefore, our AGE incorporates the different services provided by energies (intermediate inputs for production of electricity; lighting, heating, transport services for firms and institutions, etc.) and differences in CO_2 emission factors.

Figure 1. Production technology structure chain



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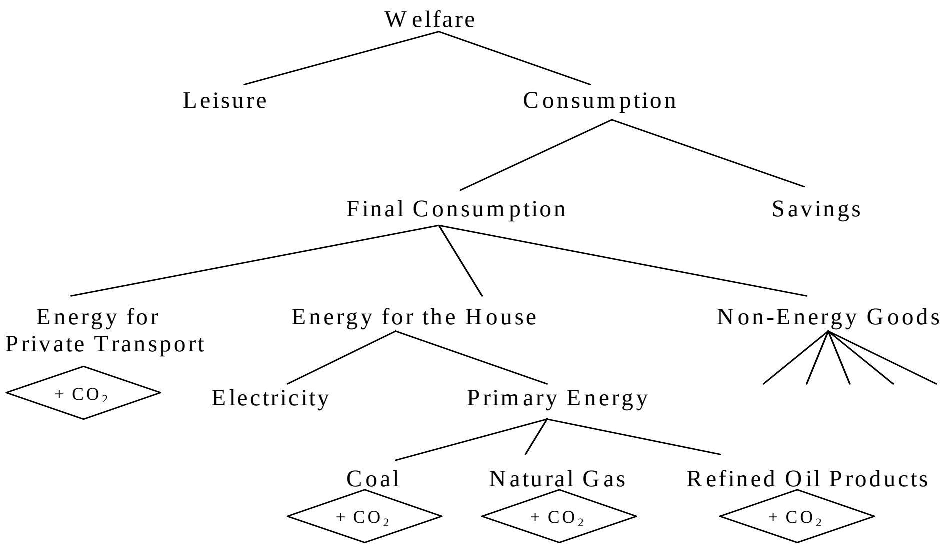
We follow the Armington approach to model the international trade of goods as usual in the literature (Shoven and Whalley, 1992): imported products are imperfect substitutes for national production. Maximization of benefits by each sector, determined via a constant elasticity of transformation (CET) function, allocates the supply of goods and services between the export market and domestic consumption. Since the Spanish economy is small and most commodity trade is made with countries in the European Monetary Union, the exchange rate is fixed (i.e. the simulated policy is assumed to have no significant impact on the exchange rate) and all agents face exogenous world prices. Capital supply is inelastic (exogenously distributed between institutions), perfectly mobile between sectors but immobile internationally. Labor supply by households to maximize utility is also perfectly mobile between sectors but immobile internationally. The model assumes a competitive labor market and thus an economy without involuntary unemployment.

The representative household has a fixed endowment of time, which is allocated between leisure and labor, and maximizes utility, which is a function

[2] The Appendix contains a detailed description of sectors and elasticities of substitution.

of leisure and of a composite good made up by goods and savings, subject to the budget constraint. As in Böhringer and Rutherford (1997) we assume that consumers have a constant marginal propensity to save, which is a function of disposable income[3]. Household consumption of goods and services is defined by a nested CES function, as shown in Figure 2, with special attention being paid to the consumption of energy goods. An important contribution of the AGE model is the distinction between energy for the house, energy for private transport and other energy products (a composite good via a Cobb-Douglas function).

Figure 2. Chained household consumption function structure



Source: The authors

The public sector collects direct taxes (income taxes from households, and labor taxes from households and sectors) and indirect taxes (from production and consumption). Consumption of goods and services by the government is determined by a Cobb-Douglas function and the public deficit is an exogenous variable. In consequence, total public expenditure, capital income and tax receipts are balanced to satisfy the budget restriction.

In fact, the AGE model represents a structural model based on the Walrasian concept of equilibrium. Therefore, for each simulated policy, the model must find a set of prices and quantities to clear up all markets (capital[4], labor and commodities). Total savings in the economy are defined endogenously, being equal to the sum of savings by each institution. The macroeconomic equilibrium of the model is determined by the exogenous

[3] Disposable income is the sum of transfers, capital and labor income net of social contributions (labor taxes), minus income taxes.
[4] There is no quantity adjustment in total supply of capital in the economy, only between sectors, because capital endowment is an exogenous variable. The equilibrium condition is attained through changes in the price of capital services.

financing capacity/need of the economy with the foreign sector, i.e. the difference between national savings, public deficit and investment[5]. International prices, transfers between the foreign sector and other institutions, and the consumption of goods and services in Spain by foreigners are exogenous variables. Consequently, exports and imports have to be balanced to satisfy the restriction of the foreign sector.

Regarding the environmental side, the model simulates energy-specific CO_2 emissions generated during combustion of fossil fuels by different sectors and institutions[6]. This is done through the technological relationship between the consumption of fossil fuels in physical units and emissions (θ_C, θ_R and θ_G respectively for coal, refined oil products and natural gas). For example, CO_2 emissions from sector i are calculated as

$$CO2_i = \theta_{Ci} \cdot COAL_i + \theta_{Ri} \cdot REF_i + \theta_{Gi} \cdot GAS_i \qquad (1)$$

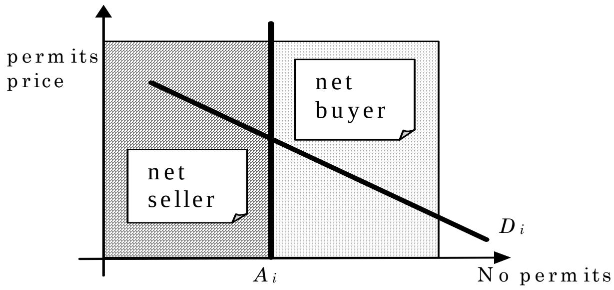
where $COAL_i$, REF_i and GAS_i stands for coal, refined oil products and natural gas consumed by sector i.

The model obviously incorporates a competitive market for pollution permits. The supply curve is the constant quantity of permits issued by the government and freely distributed across sectors. Thus we assume that the total amount of permits owned by each sector A_i is supplied to the market, as shown in Figure 3. The sum of individual demands from each sector at each price, D_i, conforms the aggregated demand curve of permits, where the equilibrium and clearing price of the market are determined by the intersection of aggregated demand and supply curves. In the benchmark scenario (without environmental constraints) the government allocates as many permits as the amount of emissions by each sector and therefore permit price is zero.

We assume that firms simultaneously maximize their returns from the market for permits and production activities. The latter is constrained by the consumption of fossil fuels and permits (the sum of CO_2 emissions from the combustion of each fossil fuel) as observed in Figure 1. As a consequence, each sector becomes a net seller (buyer) of permits if its demand at equilibrium prices is smaller (greater) than its endowment of permits, as depicted by Figure 3.

[5] National investment is a composite good through a Leontief function that incorporates the commodities used in gross capital formation.
[6] Other greenhouse gases are not contemplated. Moreover, non-energy related CO_2 emissions (e.g. in cement or chemical production) are not considered as they only represent 7% of total Spanish emissions (INE, 2002a).

Figure 3. Individual demand and supply of pollution permits by each sector



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2.2. Data and Calibration

The model database is a national accounting matrix for the Spanish economy (NAM-95), calculated from the national accounts for 1995[7]. Furthermore, we have extended the database with environmental data from different statistical sources (INE, 2002a; IEA, 1998) relating consumption of different fossil fuels and emissions for each sector and institution. Based on the information obtained from the NAM-95, the parameters of the model can be obtained through calibration: tax rates or technical coefficients for production, consumption and utility functions. The criterion to calibrate the model is that it replicates the information contained in the NAM-95 as an optimum equilibrium, which will be used as benchmark[8].

Certain parameters, such as the elasticities of substitution, have not been calibrated but taken from the literature[9]. An important parameter in the model is the wage elasticity of the labor supply, assumed to be -0.4 following Labeaga and Sanz (2001). In this sense, we have followed the procedure used in Ballard et al. (1985) assuming, as in Parry et al. (1999), that leisure represents a third of the working hours effectively carried out in an initial equilibrium situation. We performed a sensitivity analysis, increasing and reducing the labor elasticity by 50%, concluding that the results from the AGE are robust.

The database contains only monetary values from the national accounts, and therefore we cannot distinguish between prices and quantities. In this context and as usual in the literature, we follow the Harberger convention to calibrate the model at the benchmark. As a result, all prices for goods and factors and activity levels are set equal to one, whereas the amounts of

[7] The matrix is based on a NAM published by Fernández and Manrique (2004) and the National Accounts (INE, 2002b).
[8] For more on this procedure, see Shoven and Whalley (1992).
[9] See the Appendix for a detailed description of the substitution elasticities.

consumption and production are set equal to the monetary values in the database. Following this procedure, we can analyze the effects of simulated policies as relative changes in prices and activity levels with respect to the benchmark. The AGE model was programmed in GAMS/MPSGE and calibrated following the procedure in Rutherford (1999) by using the solver-algorithm PATH.

3. Effects of the EUETS in Spain

3.1. Simulated Policies

In early 2007 Spanish CO_2 emissions were approximately 47% higher than those of 1990 (after a peak in 2005), and without further action the government considers that the figure would be between 50% and 55% by the end of the compliance period. Therefore, the current Spanish NAP establishes the need of internal reductions of 16% towards 2012: the difference from the estimated increase of emissions and the sum of the burden sharing agreement allocation to Spain (15%), the estimated absorption of internal reforestation projects (-2%) and the use of other flexible (project-based) mechanisms of the Kyoto Protocol (-20%)[10]. Thus, the size of the requested emission reductions of the current NAP is high enough to define Spain as an interesting example of an intense and rather quick climate change policy, with a clear outcome in terms of large efficiency and distributional effects.

The simulations are performed assuming an isolated Spanish market which, given the size of the requested reductions when compared to other countries in the EUETS, will definitely produce a higher permit price and thus bigger distributional and efficiency effects (so they should be taken as upper estimates). In particular, the number of permits issued by the government in all scenarios is an endogenous variable to comply with the above-mentioned emissions constraint. Moreover, the simulations assume that there are no complementary environmental policies applied to non-subject sectors (e.g. supplementary command and control regulations, taxes, etc.), as is the case in Spain so far (see also note 10).

The first simulation is the so-called ***real market***, which involves the grandfathered allocation of permits as included in the Spanish NAP[11]. A second simulation extends the application of the emissions trading Directive to all sectors in the economy, only keeping households outside the market,

[10] This is designed, following the Spanish NAP, to offset the expected increase in GHG emissions from non-EUETS sectors.
[11] We do not incorporate paper and pulp due to lack of data. However, this should not have a significant impact in the results, as CO_2 emissions by this sector are of scarce importance (1.35% of total emissions).

resembling a ***wide market***. The third scenario is similar to the preceding, but assuming the auction of all permits by the government. Such an ***auctioned market*** obviously brings about public receipts, which are assumed to be returned to households in a lump-sum fashion.

The primary purpose of the second scenario is to analyze the efficiency costs of the narrow nature of the EUETS. This is clearly of interest when there are a great number of mobile and non-mobile emitters (e.g. road transport, small firms, agriculture, etc.) that are not subject to the scheme, representing a big portion of total emissions[12] and probably including emitters with low abatement costs. Another reason for this scenario is to compare the distributional profiles of different policies that are nevertheless designed to attain the same environmental objective. Yet given the difficulties in extending the market to all agents, with large administrative (regulatory) costs related to monitoring and control and high compliance (private) costs for small agents, the wide market simulation could be interpreted as the introduction of (cost-effective) complementary policies on sectors that are not subject to the European Directive.

The third scenario approximates, under some conditions, the differential effects brought about by a wide application of a carbon tax. Lump-sum transfers to households of the auction (tax) receipts are designed to keep public expenditure constant in real terms, ensuring that the only efficiency distortions are created by the pollution market[13]. Of course, as indicated before, receipts could be used in an efficiency-enhancing fashion through a reduction of distortionary taxes that conforms a green tax reform (see e.g. Bovenberg and Goulder, 2002). However, this option is beyond the scope and interest of the paper, with the results of a hypothetical green tax reform in Spain already contemplated elsewhere (Labandeira, Labeaga and Rodriguez, 2004).

3.2. Results

3.2.1. Real Market

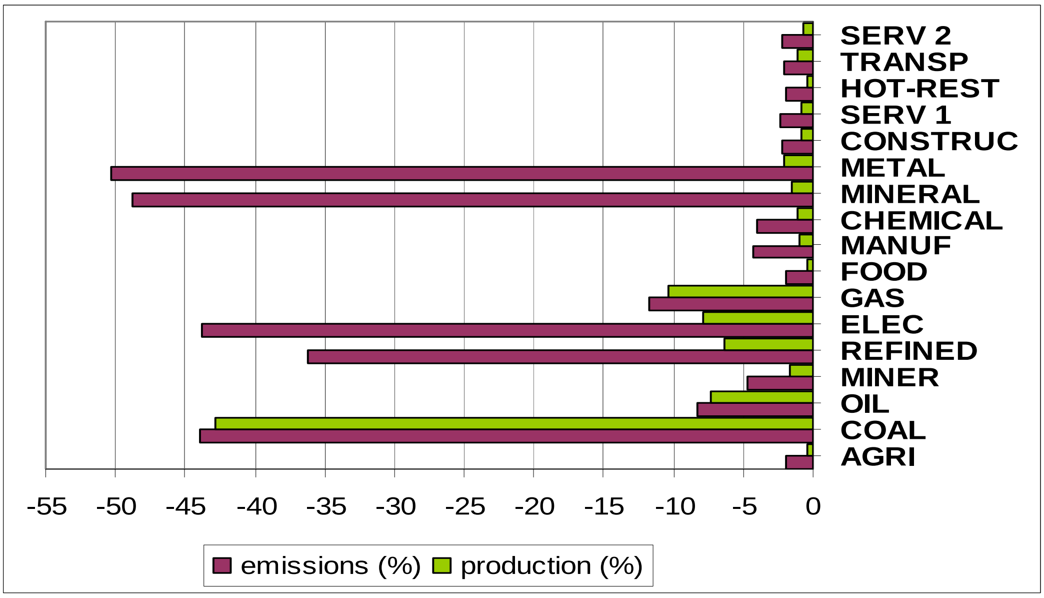
In this first simulation the number of permits issued by the government to subject sectors should lead to a reduction of their unregulated emissions (benchmark) of 44.5%. This implies a concentration of efforts in a small number of emitters to reach the 16% reduction in emissions to comply with the burden sharing agreement. Given the free allocation of permits, there are no significant effects on the remuneration of labor and capital (in real terms) or on

[12] Indeed more than 50% in all EU countries. In the case of Spain the transport sector alone causes approximately 25% of total CO_2 emissions, showing a 60% increase between 2002 and 1990.
[13] We also considered the effects of a full increase of public expenditure with the auction receipts, observing very limited differences with respect to the case of lump-sum transfers.

the labor supply by households. Indeed, gross domestic product (GDP) only decreases 0.7% and prices also show a slight increase (0.2%). As a consequence, welfare losses (measured as equivalent variations with respect to the benchmark level) are also limited to 0.3%, which has to do with the fact that household energy expenditure represents on average less than 10% of total expenditure. In sum, the overall economic effect of the real market (or real NAP) is rather limited.

However, this is not the case when the analysis focuses on specific sectors, as shown by Figure 4. The most significant effects on production and emissions obviously take place in the sectors that participate in the market and in all remaining energy sectors. Refined oil products (*REFINED*) and the electricity sector (*ELEC*) become net buyers of permits, with reductions in emissions of respectively 36% and 44%, whereas the metal products sector (*METAL*) and mineral products (*MINERAL*) are net sellers with a decrease in emissions of respectively 50% and 49%. Moreover, it is interesting to note that energy sectors such as coal (*COAL*) and natural gas (*GAS*) experience an important decrease in their emissions (44% and 12%, respectively). Finally, there are also significant effects on carbon emissions by the remaining sectors which, on average, reduce their emissions by 2.6%.

Figure 4. Sectoral effects on production and emissions in *real market*



Source: The authors

Regarding the sectoral effects on activity, they are clearly relevant for energy industries. In this sense, the coal sector accounts for the biggest contraction in production (43%), but there are also important activity losses in natural gas (10%), electricity (8%) and refined oil products (6.4%). Actually, the high indirect taxes on refined oil products at the benchmark reduce the impact of the price of permits on production costs and thus on activity levels. Moreover, thermal power utilities (coal, fuel oil, gas) directly subject to carbon pricing only represent 40% of the total capacity of electricity generation in Spain and so electricity becomes relatively cheaper with respect to fossil fuels. This encourages non-carbon electricity consumption[14] through substitution of natural gas. There is also a significant reduction in the activity of *METAL* and *MINERAL* sectors, around 2%, whereas the remaining non-energy and non-Directive sectors experience limited effects on their activity.

Therefore, the electricity-induced collapse of the Spanish coal sector is the main source behind the reduction in CO_2 emissions[15] in the real market, a result confirmed by bottom-up models that consider the operation of the Spanish electricity system (Linares et al., 2004). In general and as expected, there are no significant changes on production costs except in some Directive sectors, but even in those cases the competitiveness effects will be limited due to their small exposure to foreign markets[16].

3.2.2. Wide Market

In this case the number of permits issued by the government to subject sectors leads to a reduction of benchmark carbon emissions of around 22%[17]. As advanced by intuition, the overall costs for the economy are lower than in the previous scenario: GDP decreases 0.42% with respect to the benchmark, only 59% of the costs in the *real market,* to achieve the same environmental objective. Moreover, the welfare losses (measured as equivalent variations) are reduced by 0.14% and they now represent 40% of the costs in the real market.

Figure 5 depicts the effects of the wide market on the sectoral levels of activity and emissions, which are obviously more evenly distributed across the economy. Starting with the environmental profile of the simulated policy, sectors not included in the Directive, and non-energy sectors in general, reduce their CO_2 emissions by an average 17%. On the other hand, Directive and energy sectors in general reduce their emissions in a range from 24% (*MINERAL, REFINED*) to 39% (*COAL*).

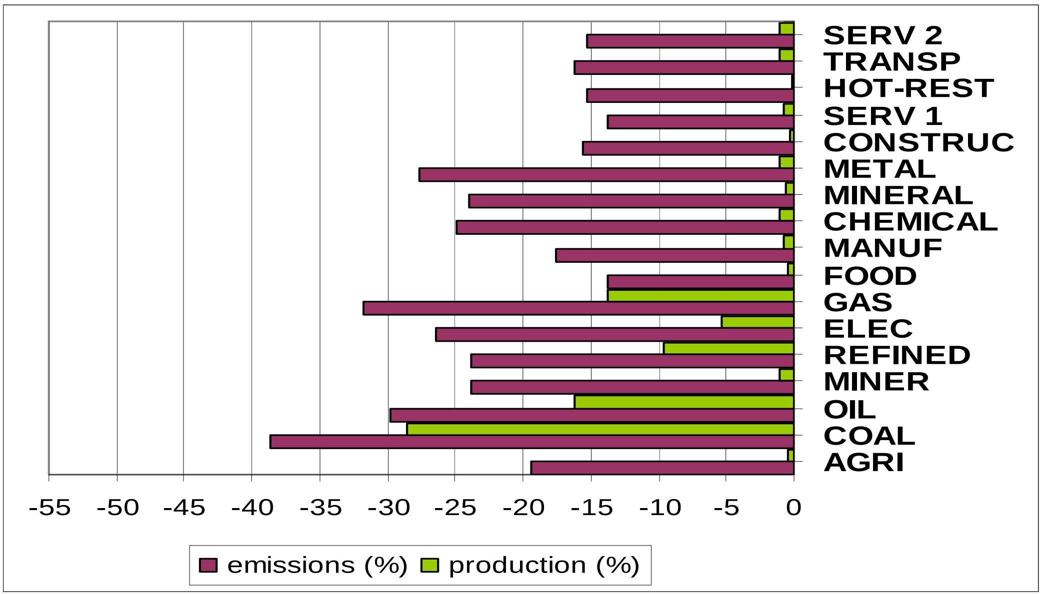
[14] There is an induced change in generation technologies, as coal-fired power plants reduce their share due to increased operational costs. This leads to an important effect on the coal sector, which in fact is not subject to the trading Directive.

[15] The electricity sector represents 70% of final energy consumption in Spain and an important share of Spanish CO_2 emissions.

[16] The exception is the metal sector, where the ratio of exports over total production is around 20%. Again, this is possibly another reason for the selection of the Directive sectors.

[17] Recall that households are excluded from the market, which explains why the reduction does not coincide with the mandated objective (16%).

Figure 5. Sectoral effects on production and emissions from the *wide market*



Source: The authors

When performing a sectoral comparative analysis of the effects on activity, the construction sector (*CONSTRUCT*), *MINERAL*, *METAL* and hotels and restaurants (*HOT-REST*) are those that benefit most with the wide market, with improvements in production levels in the range of 50-60%. Other sectors such as *COAL*, *ELEC* and *MINER* also show large improvements with the wide market, increasing their activity levels by more than 30%. The opposite occurs with *REFINED* and education, health, and other services (*SERV2*), which show reductions in production by respectively 50% and 43%. *GAS* and agriculture, livestock, forestry, fishing and aquiculture (*AGRI*) are also among the sectors that experience significant differences between the wide and the real market, with activity reductions close to 30%.

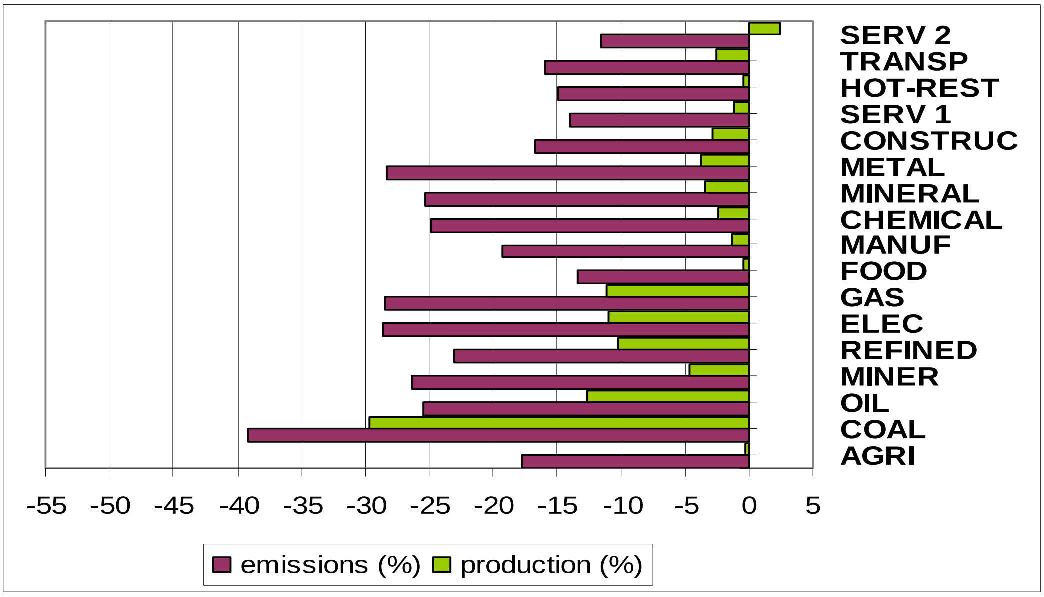
It is interesting to note that all Directive sectors, and particularly the energy sectors, become net sellers of permits in this second simulation. This means that they are the sectors with the lower abatement costs in the economy and justify, to a certain extent, their inclusion in the EUETS. Besides, this reduces the potential efficiency gains of extending the market, as most non-subject sectors present high abatement cost curves.

3.2.3. Auctioned Market

The final simulation involves a reduction of emissions of approximately 22% by subject sectors (with respect to the unregulated situation or benchmark). The costs for the economy when pollution permits are auctioned (instead of being freely allocated) are similar to those of the real market, as

GDP decreases by 0.64%, and consequently are higher than those caused by the wide market. However, there is now an important increase in welfare losses, representing up to 0.65% of the benchmark welfare level (measured as equivalent variations). Therefore, welfare costs have almost doubled with respect to the real market and almost quadrupled when compared to the wide market. This result corroborates the fears expressed by industrial sectors with regard to carbon taxes, equivalent to auctioned permits under some circumstances, as they are paid for any level of emissions.

Figure 6. Sectoral effects on production and emissions from the *auctioned market*



Source: The authors

Figure 6 shows the effects of this auctioned market on the level of activity and emissions of different industries and sectors. The sectoral reduction of emissions is similar to the wide market scenario, but the effects on production are much larger than in any of the other two policy options. Indeed, when comparing the relative changes of production between the wide market and the auctioned market, large differences arise in several sectors: 327% for *MINER*, 467% for *MINERAL*, 270% for *METAL*, and 867% for *CONSTRUC*. Other sectors such as transport services (*TRANSP*), *ELEC*, *HOT-REST*, chemical industry (*CHEMICAL*) and manufacturing industries (*MANUF*) also suffer important relative production losses with respect to the wide market. On the contrary, there is an increase in the activity level of *SERV2*, which can be explained by the lump-sum transfers received by households that obviously increase their income.

4. Conclusions

Spanish emissions of greenhouse gases have followed a path of strong growth since the early 1990s. This behavior is incompatible with any environmental objective and, in addition, it reflects an inefficient and a very dependent energy system. Following the EU internal distribution of emissions reductions to attain the Kyoto target, Spain is allowed to increase greenhouse gas emissions by 15% in 2008-2012 with respect to 1990. However, in early 2007 Spanish CO_2 emissions had already grown by almost 50% in relation to 1990 levels and thus the current NAP contemplates an intense reduction of emissions by the sectors subject to the EUETS.

The objective of this paper was to analyze the effects associated with the implementation of the EUETS in Spain. Given the limited scope of the market, there are obvious efficiency and distributional concerns related to cost-effectiveness and fairness. In this sense, Spain constitutes a good case study due to the size of the requested reductions, which would undoubtedly intensify those effects. The analysis is carried out through the comparison of three alternative policies: the real market, as established by the Spanish NAP; a wider (hypothetical) market, applied to all sectors with the exception of households; and an auctioned (also hypothetical) market with wide application, equivalent to the introduction of a carbon tax.

We use a static applied general equilibrium model for a small open economy, with a detailed consideration of energy consumption by firms and households. This guarantees the required flexibility to incorporate substitution possibilities and thus to provide reliable results. The model also calculates the CO_2 emissions associated with the consumption of fossil fuels, and it contemplates the functioning of the (isolated) Spanish permit market.

The results obtained from the application of the model to the alternative (real or hypothetical) scenarios indicate that the narrow nature of the EUETS generates efficiency costs and relevant distributional effects. Other options, such as carbon taxes, would even bring about wider efficiency and distributional effects on the industrial sectors. Although the overall economic effects of any of the considered alternatives are not sizable, the specific effects on a number of sectors and industries are indeed remarkable.

The conclusions of the paper are useful in normative (public policy) terms. First of all, as a contribution to understand and quantify the differential sectoral effects caused by the climate change policies applied in the EU. Secondly, by showing the need to extend the scope of application of climate change policies. In this sense, public environmental regulations have to be introduced through a combination of cost-effective instruments. Emissions trading should therefore be complemented with other mechanisms, such as taxes or voluntary approaches, allowing for a wide coverage of polluters with reasonable administrative and compliance costs. Moreover, in view of recent regulatory controversies with electricity generators in Spain, a partial or total auctioning of permits should be probably considered in the future.

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APPENDIX

Greek letters stand for scale parameters {*α, γ, λ, φ*}, elasticity of substitution being *σ*. Latin letters stand for the share parameters in the production and consumption functions {*a, b, c, d, s*}.

Production functions in the AGE

$$Output_i = \min\left(\frac{KEL_i}{c_{0i}}, \frac{D_{1i}}{c_{1i}}, \ldots, \frac{D_{ni}}{c_{ni}}\right) \tag{A1}$$

$$KEL_i = \alpha_i \left(a_i KL_i^{\frac{\sigma_i^{KEL}-1}{\sigma_i^{KEL}}} + (1-a_i) ENERGY_i^{\frac{\sigma_i^{KEL}-1}{\sigma_i^{KEL}}} \right)^{\frac{\sigma_i^{KEL}}{\sigma_i^{KEL}-1}} \tag{A2}$$

$$KL_i = \alpha_{iKL} \left(a_{iKL} K_i^{\frac{\sigma_i^{KL}-1}{\sigma_i^{KL}}} + (1-a_{iKL}) L_i^{\frac{\sigma_i^{KL}-1}{\sigma_i^{KL}}} \right)^{\frac{\sigma_i^{KL}}{\sigma_i^{KL}-1}} \tag{A3}$$

$$ENERGY_i = \alpha_{iE} \left(a_{iE} ELEC_i^{\frac{\sigma_i^{E}-1}{\sigma_i^{E}}} + (1-a_{iE}) PE_i^{\frac{\sigma_i^{E}-1}{\sigma_i^{E}}} \right)^{\frac{\sigma_i^{E}}{\sigma_i^{E}-1}} \tag{A4}$$

$$PE_i = \alpha_{iEP} \left(a_{iEP} COAL_i^{\frac{\sigma_i^{EP}-1}{\sigma_i^{EP}}} + (1-a_{iEP}) HYDRO_i^{\frac{\sigma_i^{EP}-1}{\sigma_i^{EP}}} \right)^{\frac{\sigma_i^{EP}}{\sigma_i^{EP}-1}} \tag{A5}$$

$$HYDRO_i = \alpha_{iPET} \left(a_{iPET} REF_i^{\frac{\sigma_i^{PET}-1}{\sigma_i^{PET}}} + (1-a_{iPET}) GAS_i^{\frac{\sigma_i^{PET}-1}{\sigma_i^{PET}}} \right)^{\frac{\sigma_i^{PET}}{\sigma_i^{PET}-1}} \tag{A6}$$

$$A_i = \lambda_i \left(b_i Output_i^{\frac{\sigma_i^{A}-1}{\sigma_i^{A}}} + (1-b_i) IMP_i^{\frac{\sigma_i^{A}-1}{\sigma_i^{A}}} \right)^{\frac{\sigma_i^{A}}{\sigma_i^{A}-1}} \tag{A7}$$

$$A_i = \gamma_i \left(d_i D_i^{\frac{\sigma_i^{\varepsilon}+1}{\sigma_i^{\varepsilon}}} + (1-d_i) EXP_i^{\frac{\sigma_i^{\varepsilon}+1}{\sigma_i^{\varepsilon}}} \right)^{\frac{\sigma_i^{\varepsilon}}{\sigma_i^{\varepsilon}+1}} \tag{A8}$$

A_i represents the Armington composite good for national production and imports in (A7) and domestic production and exports in (A8).

Consumer functions in the AGE

$$W = \left(s_{UB} LEISURE^{\frac{\sigma^{UB}-1}{\sigma^{UB}}} + (1-s_{UB}) UA^{\frac{\sigma^{UB}-1}{\sigma^{UB}}} \right)^{\frac{\sigma^{UB}}{\sigma^{UB}-1}} \tag{A9}$$

$$UA = \min\left(\frac{SAV_H}{s_{UA}}, \frac{FCHOUSE}{(1-s_{UA})}\right) \tag{A10}$$

$$FCHOUSE = \varphi_{CFH} \left(s_E EHOUSE^{\frac{\sigma^{CFH}-1}{\sigma^{CFH}}} + s_F TRANSP\_FUEL^{\frac{\sigma^{CFH}-1}{\sigma^{CFH}}} + (1-s_{EH}-s_{RH}) NEG_H^{\frac{\sigma^{CFH}-1}{\sigma^{CFH}}} \right)^{\frac{\sigma^{CFH}}{\sigma^{CFG}-1}} \tag{A11}$$

$$EHOUSE_h = \varphi_{EH} \left(s_{EH} ELEC_H^{\frac{\sigma^{EH}-1}{\sigma^{EH}}} + (1-s_{EH}) PEHOUSE^{\frac{\sigma^{EH}-1}{\sigma^{EH}}} \right)^{\frac{\sigma^{EH}}{\sigma^{EH}-1}} \tag{A12}$$

$$NEG_H = \prod_{i=1}^{17} D_{iH}^{SO_i} \quad i \neq \{electricity,\ coal,\ natural\ gas,\ refined\ oil\ products\} \tag{A13}$$

$$PEHOUSE = \varphi_{NEH}\left(s_C COAL_H^{\frac{\sigma^{NEH}-1}{\sigma^{NEH}}} + s_G GAS_H^{\frac{\sigma^{NEH}-1}{\sigma^{NEH}}} + \left(1 - s_C - s_G\right) REF_H^{\frac{\sigma^{NEH}-1}{\sigma^{NEH}}} \right)^{\frac{\sigma^{NEH}}{\sigma^{NEH}-1}} \quad \text{(A14)}$$

Elasticities

The preferences of the representative household are depicted through the following elasticities of substitution. The elasticity of substitution between fuel for private transport, energy for the home and an aggregate commodity (representing the remaining goods) is 0.1. The elasticity of substitution between electricity and the remaining household energy goods is 1.5. The elasticity of substitution between coal, natural gas and the remaining refined oil products that provide energy for the household is 1. The previous elasticities are similar to those used in Böhringer and Rutherford (1997), but lower in some cases due to precautionary reasons.

Table A1 describes the elasticities of substitution in CES production functions: σ_i^{KEL} is the elasticity of substitution between the composite goods value added (KL) and energy; σ_i^{KL} is the elasticity of substitution between capital and labor; σ_i^{E} is the elasticity of substitution between electricity and the composite good primary energies; σ_i^{EP} is the elasticity of substitution between coal and the composite good hydrocarbon fuels; σ_i^{PET} is the elasticity of substitution between natural gas and refined oil products; σ_i^{A} is the elasticity of substitution between imported goods and domestic production; and σ_i^{ε} is the elasticity of substitution between exported goods and domestic supply of goods.

Table A.1. Elasticities of substitution in the different activities

	σ_i^{KEL} (3)	σ_i^{E} (4)	σ_i^{KL} (1)	σ_i^{NE} (4)	σ_i^{PET} (4)	σ_i^{A} (1)	σ_i^{ε} (2)
AGRICULTURE	0.5	0.3	0.56	0.5	0.5	2.2	3.9
CRUDE	0.5	0.3	1.26	0.5	0.5	2.8	2.9
MINING	0.96	0.3	1.26	0.5	0.5	1.9	2.9
FOOD	0.5	0.3	1.26	0.5	0.5	2.8	2.9
MANUFACTURING	0.8	0.3	1.26	0.5	0.5	2.8	2.9
CHEMICAL	0.96	0.3	1.26	0.5	0.5	1.9	2.9
MINING PROD.	0.96	0.3	1.26	0.5	0.5	1.9	2.9
METAL	0.88	0.3	1.26	0.5	0.5	2.8	2.9
CONSTRUCTION	0.5	0.3	1.40	0.5	0.5	1.9	0.7
SERVICES1	0.5	0.3	1.26	0.5	0.5	1.9	0.7
HOTEL-REST.	0.5	0.3	1.68	0.5	0.5	1.9	0.7
TRANSPORT	0.5	0.3	1.68	0.5	0.5	1.9	0.7
SERVICES2	0.5	0.3	1.26	0.5	0.5	1.9	0.7
COAL	0.5	0.3	1.12	0.5	0.5	2.8	2.9
OIL	0.5	0.3	1.12	0.5	0.5	2.8	2.9
ELECTRICITY	0.5	0.3	1.26	0.5	0.5	2.8	2.9
GAS	0.5	0.3	1.12	0.5	0.5	2.8	2.9

Source: The authors

Notes: (1) GTAP (Hertel, 1997); (2) de Melo and Tarr (1992); (3) Kemfert and Welsch (2000); (4) Böhringer et al. (1997).

Table A.2. Sectors in the NAM-1995 and correspondence with the SIOT-1995

Sectors NAM-95	**Description**	**Code SIOT 1995**
AGRICULTURE	Agriculture, livestock and hunting, forestry, fishing and aquiculture	SIOT 01, 02, 03
COAL	Extraction and agglomeration of anthracite, coal, lignite and peat	SIOT 04
CRUDE	Extraction of crude oil and natural gas. Extraction of uranium and thorium minerals	SIOT 05
MINING	Extraction of metallic, non-metallic nor energetic minerals	SIOT 06, 07
OIL	Coke, refined oil products and treatment of nuclear fuels	SIOT 08
ELECTRICITY	Electricity	SIOT 09
GAS	Natural gas	SIOT 10
FOOD	Food and drink	SIOT 12-15
MANUFACTURING	Other manufacturing industries	SIOT 11, 16-20, 31-38
CHEMICAL	Chemical industry	SIOT 21-24
MINING PROD.	Manufacturing of other non-metallic minerals, recycling	SIOT 25-28, 39
METAL	Metallurgy, metallic products	SIOT 29, 30
CONSTRUCTION	Construction	SIOT 40
SERVICES1	Telecommunications, financial services, real estate, rent, computing, R+D, professional services, business associations.	SIOT 41-43, 50-58, 71
HOTEL-REST	Hotel and restaurant trade	SIOT 44
TRANSPORT	Transport services	SIOT 45-49
SERVICES2	Education, health, veterinary and social services, sanitation, leisure, culture, sports, public administrations	SIOT 59-70

Source: The authors.
Note: The Symmetric Input Output Table (SIOT) codes represent the different activities included in INE (2002b).

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