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Carbon leakage and the future of Old Industrial Regions after Copenhagen

Mikel Gonzalez-Eguino(*)[1], Ibon Galarraga(*) and Alberto Ansuategi(**)

CO2 prices will continue to differ from one country to another for a long time, even if a global post-Kyoto agreement is achieved in the near future. The non-homogeneous nature of climate policies may decrease the competitiveness of some industries with the risk of relocation of activities due to carbon leakage. One of most exposed industries in Europe is iron and steel, as it is highly CO2-intensive and relatively open to international trade. Most studies estimate a leakage of up to 20% as a consequence of all the industrial production activities that are expected to be relocated, and a level of relocation ranging from 1.5% to 35% specifically for the iron and steel sector. This might seem a relatively small macroeconomic impact if measured at country or EU level. However, the picture may be quite different if the analysis is conducted at sub-national level. Therefore, one could argue that there is an important gap in the literature as the relevant studies are applied to a large geographical scale when the fact is that in Europe this industry is highly concentrated in certain specific regions, i.e. the so-called Old Industrial Regions (OIR). This paper seeks to analyze the impact that different levels of relocation of the iron and steel industry in the OIRs will have as a consequence of climate policy. This is done using an AGE (Applied General Equilibrium) model. The results show that although these effects may be diluted from a national perspective, the impact for incumbent regions may be very large, and may in fact significantly reduce their GDPs. Another important outcome emerges when the costs of CO2 reduction derived from industry relocation and from cost-effective policies are compared. Although relocation of industrial activity (i.e. forced output change) can reduce CO2, the cost is very high compared with other options (e.g. induced input substitution). These results can help national and regional policy makers understand the necessary linkages between their environmental and industrial policies.

Keywords: Climate Policy, Regional Economics

JEL Classification: R10, Q58

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1. Introduction

CO_2 emissions are being increasingly scrutinized, regulated and priced. Although a post-Kyoto agreement is still being negotiated and the Copenhagen meeting left many uncertainties to be discussed further in 2010, there is a firm commitment from some developed countries to reduce emissions by 2020. For instance, the EU has set the target of reducing its emissions of greenhouse gases by 20-30%, Japan is committed to a reduction of 25% and the United States of America (US), according to the Markey-Waxman law, to a reduction of 4%. To achieve this, we can expect a battery of climate policy measures to be introduced, such as the extension of the European Emissions Trading Scheme (EU-ETS) to other countries and the implementation of taxes.

There is an extensive body of literature focusing on the economics of CO_2 control at global level (Nordhaus 2009, Stern 2009, World Bank 2007), at country level (Strachan and Kannan 2009) and even at regional level (Gonzalez-Eguino and Dellink 2007). However, given the stringency of the policies required and the differences between countries, a growing literature is now examining how these asymmetries in climate and energy policies can affect competitiveness (Hauser et al 2008, Smale et al 2006, IEA 2005).

The concept of competitiveness can be very complex (Porter 1990, Krugman 1994). In the context of climate policy it refers mainly to the risk that, like any other factor or commodity, the price of CO_2 could affect the profits and output of some firms. One of the main concerns in the EU in regard to establishing more stringent cuts in emissions within the ETS, or auctioning more permits instead of grandfathering them, has been precisely the fear of losing competitiveness in some industries. This discussion is at the heart of the new Directive 2009/29/CE of the European Parliament and of the Council of 23 April 2009, amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Although there could be some benefits in being a leader in a carbon constrained world, it also entails costs in terms of the risk of relocation of some of the more energy and CO_2 intensive production sectors. Most equilibrium modelling estimates an economy-wide leakage from Kyoto action in the order of 5 to 20% (World Bank 2007, IPCC 2007). That is, for every five tonnes of CO_2 cut in a country with a climate policy, one additional tonne will be emitted elsewhere. Thus, it becomes very important to understand who the winners and losers will be in the carbon leakage phenomenon.

The iron and steel industry, which is included in the ETS, is one of the most exposed industries in Europe to carbon leakage, since it is both highly CO_2-intensive and relatively open to international trade (Hourcade et al 2008). The European Commission is aware of this exposure, and included iron and steel in the sectors and subsectors exposed to significant risk of carbon leakage in its Decision of

24 December 2009[2]. Moreover, this sector is very significant in terms of GDP for many countries and regions.

In 2005 the iron and steel industry accounted for around 16% of total production in the EU-27, 20% of final energy consumption and 25% of total emissions from the manufacturing sector. The average cost of steel production in the EU-27 is 10–20% higher than the avedrage for the rest of the world, and up to 30-40% higher than in countries with easy access to abundant iron ore and cheap energy, such as Brazil or Russia (Hourcade et al 2008). This price gap has been sustainable with stable production in OECD countries since the eighties for three main reasons: (1) the growth of aggregate consumption in the last ten years; (2) the specialisation and quality standard requirements for many products; and (3) the creation of close business relationships with local sectors, such as construction and automotive manufacturers. In any case, there is no doubt that that the iron and steel industry faces new challenges in the coming decade from globalisation and from climate policy.

Some studies have focused specifically on the impact of the CO2 price in the iron and steel sector. Gielen and Moriguchi (2002) develop a large scale partial equilibrium model (STEAP model), that covers the life cycle analysis (LCA) of many different technology options. They find that if Europe and Japan alone introduced such a tax, their CO2 emissions would indeed decline, but that lower production in these regions would be offset by increased production and emissions elsewhere. They show that a tax of $12-50/tCO2 would reduce steel production by 20-35% by 2020 and generate a leakage rate of 35-50%. An OECD report (OECD 2002) also concludes that a unilaterally-applied carbon tax of $ 25/tCO2 in EU-13 (excluding Finland and Sweden) would lead to a 12% reduction in steel output and a leakage rate of 60%. Hidalgo et al. (2002) find, with a world steel industry model (ISIM model) based on the partial equilibrium model POLES, that a 2-5% per cent relocation of production from the EU-15 is expected for a € 20-50/tCO2 price by 2030. Finally, Demailly and Quirion (2008) apply a “small” partial equilibrium model that uses marginal abatement costs (MAC) from “large” models (POLES, PRIMES and MARKAL). They measure the two key dimensions of competitiveness – production and profitability – and conclude that for this sector losses in competitiveness will be small. Results from their reference scenario show a decrease in production of 1.5% and a leakage rate of 5% for a price of 20 €/tCO2.

There is, however, an important gap in the literature. So far, all the studies that have looked into the impacts of carbon leakage in the iron and steel industry have done so on a large geographical scale, either at country level (Japan, US, China) or at supra-national level (UE-27, Asia). This means that an important feature of this sector is omitted: the fact that from its origin this industry has been highly concentrated in specific regions (the so-called Old Industrial Regions, OIR), as can be seen from the

[2] The COMMISSION DECISION of 24 December 2009 draws up, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage.

European Steel Map[3]. For instance, in Spain it is mainly concentrated in the Basque Country, and in the UK in Wales and North-West England. This adds extra importance to comprehending the impacts and learning who the losers will be.

The OIR are regions that were at the vanguard of early industrialisation in the European economy, for reasons related to cheap access to raw materials such as iron ore, carbon and coke, and much of their activity continues to centre on heavy industry and energy intensive sectors. The key drivers of these OIR economies are normally the production of capital goods and infrastructure industries such as iron and steel, shipbuilding, heavy engineering and railway engineering, which are normally highly interconnected. The relocation of any one of these industries could have an important knock-on effect on others that should also be taken into account. In fact, it would also affect the cost-effectiveness of climate policy as it would increase the cost of CO2 mitigation policies. It must be taken into account that energy efficiency has improved "dramatically" in the European iron and steel industry in the last ten years, so further major improvements will prove very difficult and costly. That is, the marginal costs of further improvements are significantly high and growing (Eurofer 2000).

This paper seeks to analyse the impact of the carbon leakage and relocation phenomenon on a geographical scale better suited to the intrinsic characteristics of the iron and steel industry. The analysis centres on the Basque Country; an OIR that produces 10% of EU's total output from Electric Arc Furnace (EAF) mills. To account for economy-wide effects we use an AGE (Applied General Equilibrium) model. The results show that although total effects may be diluted from a national perspective, the impact on the region may be large and may significantly reduce its GDP. The article also calculates the maximum benefit that could be obtained if the government implemented the measures that would be needed to prevent delocalisation from happening as a side-effect of a globally asymmetric climate policy. The results show an enormous gap between the implicit cost of relocation-related emission reductions and emission reductions through a cost effective policy.

The paper is structured in five sections. After this introduction, Section 2 outlines the main features of the Basque Country as an OIR. The AGE model is presented in Section 3. Section 4 sets out the main results of the analysis. Section 5 draws conclusions and lists some limitations and possible extensions of the study.

2. The Basque Country as an Old Industrial Region in Europe

Old Industrial Regions (OIR) are generally the most critical places in Europe in the face of the prospect of a low carbon economy. OIRs (Birth et al 2009) are regions (see Figure 1[4]) that were at the

[3] http://www.eurofer.org/index.php/eng/Facts-Figures/European-Steel-Map
[4] The regions are based upon NUTS2 designations from Eurostat as shown in Table A6 in the appendices.

forefront of early industrialisation in the European economy, geared to the exploitation of coal and other raw materials, and more importantly a (comparatively) high proportion of their activity remains focused on heavy industry and energy intensive sectors. The key drivers of these economies are the production of capital goods and infrastructure industries such as iron and steel, shipbuilding, heavy engineering and railway engineering. Despite slow progress and efforts to diversify (e.g. towards high-tech and service sectors) these regions continue to rely upon these traditional sectors.

Figure 1**:** Old Industrial Regions in the Largest European States

Source: Birch, Mackinnon and Cumbers (2009)

Table 1 shows the trend in industrial employment from 1996 to 2007. It can be seen that, along with two regions in France and two in Germany, the Basque Country in Spain is one of the few regions in Europe that has managed to maintain the weight of industrial employment at the significant 25% level in the last ten years.

The Basque region is currently one of the wealthiest regions in Spain, with a gross domestic product (GDP) per capita around 25% higher than the national average. The main economic activities in the Basque Country have long been the steel and shipbuilding industries, mainly due to the rich iron ore resources found around Bilbao in the 19th century. The Estuary of Bilbao was the centre of the Basque Country's industrial revolution in the 19th century and the first half of the 20th. These activities went into decline in the recessions of the 1970s and 1980s, giving rise to a deep, convulsive restructuring of industry and the development of new technology-intensive activities and the service sector. Although the share of industry in total activity has decreased over the last 30 years, it is still high compared with other regions in Europe (see Figure 2) in terms of GDP, and the strongest industries are currently iron and steel, machine-tools, vehicle making, wind turbines, rolling stock and railways.

The Basque Country has one of the highest concentrations of iron and steel producers in Europe (see Table 2) and a large processing industry which produces a wide range of steel products, especially long products, stainless steel and specialty steels. This sector accounts for nearly 50% of steel production in Spain and 10% of all the steel produced in Europe with EAF technology. It should also be noted that all the iron and steel produced in the Basque Country uses this technology. Total production of raw steel in 2005 in Spain was 17.8 million tonnes, of which the Basque Country produced 6.9 million tonnes. This is a highly significant proportion considering that the Basque Country accounts for around 6% of Spain's overall GDP. The production of steel in the Basque Country can even be compared directly with some whole countries; its output is similar to that of Australia (7.6 million tonnes), the Netherlands (6.9), the Czech Republic (6.4) and Greater Indonesia (3.6). In fact, there are only 24 countries in the world that produce more steel than the Basque Country. The steel industry provides 23,188 direct jobs in the Basque Country (2.5% of total employment) and accounts for 5.9% of Basque GDP.

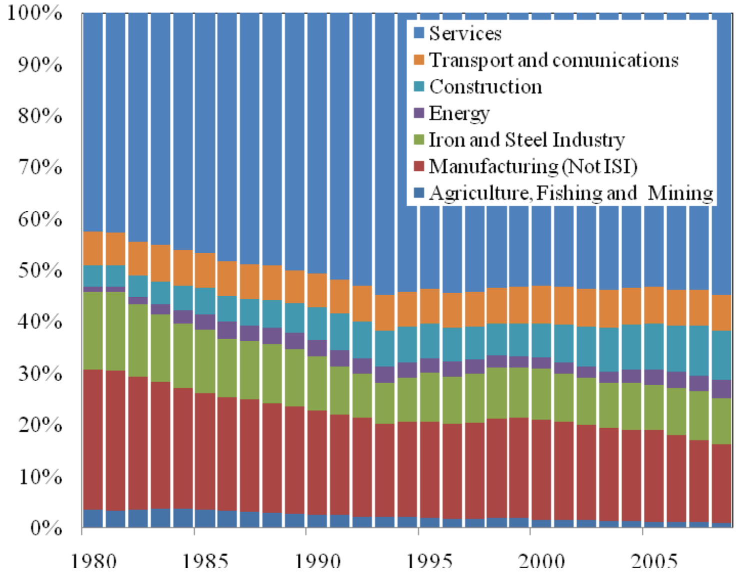
Table 1: % of employment in industry 1996-2007

Country	NUTS 2 Region	1996	2001	2007	% 96-07
Germany		24.0	23.6	22.6	-6.0
	Düsseldorf	24.7	22.3	21.0	-15.2
	Münster	23.8	22.1	25.1	5.2
	Arnsberg	29.6	27.8	25.9	-12.7
	Saarland	23.3	22.9	18.9	-18.6
Spain		18.7	18.8	15.5	-17.1
	Basque Country	26.4	27.5	23.2	-12.1
France		18.5	18.6	15.9	-14.1
	Nord-Pas-de-Calais	24.5	26.2	24.0	-1.9
	Picardie	22.2	21.1	16.9	-24.0
	Lorraine	21.4	23.3	24.8	16.0
United Kingdom		19,2	16.3	12.9	-33.2
	Tees Valley and Durham	23.9	22.0	15.3	-35.9
	Northumberland, Tyne and Wear	20.5	17.1	12.8	-37.5
	Lancashire	25.0	23.6	16.0	-35.8
	South Yorkshire	21.6	18.9	13.8	-36.2
	Derbyshire and Nottinghamshire	26.4	22.1	17.1	-35.1
	Shropshire and Staffordshire	26.9	23.3	15.5	-42.3
	West Wales and The Valleys	22.1	17.9	15.0	-32.2
	South Western Scotland	20.1	14.5	10.8	-46.3

Source: Eurostat, Regions – Economic Accounts, NACE D classification

From 1990 to 2005 steel production grew by 10% while direct emissions of CO_2 resulting from the production process decreased from 3760 tCO_2 to 1235 tCO_2. This change is attributable to industrial restructuring and technological change (Ansuategi and Arto, 2004). After the industrial restructuring of the nineteen eighties, integrated steelmaking plants were closed and replaced entirely by several new Electric Arc Furnace (EAF) facilities. Currently all the steel produced in the region is made in mini-mills with EAF technology. This made it possible to increase production while considerably decreasing energy consumption. On average, these are the least CO_2 intensive plants in the world (see Figure 3). Thus, energy efficiency in the iron and steel industry in the Basque Country is very close to the current limits of technology and could only be substantially improved by new processes or innovations.

Figure 2: % value added by sector, Basque Country, 1980-2009



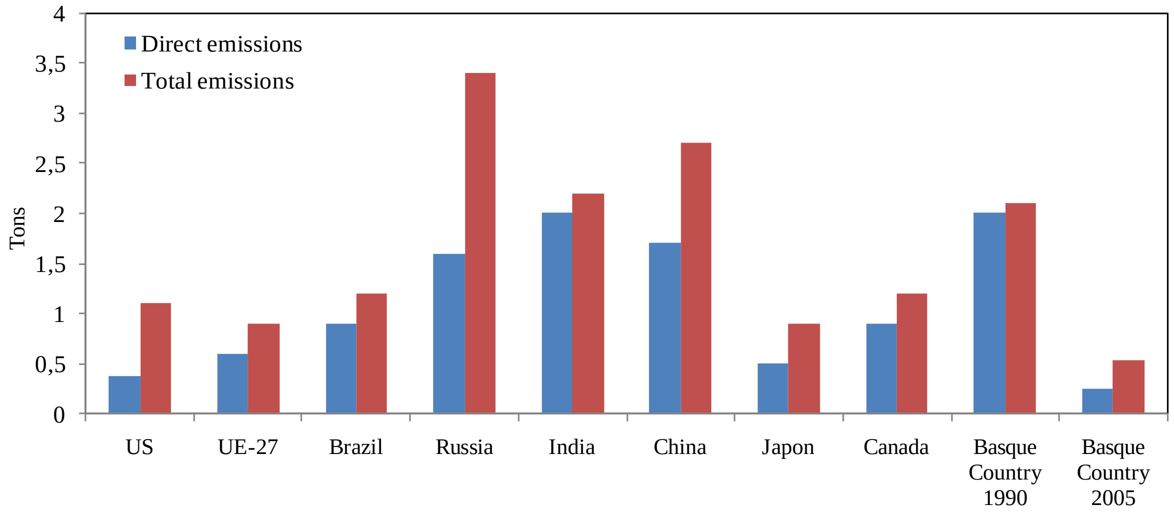
Source: Eustat, Economic Accounts

Table 2: % of output by region and sector, 2005

	Basque Country	Spain	EU-27
Agriculture, Fishing and Mining	1.2%	3.5%	2.7%
Industry	26.6%	15.8%	17.3%
Iron and Steel Industry	*8.9%*	*2.6%*	*2.4%*
Energy	3.0%	2.0%	2.1%
Construction	8.9%	11.5%	6.0%
Transport and communications	7.0%	6.9%	7.0%
Services	53.3%	60.2%	64.9%
Total	100%	100%	100%

Source: Eurostat, Regions- Economic Accounts

Figure 3: Carbon intensity of steel, 2005 (tonnes of CO_2 per tonne of steel)



Source: ISSI (2005) and UNESID (2008)

3. The model

This section presents the main characteristics of the static version of the AGE model used. Appendix A contains the algebraic formulation of the model. AGE models are empirical versions of a Walrasian model which enable interdependencies between different economic agents to be taken into consideration. An introduction to general equilibrium models can be found in Shoven and Whalley (1992).

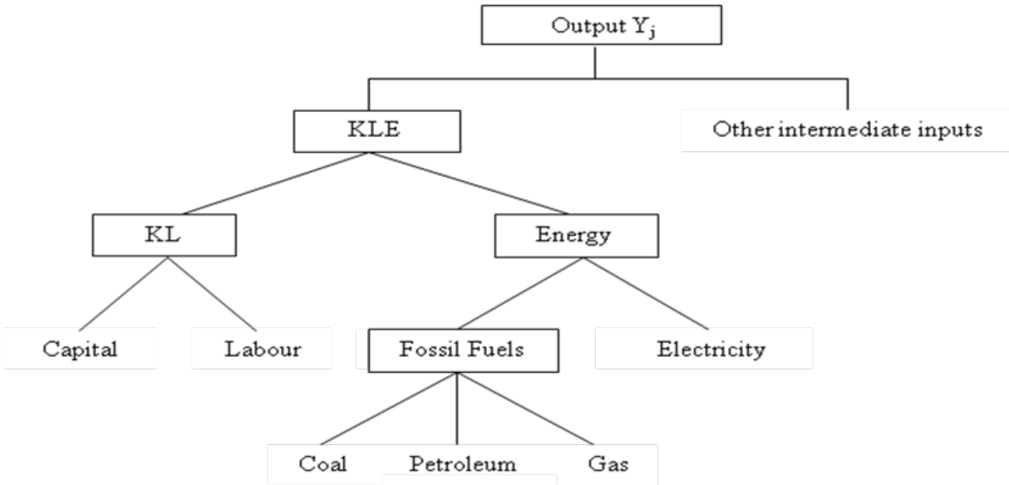
3.1. General description

The model comprises (1) 19 production sectors; (2) a representative consumer; (3) a government which collects taxes, supplies goods and services and monitors CO_2 emissions; and (4) the "Rest of the World", an aggregate that brings together the foreign sector. Primary factors include labour and capital. Labour and capital are mobile across economic sectors, but cannot move between regions. Some particularities are introduced to model the iron and steel industry (see Subsection 3.2).

The choice of production sectors pays specific attention to energy goods/sectors (coal, natural gas, crude oil, refined oil products and electricity). The iron and steel industry is separated from the metal products industry. This allows us to split the production of steel, responsible for most CO_2 emissions, from the manufacturing and processing of these products. The rest of the production sectors include major CO_2 emitting activities (wood and paper, cement and transport) and other sectors with high economic weights (food and textile industry, construction and services).

Cost functions are derived from nested constant elasticity of substitution (CES) production functions, which represent profit maximizing behaviour. Production functions are employed to specify the substitution possibilities in domestic production between capital, labour, energy and other intermediate inputs. At a second level, another CES function describes the substitution possibilities between labour, capital and the energy composite. At a third level, an energy composite trade-off is captured through a CES function of electricity and fossil fuels (coal, oil and gas) as shown in Figure 4. The only exception to this type of structure is the iron and steel industry, which is implemented with a Leontief Function. This is due to the fact that all the steel in the Basque Country is produced with EAF technology and the scope for technological changes capable of reducing CO2 emissions is very small.

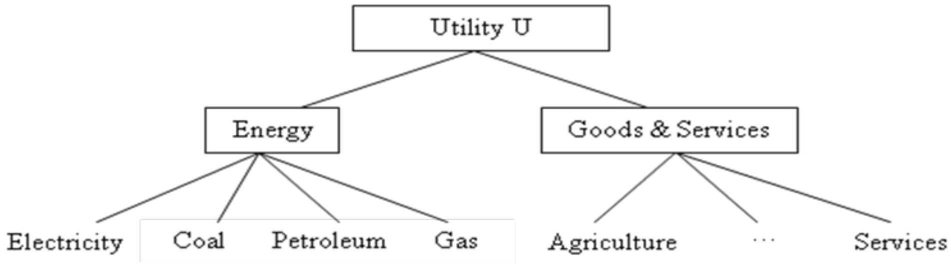
Figure 4: Output function structure



Source: MIT-EPPA model (Babiker et al 2005)

Final private demand for goods and services is derived from utility maximisation of a representative household subject to a budget constraint. The total income of the representative household consists of factor income and transfers. The final demand of the representative agent is given as a CES composite of an energy aggregate and a non-energy consumption composite. Substitution patterns within the energy aggregate and the non-energy consumption bundle are reflected via Cobb-Douglas functions following Figure 5. In our comparative-static framework, investment demand is fixed at the reference level.

Figure 5: Utility function structure



Source: MIT-EPPA model (Babiker et al 2005)

The government provides public goods, which are produced with commodities purchased at market prices, and distributes transfers. The preferences of the government are modelled via a Leontief function that enables the structure of public spending to be kept fixed with policy simulations. The government obtains its income through taxes on capital and labour (and additional income when it auctions CO2 emission permits). The level of public spending remains constant.

All commodities are traded internationally. We assume 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. We also apply the so-called Armington assumption (Armington 1969), which means that domestic and imported/exported goods are imperfect substitutes. In practice, this means modelling total supply as a CES function that aggregates domestic output and imports; and total demand by means of a transformation function which breaks down that aggregate into domestic demand and exports. Finally, as a "closure rule", we assume that the trade deficit, i.e. imports minus exports, is constant.

The total supply of labour and capital is considered to be exogenous. However, it is important to specify a relationhip between investment and capital flows. In a dynamic context the level of investment in an economy depends on interest rates, on the capital stock and on depreciation. As these points cannot be incorporated into a static model, we assume that the initial capital stock is adjusted following the condition that the price of investment in equilibrium must be equal to the price of capital. Thus, investment decisions are at least consistent with the return of capital (Hayashi 1982).

Finally, 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.

3.2. Modelling the relocation of iron and steel production

Iron and steel production is modelled using a Leontief production function (LT), which means that there are no substitution possibilities between inputs (see Equation 1). This assumption is consistent with the fact that the production technology for steel production in the Basque Country is 100% based on EAF technology, which means that although some CO2 reduction would be possible through energy efficiency and fuel switching, most of it would have to be found in changes in the production process. . Steel output ($\bar{Y}^S$) is obtained by combining in a fixed proportion of intermediate inputs ($Y_{j,S}^{ID}$), capital (K_S) and labour (L_S), where *j=1...J* represent production sectors in the economy and S is the iron and steel industry (the 11th *j*).

$$\bar{Y}^S = LT(Y_{1,S}^{ID}, \dots, Y_{J,S}^{ID}, L^S, K^S) \tag{1}$$

In order to include the relocation of iron and steel production in our model we assume that: (1) relocation is determined exogenously accordingly to the estimations used in the relevant literature; (2) the reduction in production due to relocation is perfectly substituted with imports from ROW; and (3) the proportion of capital related to the loss in production moves to ROW, thus reducing the capital stock.

The first assumption is reflected in equation 2, where production is exogenously determined ($\overline{Y_S}$) by the level of relocation of iron and steel production ($rs = [0,1]$) which fixes the proportion of reduction with respect to the benchmark level (Y_S^o).

$$\bar{Y_S} = Y_S^o(1 - rs) \tag{2}$$

The second assumption is represented by equation 3.1. Since we are using the Armington assumption to model trade (see the trade block of equations in Appendix A), this assumption can be captured considering perfect elasticity of substitution ($\sigma_S \rightarrow \infty$) between iron and steel production (Y_S) and imports (M_S), which in turn will make it possible to maintain total supply (Y_S^{TS}) constant, as expressed in 3.2.

$$\nabla Y_S = \Delta M_S \tag{3.1}$$

$$Y_S^{TS} = CES(Y_S, M_S) = \left[\mathrm{a} Y_S{}^{\sigma_S - 1/\sigma_S} + (1-\mathrm{a}) M_S{}^{\sigma_S - 1/\sigma_S} \right]^{\sigma_S/\sigma_S - 1} \quad (3.2)$$

Finally, the third assumption is expressed in equation 4. Since technology in the iron and steel industry is represented through an LT function, any reduction in production any reduction in production (Y_S) should be proportional to the reduction in capital (K_S), according to the exogenous parameter rs. Therefore, the capital stock or endowment ($\overline{K}$), i.e. the sum of all the capital allocated in the J sectors of the economy, will be reduced in the same proportion as the loss in capital due to relocation of activity in the iron and steel industry.

$$\overline{K} = \sum_{J=1}^{J} K_j - K_S(1 - rs) \quad (4)$$

3.3. Modelling CO2 emissions and the emission trading market

CO2 emissions from sector j (E_j) are calculated by multiplying emission coefficients (α_e) and intermediate consumption levels of coal, oil and gas (noted by the subscript e). As emissions from the residential sector are not considered, total emissions (E) are the sum of the emissions from all the sectors in the economy (see Equation. 5).

$$E = \sum_{j=1}^{J} E_j = \sum_{e=1}^{3} \alpha_e Y_{e,j}^{ID} \quad (5)$$

The restriction in CO2 emissions (see Subsection 4.3) is implemented with a market for tradable emission permits. The government sets the number of permits for each period, auctions them and allows them to be traded freely on the market. Thus, permits are just another production factor (which is linked directly to CO2 emissions) that reaches an equilibrium price via interaction of supply and demand. This is a natural way of simulating the cost of CO2 abatement in AGE models (Dellink 2005).

Therefore, a restriction in emissions can be simulated by reducing the number of initial emission permits ($re = [0,1]$) as shown in equation 6. We assume an equal yield tax reform, that is, the additional income collected by the government from controls on CO2 emissions is transferred directly to consumers, so that the level of public spending remains constant,. In these circumstances, each agent has an incentive to use the best mitigation options available (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 will be the same as the price of that unit.

$$\bar{E} = E^{O}(1 - re) \qquad (6)$$

3.4. Calibration

The initial equilibrium data come from an SAM drawn up by integrating[5] the data from the Symmetric Input Output Table (Eustat 2005) and the data from energy balance sheets for each sector (EVE 2005). The integration of these two tables reveals the underlying energy flows in the Input Output Table, so that CO2 emissions can then be calculated.[6] The reaction of agents to changes is reflected through elasticities of substitution from the MIT-EPPA model (Babiker et al 2001) and emissions are calculated via the standard coefficients for coal, oil and gas. The model is programmed using GAMS/MPSGE language and solved with the PATH algorithm (Dirkse and Ferris 1995).

4. Results

4.1. General Results

Most of the studies in the relevant literature consider losses from relocation in terms of production losses in the sector involved. Macroeconomic consequences are small enough to remain diluted at a state level. However, in an OIR steel production is concentrated enough to have consequences within the region that can be measured in terms of GDP losses. Understanding who the winners and losers in climate policy will be is vital for designing an effective policy.

[5] Energy data are integrated by inserting new rows into the IO Table for demand for energy goods (crude oil, coal, oil, 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).
[6] The database used to draw up the SAM is the symmetric IO Table from Eustat (Basque Statistics Office), so the data are valued at basic prices. Tax on labour includes social security contributions payable by workers. All remaining taxes are grouped under a tax on capital.

Figure 6 shows the link between steel output reduction and gross domestic product (GDP). The quasi-linear form of this function indicates that the costs will increase proportionally as the level of relocation increases. This relationship can be explained by the fact that i) the iron and steel industry is modelled with an LT structure; and ii) the possibility of substitution between materials and the Energy-Capital-Labour composite is zero (see Figure 4 and Table A6). The figure shows that a relocation of this activity of between 0 and 50% means a drop in GDP that may come close to 4%. This result reflects not only the direct impact of relocation but also its indirect effects.

Figure 6: Economic impact of the relocation of the iron and steel industry

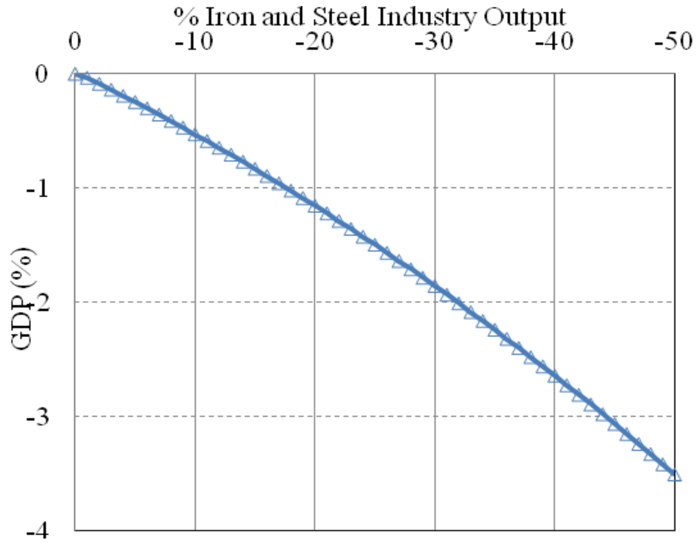


Table 3 shows the results broken down according to general variables, sector-related variables and energy-related variables for three exogenous relocation levels of reduction: 1.5%, 15% and 35%[7].The results show a drop in utility, GDP, consumption and investment. Utility, an indicator of loss of welfare, drops by between 0.05% and 1.62% and GDP by between 0.09% and 2.26%. GDP reduction reflects the trend in consumption and investment, since public spending and the foreign trade deficit are constant. The fall in consumption is due to a reduction in the value of endowments owned by consumers, as part of the capital stock is lost on relocation. On the other hand the sectors most affected are capital intensive, so flows of investment[8] are also reduced.

Table 3 also includes the effects on the economic structure, with the data aggregated under Agriculture, Industry and Services. The results show a high impact on Industry (-2.62% for a 15% relocation) due to the strong linkages of iron and steel with other industries. For high levels of relocation of the iron and steel industry, indirect effects also extend into Agriculture and Services[9].

[7] These relocation levels are in line with those estimated in the relevant literature.
[8] It must be pointed out as a caveat of the analysis that in a static model it is not possible to reflect how future economic growth will be affected by lower levels of investment.
[9] It is also worth mentioning that, although the impact on economic activity in services amounts to a reduction of not quite 1%, given the high share of total output represented by commercial and non commercial services

The model allows for shifts of resources from one sector to another due to the possibilities of substitution in the output and utility functions. As we show in the following subsections, these substitution effects are the mechanisms by which economic activity is partially channelled towards less energy intensive sectors.

Another significant effect that can be measured is the impact on energy consumption. On the one hand, the relocation of the iron and steel industry induces a change that is proportional to the energy mix of the industry. Given that in the Basque Country iron and steel production is based entirely on EAF technology that consumes coal, gas and electricity, these are the energy inputs that show the highest reduction rates. On the other hand, the energy mix is also altered by the fact that most indirect effects affect heavy industry, which consumes more coal. In the case of a 15% relocation of the iron and steel industry, coal consumption is reduced by 3.4%, oil by 1%, gas by 2.8% and electricity by 2.7%. Oil shows the lowest impact, due to the fact that the transport sector is not highly affected by the relocation of the iron and steel industry.

Table 3: General Results (%) for different levels of relocation of iron and steel production

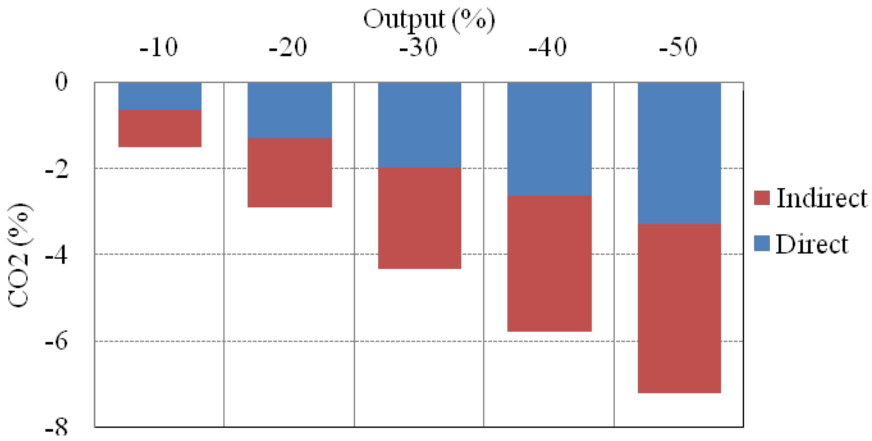
Scenarios	-1,5%	-15%	-35%
General			
Utility	-0,05	-0,59	-1,62
GDP	-0,09	-0,92	-2,26
Consumption	-0,05	-0,59	-1,62
Investment	-0,19	-1,82	-4,25
Sectors			
Agriculture	-0,04	-0,40	-0,93
Industry	-0,27	-2,62	-5,66
Services	-0,15	-0,31	-1,02
Energy Consumption			
Coal	-0,36	-3,43	-7,36
Oil	-0,10	-1,01	-1,40
Gas	-0,29	-2,82	-6,34
Electricity	-0,27	-2,70	-6,06
Others			
Iron and Steel Output	1,50	15,00	35,00
CO2 emissions reduction	-0,23	-2,23	-4,42
Implicit cost of CO2 (€/Tco2)	187,8	191,9	202,1

The model estimates that a relocation of iron and steel production of between 5% and 35% would entail reductions in CO2 emissions of between 0.23% and 4.42% (100 to 705 KtCO2). This effect captures both the direct reduction of CO2 emissions in the iron and steel industry and their indirect reduction in other sectors. Figure 7 shows a disaggregation of the two effects and highlights

(25.8% and 10.6 % respectively according to Table A5) the impact on output through services is by no means negligible.

the importance of taking into account the indirect effects. The indirect reduction of CO2 accounts for almost half of the total effect.

Figure 7: CO2 variation for different relocation scenarios



The reduction of CO2 emissions could be considered a positive outcome of the relocation of the iron and steel industry, since it results in less need for emissions allowances. For a price of 20€/TCO2 this would mean a saving of 2M€ to 14.1M€. However, if the real cost of this reduction in terms of GDP loss is examined the picture changes dramatically. To reduce emissions by 0.23-4.42% via relocation of the iron and steel industry, GDP would have to fall by between 0.09% and 2.26%. This means a total loss in Basque GDP of between 470 M € and 1686 M €. The real cost paid per unit of CO2 reduction is therefore between 187 €/Tco2 and 202 €/Tco2.

Finally, it should be noted that if this steel is produced elsewhere, global CO2 emissions may well increase since developing countries emit on average twice as much CO2 per unit of production of steel as OIRs.

4.2 Results by sectors

One of the advantages of AGE models is that they allow each scenario to be analysed at sector level. In doing this we should take into account that in an AGE model the inputs are exogenous, so changes in sectors should be understood as shifts of resources from some sectors to others that have become less profitable due to an exogenous shock or restriction.

In our case, the main effect comes from the fact that a relocation of iron and steel production reduces the inputs that this sector uses. Thus, in the first round the energy sector and commercial services are the two sectors affected most, since these are the main components of the costs of production (see Table A2) and there are no substitution possibilities within the iron and steel industry. In the second round the impacts are more complex. The sectors affected most are those that produce goods that consume energy and commercial services, with the particularity that in all these sectors there are some substitution possibilities (see Figures 4 and 5). Finally, since the production and final demand of some goods change, consumers also change their consumption structure in order to maximise their utility. Table 4 shows the effects of the three scenarios considered. As might be expected, the sectors affected most are those closely related to energy: natural gas, electricity and other industries.

Table 4: Results by sectors (%) for different levels of relocation of iron and steel production

	1.5%	15%	35%
Agriculture	-0.04	-0.40	-0.93
Mineral extraction	0.00	0.00	0.00
Food and textile industry	-0.03	-0.26	-0.61
Wood & paper industry	-0.03	-0.26	-0.60
Oil refining industry	-0.10	-1.04	-2.42
Chemical industry	-0.02	-0.19	-0.44
Glass industry	-0.01	-0.06	-0.14
Cement industry	-0.05	-0.47	-1.09
Iron and Steel industry	-1.50	-15.00	-35.00
Metal products industry	0.00	-0.02	-0.05
Other industries	-0.19	-1.89	-4.41
Electricity	-0.29	-2.88	-6.73
Natural gas	-0.31	-3.08	-7.20
Construction	-0.19	-0.85	-2.33
Transport	-0.06	-0.61	-1.43
Commercial services	-0.06	-0.56	-1.30
Non commercial services	-0.01	-0.14	-0.32

4.3. A comparative analysis with a cost-effective mitigation policy

Previous sections of the paper have analysed the impact of different scenarios of relocation of the iron and steel industry. This relocation, which we assume could be a consequence of climate policy, would reduce greenhouse gas emissions by a certain amount. In this section we look at the economic impact of achieving CO2 reductions if a cost-effective policy is used, i.e. if a reduction in emissions is attained with the minimum cost (see Subsection 3.3). In other words, the aim of this section is to compare the cost of CO2 reduction in a situation where inputs and economic structure can be adapted endogenously (see Table 5) with the situation when the reduction of emissions comes from an exogenous change (a reduction in the output of the iron and steel industry due to relocation) in the economic structure (see Table 3).

Comparing these two situations will give us an indication of the maximum benefits that could be obtained if the government implemented the necessary measures to guarantee that no production is taken overseas. This, of course, is indicative of the amount of resources that should/could be devoted to preventing relocation from happening. Or, looking at the issue in a different way, it can be interpreted as the increase in the cost of reducing GHG emissions that could occur as a consequence of a policy that generates carbon leakage.

Figure 7 shows this relationship between CO2 reduction and GDP loss. A straightforward result is that reducing CO2 emissions has a cost in terms of GDP when CO2 is priced compared to a situation in which there are no constraints or costs in place. Moreover, the convexity of this function (explained by the CES function adopted and the possibilities of substitution between energy inputs) indicates that costs will increase disproportionately as the level of reductions increases and the best mitigation options are exhausted. However, note that although this could be considered as similar to a "least cost" function of CO2 reductions, other options apart from a fuel switch are not considered (which would decrease costs) and nor are market failures and transaction costs (which would increase them).

Figure 7: Mitigation costs for a cost-effective policy

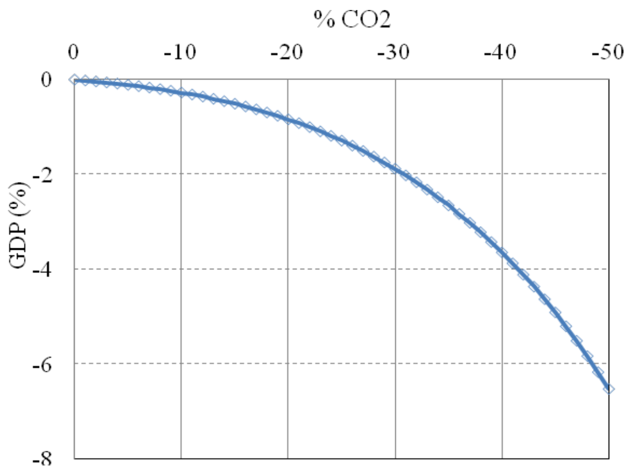
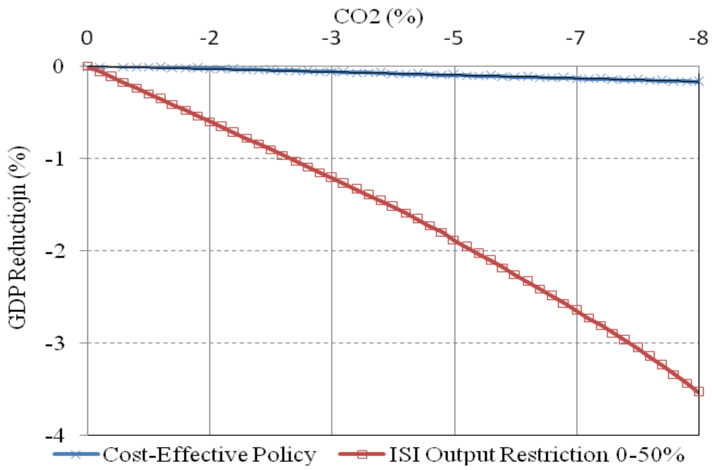


Table 5 shows the results for CO2 reductions of 5%, 25% and 50%. According to the model, utility, GDP, consumption and investment will all fall as a consequence of this policy (by 0.74%, 0.7% and 1.82% for the 25% emission reduction scenario). Table 5 also reveals some effects on the economic structure, with a shift towards the service sector which is reduced by a smaller proportion. Another significant point is the impact on energy consumption. Note that the policy induces a change that is to some extent proportional to the carbon content of each fuel used to generate energy. That is, for a reduction of 25% in emissions coal consumption is reduced by 49%, oil by 11%, gas by 3.3% and electricity by 5.6%. Note that the reduction in electricity use is the result of an indirect effect (the sector itself is not coupled to emissions), through the use of fossil fuels in the production of electricity.

Table 5: General results (%) for different levels of reduction of CO_2 emissions

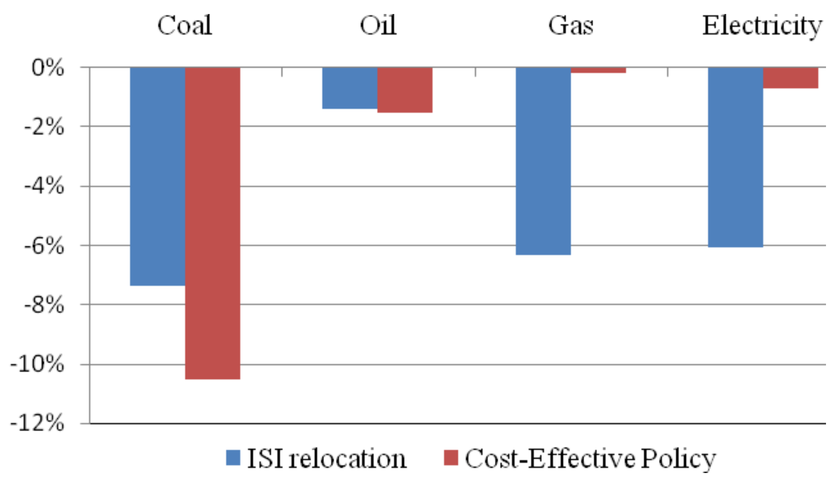
Scenarios	-5%	-25%	-50%
General			
Utility	-0.06	-0.74	-3.68
GDP	-0.10	-1.00	-4.35
Consumption	-0.06	-0.72	-3.52
Investment	-0.20	-1.82	-7.08
Sectoral			
Agriculture	-0.18	-1.95	-7.89
Industry	-0.28	-2.35	-8.46
Services	-0.01	-0.23	-1.29
Energy Consumption			
Coal	-10.52	-49.02	-78.54
Oil	-1.53	-11.08	-30.12
Gas	-0.17	-3.37	-16.12
Electricity	-0.68	-5.67	-19.51
Others			
CO2 emissions	-5.00	-25.00	-50.00
Iron and Steel Output	0.46	-3.56	-14.47
Implicit cost of CO2 (€/Tco2)	62.6	125.2	273.2

Figure 8: Cost of CO2 reduction by a cost-effective policy or by relocation of the iron and steel industry (ISI)



A comparison of Tables 3 and 5 gives an indication of the cost of reducing emissions in both situations. The implicit cost of a 5% reduction in emissions as a consequence of relocation of industrial activity is around 200 €/tCO2, whereas in a cost-effective policy this figure could be obtained for the much lower cost of 62.5 €/tCO2. For an emission reduction cost of 200 €/tCO2 emissions would be reduced by close to 50%. This enormous cost gap (which can be seen in Figure 8) can be clearly observed through the effect of relocation on the true source of emissions: fossil fuels. Figure 9 shows how in a cost-effective emission reduction the energy mix changes in proportion to the carbon content of each fuel. However in the case of relocation this logic does not hold, because the fuels which are cut most are reduced mainly as a function of the energy structure of the iron and steel industry.

Figure 9: Energy mix generated for a 5% reduction in emissions



5. Conclusions

The trend in global climate policy after Copenhagen will determine many of the economic impacts derived from this policy. Whether an overall CO2 pricing scheme should be implemented internationally is a key question that needs to be answered in the coming years. Furthermore, it should be clarified what policy instruments will be used and where will they be implemented.

With regard to European climate policy, the new Directive 2009/29/CE seems to suggest that the ETS will continue in place. It also implies that the ETS will require changes in order to prevent undesired potential effects through relocation in some sectors. The European Commission is fully aware that an asymmetric global climate policy might generate negative effects in terms of competitiveness and could lead to the so-called carbon leakage phenomenon. Thus, it is extremely important to fully understand who the “winners” and the “losers” in the policy will be. This paper argues that analysis at a national scale might fail to reveal the importance of the impacts of relocation of the iron and steel industry in OIRs.

The results of the AGE model developed to estimate these impacts in the Basque economy show that for a rate of relocation ranging from 1.5% to 35% the total loss in terms of GDP for that region may be as much as 2.26 %. This is clearly a very serious economic impact that cannot be fully appreciated in studies conducted at a national or supra-national geographical scale.

But carbon leakage may have another undesired and significant effect: an increase in CO2 emission reduction costs. The paper shows that if the reduction in emissions is achieved through some degree of relocation of the iron and steel industry, then the cost of mitigation may rise to 200 €/tonne (see Table 3), whereas the same reduction can be achieved for 62.5 €/tonne (see Table 5) if an efficient carbon emission trading scheme is used[10].

Many different policy recommendations could be drawn from this analysis. In our view, the most important conclusion is that when designing climate policy special attention should be paid to the burden imposed on sectors prone to relocation. More specifically, we believe that environmental policy applied to industrial sectors such as the iron and steel industry, which are concentrated in just a few regions in Europe, should be the subject of careful design. These are usually sectors in which there is little room for further improvements in energy efficiency. Additional measures should be incorporated when needed to avoid or offset the undesired impacts of asymmetric global climate policy in OIRs.

It should be noted, however, that these results do not call for any type of new protectionism. They suggest that ETS policy can be a very effective instrument if carefully designed to avoid negative impacts in OIRs. The new Directive tries to do this and decision makers should understand why this is so important. A policy that generates relocation in some sectors will have noticeable, important impacts in terms of GDP, consumption and investment[11]. Paradoxically, such a policy will make efforts to reduce CO2 extremely expensive.

Some caveats should be taken into account in order to put these results into perspective. First, there is still considerable uncertainty concerning the size of the relocation effect driven by changes in CO2 prices. We have chosen different scenarios within the range of estimates found in the literature, but that range is probably too wide. Second, the model is based on perfectly competitive markets and perfectly mobile factors between sectors. It considers direct and indirect impacts but does not include other costs such as transaction or adaptation costs. It is also important to recall that rigidities in labour

[10] In fact, the range of cost per tonne of CO2 obtained from relocation would be by far the highest of any technological measure available to mitigate emissions. IEA, for example, predicts that capture and storage (CCS) technology would cost in the range of 35 to 60$ per tonne of CO2 by 2030 and McKinsey foresees a price in the range of 30 to 45$. Even the most expensive measures for mitigating CO2 emissions, which are related to transformation of the transport sector and development of alternative fuels and vehicles, would not, according to IEA estimates, exceed 150 € per tonne of CO2.

[11] In this paper we only consider relocation of one of the vulnerable sectors listed in Directive 2009/29/EC. If all such sectors were considered the aggregate impacts would be much greater.

markets are not included, which could be relevant in the short term. Third, there are also caveats concerning the trade specification. As usual in the relevant literature, we use the Armington assumption, considering a multi-regional specification of the model to be beyond the scope of this paper.

We conclude by suggesting some interesting areas for further research. On the one hand, modelling the impact of carbon leakage driven relocation in more than one vulnerable sector would shed light on the aggregate costs of the phenomenon for OIRs. On the other hand, different policy options could also be modelled to achieve a better understanding of how to design effective policies.

References

Ansuategi A., Arto, I. (2004) La evolución de la intensidad energética de la industria vasca entre 1982 y 2001: un análisis de descomposición, Economía Agraria y Recursos Naturales, 4, 63-91.

Armington, P.S. (1969) A theory of production distinguished by place of production. IMF Staff Papers 16, 159-178, Washington.

Babiker, M.H., Mayer, M., Wieng, I. Hyman, R., 2001. The MIT emissions prediction and policy analysis EPPA model, MIT Global Change Joint Program, 71, Cambridge, MA.

Birch, K, Mackinnon, D. and Cumbers, A. (2008) Old Industrial Regions in Europe: A Comparative Assessment of Economic Performance, Regional Studies, 1, 1-19.

Dellink, R, Hofkes, M, van Ierland, E, Verbruggen, H., (2004) Dynamic modelling of pollution abatement in a CGE framework, Economic Modelling, 21, 6, 965-989.

Demailly D., Quirion P. (2008) European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry, Energy Economics, 30, 2009–2027.

Dirkse, S.P., Ferris, M.C, (1995) The PATH solver: A non-monotone stabilization scheme for mixed complementarity problems. Optimization Methods and Software, 5, 123-156.

EUROFER (2000) The European Steel Industry and the Climate Change, European Association of Iron and Steel Industry. (www.eurofer.org)

EUSTAT (2005) Input-Output Tables. Basque Statistics Office, Vitoria. (www.eustat.es)

EVE (2005) Energy statistics 2005. Ente Vasco de la Energía, Bilbao. (www.eve.es)

Gielen, D.J., Moriguchi, Y. (2002) CO2 in the Iron and Steel Industry: an Analysis of Japanese Emission Reduction Potentials, Energy Policy, 30, 849-863.

González-Eguino M., Dellink R. 2007. Impact of climate policy on the Basque economy, Economía Agraria y de los Recursos Naturales, 12, 187-213.

Hauser, T, Bradley, R., Childs, B., Werkman, J., Heilmayr, R. (2008) Leveling the carbon playing field: International competition and US climate policy design, Peterson Institute for International Economics, World Resource Institute, Washington, DC.

Hayashi, F., (1982) Tobin's q, rational expectations and optimal investment rule, Econometrica, 50, 213-224.

OECD (2002) Environmental policy in the steel industry: using economic instruments, Report for the Joint Meeting of Tax and Environment Experts, Paris.

Hidalgo, I., L. Szabo, (2005) Technological prospects and CO2 emission trading analyses in the iron and steel industry: A global model, Energy, 30, 583-610.

Hourcade, J.C, Neuhoff, K., Demailly, D., Sato, M., (2008) Differentiation and dynamics of EU ETS industrial competitiveness impacts, Climate Strategies Papers.

IEA (2005) Industrial competitiveness under European Union Emissions Trading Scheme, IEA/OECD, Paris.

IPCC (2007) Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

IISI (2005) International Iron and Steel Institute, Steel statistic archive, (http://www.worldsteel.org)

Krugman, P., (1994) Competitiveness: a dangerous obsession, Foreign Affairs, 73.

Kuik, O., Gerlagh, R., (2003) Trade liberalization and carbon leakage, The Energy Journal, 24, 97-120

Nordhaus, W. (2008) Question of Balance: Weighing the Options on Global Warming Policies, Yale University Press, New Haven.

Porter, ME. (1990) The Competitive Advantage of Nations. New York: Free Press.

Rutherford, T. Paltsev, S., (2000) GTAP-Energy in GAMS: The Dataset and Static Model, Univ. of Colorado (www.gtap.agecon.purdue.edu)

Smale, R., Hartley, M., Hepburn, C., Ward, J., Grubb, M., (2006) The impact of CO2 emissions trading on firm profits and market prices. Climate Policy 6 (1), 31–48.

Stern, N. (2008) The Economics of Climate Change, American Economic Review, 98, 2, 1-37.

Strachan, S. Kannan, R.,(2008) Hybrid modelling of long-term carbon reduction scenarios for the UK, Energy Economics, 30, 6, 2947-2963.

Szekely, J., (1996) Steelmaking and Industrial Ecology Is Steel a Green Material?, IISIJ International, 36,1, 121-132.

Shoven, J., Whalley, J. (1992) Applying General Equilibrium, Cambridge University Press, Cambridge.

UNESID (2008) Spanish Iron and Steel Industry Overview, Spanish Association of Iron and Steel Industry (www.unesid.org)

World Bank (2007) Institutional Perspectives International Trade and Climate Change: Economic, Legal and Institutional Perspectives, Washington.

A1. Appendices: model

This appendix presents an algebraic summary of the static general equilibrium model used and its equations. The general equilibrium can be described by a set of rational economic agents - households and firms - that demand and supply different goods, behave rationally, and solve their own optimization problems.

Three classes of conditions characterise a competitive equilibrium: zero profit conditions, market clearance conditions and income balance conditions. Producers operate under full competition and maximise profit subject to current technology. Under constant returns to scale net profits are zero; the value of output has to equal the value of all inputs used (zero profit condition). Consumers have an initial endowment of factors and maximise utility subject to the budget constraint; the value of income must equal the total value of expenditures (income balance condition). Finally, equilibrium is characterised by a set of equilibrium prices such that demand equals supply for all commodities simultaneously (market clearance condition). In this situation agents cannot do better by altering their behaviour. Differentiating the profit and utility functions with respect to input and output prices provides compensated demand and supply coefficients (Shephard's lemma), which appear subsequently in the market clearance conditions.

For the sake of simplicity, we do not write down the explicit functional forms but instead use the acronyms: LT (Leontief); CD (Cobb-Douglas), CES (Constant Elasticity of Substitution) and CET (Constant Elasticity of Transformation) to indicate the class of functional form in place. This form of presenting an AGE follows the approach of Dellink *et al* (2004). The model is programmed using GAMS/MPSGE language and resolved with the PATH algorithm.

A.1.1 Basic AGE model

Producers

Production functions[12]:

$$Y_j = CES(Y_{1,j}^{ID}, \dots, Y_{J,j}^{ID}, K_j, L_j), \forall j \in (1, \dots, J) \qquad \text{(Ec. 1)}$$

[12] 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.

Zero profit conditions:

$$\Pi_j = 0 = Y_J P_j - \sum_{jj=1}^{J} Y_{jj,j}^{ID} P_j + (P_K + \tau_j^K)K_j + (P_L + \tau_j^L)L_j, \forall j \in (1, \dots, \mathrm{J}) \quad \text{(Ec. 2)}$$

Consumers

Utility function for representative consumer

$$U = CES\left(C_1, C_2, \dots, C_J\right) \quad \text{(Ec. 3)}$$

Income balance:

$$P_K K_j + P_L L_j + T = \sum_{j=1}^{J} P_j\, C_j + S \quad \text{(Ec. 4)}$$

Government

Expenditure function

$$\bar{G} = LT\left(G_1, G_2, \dots, C_J\right) \quad \text{(Ec. 5)}$$

Income balance:

$$\sum_{j=1}^{J} \left(\tau_j^L \cdot L_j + \tau_j^K \cdot K_j\right) = \sum_{j=1}^{J} P_j \cdot \bar{G}_j + T \quad \text{(Ec. 6)}$$

The Foreign Sector

Total supply from import and production of goods

$$Y_j^{TS} = CES(Y_j, M_J), \forall j \in (1, \dots, \mathrm{J}), \quad \text{(Ec. 7)}$$

Total supply from import and production of goods

$$Y_j^{TD} = Y_j^{TS} = CET(Y_j^D, X_J), \forall j \in (1, \dots, \mathrm{J}) \quad \text{(Ec. 8)}$$

Closure rule

$$\sum_{j=1}^{J} \left[P_X(M_j - X_j)\right] = \overline{XD} \quad \text{(Ec. 9)}$$

Market Balance

$$Y_j^D = \sum_{jj=1}^{J} \left[Y_{jJ,J}^{ID} + C_j + G_j + I_j + (M_J - X_J)\right], \forall j \in (1, \dots, \mathrm{J}) \quad \text{(Ec. 11)}$$

$$\bar{L} = \sum_{J=1}^{J} L_j \, , \forall j \qquad \text{(Ec. 12)}$$

$$\bar{K} = \sum_{J=1}^{J} K_j \, , \forall j \qquad \text{(Ec. 13)}$$

$$S = \sum_{J=1}^{J} P_j \, I_j + \overline{XD}, \forall j \qquad \text{(Ec. 14)}$$

A.1.2 Additional equations for policy simulations

Emission restriction

$$\bar{E} = \sum_{j=1}^{J} E_j = \sum_{e=1}^{3} \alpha_e Y_{e,j}^{ID} \qquad \text{(Ec. 10)}$$

$$\bar{E} = E_0(1 - re) \qquad \text{(Ec. 19)}$$

Iron and Steel industry relocation modeling

$$\overline{Y_S} = Y_S^o(1 - rs) \qquad \text{(Ec. 20)}$$

$$\nabla Y_S = \Delta M_S \qquad \text{(Ec. 21.1)}$$

$$Y_S^{TS} = CES(Y_S, M_S) = \left[\mathrm{a}{Y_S}^{\sigma_s - 1/\sigma_s} + (1 - \mathrm{a}){M_S}^{\sigma_s - 1/\sigma_s}\right]^{\sigma_s/\sigma_s - 1}, \text{for } \sigma_s \to \infty \qquad \text{(Ec. 21.2)}$$

$$\bar{K} = \sum_{J=1}^{J} K_j - K_S(1 - rs) \qquad \text{(Ec. 21)}$$

A.1.3 Notation

Indices

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

Parameters

Label	*Description*
τ_j^L	Tax rate on labour, sector j
τ_j^K	Tax rate on capital , sector j
α_e	CO_2 emission coefficients for fuels
σ	Elasticity of substitution between inputs
re	Exogenous restriction in emission permits
ro	Exogenous restriction in output from Iron and Steel Industry sector

Variables

Name	*Description*		
Y_j	Output of sector j	C_j	Private consumption of good j
$Y_{jj,j}^{ID}$	Intermediate demand for input jj in sector j	G_j	Public consumption of good j
Y_j^D	Domestic demand for good j	S	Savings
Y_j^{TS}	Total supply of good j	I_j	Investment in sector j
Y_j^{TD}	Total demand for good j	P_j	Equilibrium market price of good j
M_j	Imports of good j	P_L	Equilibrium market price of capital
X_j	Exports of good j	P_X	Equilibrium real exchange rate price
L_j	Demand for capital of sector j	P_I	Equilibrium market price of investment
K_j	Demand for labour of sector j	E_j	CO_2 emissions by producers
U	Utility of representative consumer	E	Total CO_2 emissions

A2. Appendices: data

Table A1: Sectoral Desegregation

Sector Description	Acronym	Symmetric IO Table A-84 Code	CNAE Code
Agriculture	Y1	1.-4	A+B
Coal	Y2	5	CA:10
Oil & gas extraction	Y3	6	CA:11
Mineral extraction	Y4	7.-9	CA:12, CB
Food and textile industry	Y5	10.-19	DA+DB+DC
Wood & paper industry	Y6	20-22	DD+DE
Oil refining industry	Y7	23	DF
Chemical industry	Y8	24-28	DG+DH
Glass industry	Y9	29	DI:26.1
Cement industry	Y10	30	DI:26.5
Iron and Steel industry	Y11	32-34	DJ:27
Metal products industry	Y12	35,36,37, 38	DJ:28
Other industries	Y13	31,39-51	DI+DK+DL+DM+DN
Electricity	Y14	52	E40.1
Natural gas	Y15	53	E40.2, E40.3
Construction	Y16	54,55	E:41+F
Transport	Y17	60-66	I
Commercial services	Y18	56-59, 67-74	G,H,J,K
Non commercial services	Y19	75-88	L,M,N,O,P,Q

Source: Own work

Table A2: SAM, Basque Country 2005 (M€)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18	Y19	C	G	I	M	X	Tot
Y1	580	0	0	0	-795	-192	0	-11	0	0	0	0	-4	0	0	-30	0	-272	-22	-1143	0	-17	2029	-123	0
Y2	0	0	0	0	0	0	-46	0	0	-25	-22	0	-3	-60	0	0	0	0	0	0	0	0	156	0	0
Y3	0	0	0	0	0	0	-2738	-1	0	0	0	0	0	0	-867	0	0	0	0	0	0	0	3607	0	0
Y4	-1	0	0	145	-6	-3	0	-22	-5	-11	-27	-4	-172	0	0	-319	-1	-5	0	0	0	-3	461	-27	0
Y5	-45	0	0	0	3071	-6	0	-19	0	0	-3	-3	-40	0	0	-2	-6	-1112	-118	-3995	0	-104	4080	-1697	0
Y6	-1	0	0	-1	-72	2011	0	-54	-11	-1	-22	-50	-265	-6	-3	-132	-47	-488	-177	-329	0	-24	1215	-1545	0
Y7	-70	0	0	-1	-2	-2	3749	-4	0	-1	-4	-1	-4	-60	-3	0	-799	-13	-8	-984	0	-55	271	-2010	0
Y8	-28	0	0	-4	-51	-113	-20	3028	-16	-1	-90	-146	-644	-2	-2	-225	-32	-174	-213	-515	-336	-15	2923	-3327	0
Y9	0	0	0	0	-49	-1	0	-15	306	0	0	-7	-106	0	0	-70	-4	-6	-4	-8	0	-16	203	-223	0
Y10	0	0	0	-3	0	-2	0	-1	0	172	-12	-2	-92	0	0	-371	-3	-2	-1	0	0	0	343	-25	0
Y11	0	0	0	-1	-5	-3	0	-60	0	-3	3888	-1874	-1745	0	0	-310	-2	-21	-3	0	0	-48	4911	-4722	0
Y12	-1	0	0	-1	-57	-26	-1	-59	-3	-1	-260	6209	-1174	0	-3	-679	-9	-47	-21	-76	0	-927	1399	-4261	0
Y13	-24	0	0	-10	-32	-61	-15	-83	-12	-4	-325	-158	11695	-53	-5	-2195	-147	-764	-148	-1105	-2	-4302	7254	-9504	0
Y14	0	0	0	-5	-39	-62	-23	-94	-10	-7	-260	-96	-119	2065	-6	-126	-79	-333	-146	-639	0	0	10	-32	0
Y15	0	0	0	-3	-16	-65	-251	-47	-49	-10	-115	-17	-34	-604	1308	0	0	-22	-19	-56	0	0	0	0	0
Y16	-4	0	0	-5	-26	-17	-8	-38	-2	-3	-35	-53	-78	-24	-4	11599	-112	-2219	-274	-812	0	-7887	0	0	0
Y17	-17	0	0	-18	-134	-129	-35	-215	-28	-6	-274	-223	-460	-27	-12	-305	6104	-1333	-375	-1898	-76	-585	1586	-1540	0
Y18	-38	0	0	-13	-670	-335	-96	-598	-32	-11	-812	-840	-2096	-183	-70	-1865	-1061	27317	-1413	-14725	-266	-1975	4861	-5076	0
Y19	-3	0	0	0	-5	-4	-3	-8	0	0	-7	-10	-32	-3	-2	-59	-47	-215	11285	-5077	-6057	-73	345	-24	0
L	-59	0	0	-18	-425	-494	-47	-727	-65	-17	-745	-1513	-2345	-120	-22	-2338	-995	-6700	-5106	21735	0	0	0	0	0
K	-274	0	0	-53	-551	-348	-393	-679	-52	-63	-597	-783	-1559	-786	-284	-1719	-2246	-11187	-1498	23072	0	0	0	0	0
Taxk	0	0	0	-3	-19	-15	-62	-94	-3	-4	-42	-12	-56	-91	-21	-202	-185	-521	-302	0	1632	0	0	0	0
Taxl	-18	0	0	-5	-116	-135	-12	-198	-19	-5	-236	-417	-667	-45	-5	-652	-329	-1883	-1438	0	6180	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1074	-1074	0	0	0	0
Bal.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1515	0	0	-35653	34137	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-16033	0	16033	0	0	0
Tot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Own work based on Eustat (2009)

Table A3: Final energy consumption by sectors (ktoe), 2005

	Coal	Oil	Gas	Electricity
Agriculture	0	50	0	4
Coal	0	0	0	0
Oil & gas extraction	0	0	0	0
Mineral extraction	0	2	6	3
Food and textile industry	0	5	34	28
Wood & paper industry	0	5	153	98
Oil refining industry	550	450	5	0
Chemical industry	0	95	104	129
Glass industry	0	1	115	15
Cement industry	101	3	22	21
Iron and Steel industry	110	8	275	514
Metal products industry	0	2	40	60
Other industries	13	10	78	81
Electricity	349	131	1386	0
Natural gas	0	5	0	15
Construction	0	1	0	9
Transport	0	1777	0	18
Commercial services	0	31	55	175
Non commercial services	0	18	45	101
Total	1123	2594	2318	1271

Source: Eustat (2009)

Table A4: Standard emission factors by fossil fuel (ktCO2/ktoe)

Fossil Fuels	
Coal	4,032
Oil	3,207
Gas	2,337

Source: IEA (2008)

Table A5: Production, consumption and emission by sectors, 2005

Sector	Output		Consumption		CO2 emissions	
	(M€)	(%)	(M€)	(%)	($KtCO_2$)	(%)
Agriculture	580	0.5%	1143	3.6%	160	1.0%
Coal	0	0.0%	0	0.0%	0	0.0%
Oil & gas extraction	0	0.0%	0	0.0%	0	0.0%
Mineral extraction	145	0.1%	0	0.0%	20	0.1%
Food and textile industry	3071	2.9%	3995	12.7%	95	0.6%
Wood & paper industry	2011	1.9%	329	1.0%	374	2.2%
Oil refining industry	3749	3.5%	984	3.1%	2218	13.2%
Chemical industry	3028	2.9%	515	1.6%	548	3.3%
Glass industry	306	0.3%	8	0.0%	272	1.6%
Cement industry	3888	3.7%	0	0.0%	468	2.8%
Iron and Steel industry	6209	5.9%	0	0.0%	1112	6.6%
Metal products industry	11695	11.0%	76	0.2%	100	0.6%
Other industries	11695	11.0%	1105	3.5%	267	1.6%
Electricity	2065	1.9%	639	2.0%	5066	30.1%
Natural gas	1308	1.2%	56	0.2%	16	0.1%
Construction	11599	10.9%	812	2.6%	3	0.0%
Transport	6104	5.8%	1898	6.1%	5699	33.9%
Commercial services	27317	25.8%	14725	47.0%	228	1.4%
Non commercial services	11285	10.6%	5077	16.2%	163	1.0%
Total	106055	100%	31363	100%	16809	100%

Source: Own work (from Tables A2, A3 and A4)

Table A6: Elasticities of substitution in production, trade and consumption

σ^{Y}	Elasticity of substitution between material inputs and Capital-Labour-Energy	0
σ^{KLE}	Elasticity of substitution between Capital-Labour and Energy	0.5
σ^{KL}	Elasticity of substitution between Capital and Labour	1
σ^{E}	Elasticity of substitution between Electricity and Fossil Fuels	0.5
σ^{F}	Elasticity of substitution between Coal, Oil and Gas	1
σ^{A}	Elasticity of substitution between domestic and imported goods	3
σ^{T}	Elasticity of transformation between domestic goods and exports	3
σ^{C}	Elasticity of substitution between consumption of energy and non energy goods	0.5
σ^{CE}	Elasticity of substitution in consumption of energy goods	1
σ^{CB}	Elasticity of substitution in consumption of non energy goods	1

Source: MIT-EPPA Babiker *et al.* (2005)

Table A7: European Old Industrial Region designation

Old industrial region	NUTS 2 region	NUTS 2 code
Ruhr	Dusseldorf	DEA1
	Munster	DEA3
	Arnsberg	DEA5
Saar	Saarland	DEC0
North-east France	Picardie	FR22
	Nord-Pas-de-Calais	FR30
	Lorraine	FR41
Basque Country	Pais Vasco	ES21
UK coalfields	Tees Valley and Durham	UKC1
	Northumberland, Tyne and Wear	UKC2
	Lancashire	UKD4
	South Yorkshire	UKE3
	Derbyshire and Nottinghamshire	UKF1
	Shropshire and Staffordshire	UKG2
	West Wales and The Valleys	UKL1
	South Western Scotland	UKM3

Source: Birch, Mackinnon and Cumbers (2009)

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