University of Sussex
Business, Management & Economics

Economics Department Working Paper Series

No. 32-2012

# OLIGOPOLY AND OLIGOPSONY POWER IN THE SWEDISH MARKET[1]

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**Abstract:** We generalize Wirl's (JEEM, 2009) "oligopoly meets oligopsony" model of a permit market for the case of heterogeneous players. Both oligopolists and oligopsonists reduce welfare by restricting trade. Having both in the market reinforces this. However, oligopolists seek to increase the price whereas oligopsonists seek to decrease the price. Having both in the market leads to ambiguous results for the permit price, and hence for the trading positions of individual agents. We apply the model to the so-called Swedish market, on which non-ETS emission allowances are traded between the 27 EU Member States. The numerical results are partly as expected: Market power restricts total trade and reduce total welfare, regardless of whether there are strategic buyers, strategic sellers, or both. The impact on the permit price is ambiguous. Strategic buyers primarily affect the welfare of strategic sellers, and vice versa, whereas fringe agents may well benefit from having both strategic buyers and sellers (relative to having either).

**JEL Classification**: D43, Q54

**Key Words**: oligopoly, oligopsony, tradable permits, carbon dioxide

[1] **Acknowledgements:** This research was funded by the Energy Policy Research Centre of the Economic and Social Research Institute.

# 1. Introduction

Markets are increasingly recognized by environmental policy makers as a superior mechanism for allocating the effort of emission reduction and for minimizing the overall economic burden of regulation. The European Union has been particularly active in this regard. The EU Emissions Trading System (ETS) for carbon dioxide permits is well-known, but there is also a nascent market for non-ETS abatement credits (European Parliament and Council of the European Union 2009), the so-called Swedish market (after its main sponsor). A key distinction between the ETS and the non-ETS market is that the former has some 10,000 buyers and sellers whereas the latter has 27 – and there are a number of very small traders among the 27. Market power is therefore a real possibility, both on the demand and the supply side. This paper studies both monopoly and monopsony power in the non-ETS market.

The EU has set itself targets for greenhouse gas emission reduction for the year 2020. About half of all emissions are regulated under the ETS. The other half are covered by a wide variety of national regulations. The decision on targets considered abatement costs, but costs estimates were based on a single scenario and a single model. Various proposals were tabled to hedge the uncertainty about the costs of meeting the non-ETS targets. The Swedish proposal was accepted. It allows Member States to purchase excess non-ETS emission reduction credits from other countries. The modalities of the market have yet to be decided (Gorecki et al. 2009). There are only 27 participants in the Swedish market. Some of these will buy or sell small amounts of credits because their economy is small. It may not be in the interest of other countries to partake in the market. The Swedish market is therefore likely to be dominated by a small number of large buyers and sellers.

We consider a model of trade between EU countries in permits for those greenhouse gas emissions not covered by the Emissions Trading System (ETS). Our model generalizes that by (Wirl 2009). Wirl assumes that all firms in the market are identical in their levels of emissions in the absence of abatement and in their number of grandfathered permits. Firms differ only in the cost coefficients of their emission reduction activities, with all permit buying firms having the same high cost coefficient and all permit selling firms having the same low cost coefficient. In this paper, countries differ in their level of emissions in the absence of abatement, in their emission reduction requirement, and in their abatement cost coefficient. Consequently, whether a country acts as a buyer or a seller of permits depends on the interaction of these characteristics, rather than the cost coefficient alone. We use projections of non-ETS emissions and emission reduction requirements as in (Tol 2009b) and calibrate our model to the estimated cost of non-ETS carbon emission permits in that paper.

There is a rich literature on market power in emissions trade (Antelo and Bru 2009;Hahn 1984;Hintermann 2011;Liski and Montero 2011;Tanaka 2012). Most papers focus on the market power of sellers, and some papers consider either buyer or seller power (Muller et al. 2002). (Wirl 2009) and (Godal and Meland 2010) consider simultaneous buyer and seller power. This matters because strategic buyers seek to push the market in the opposite direction than strategic sellers. We generalize (Wirl 2009) to allow for heterogeneous agents and apply the model to the Swedish market.

The paper proceeds as follows. Section 2 presents the analytical model and derives qualitative results. Section 3 fills the model with data and applies it to the trade of non-ETS emission allocations between EU Member States. Section 4 concludes.

## 2. Analytical results

### *2.1. Permit trading in an efficient market*

The model follows the structure of (Rehdanz and Tol 2005;Rehdanz and Tol 2008;Tol 2009a;Tol 2009b;Wirl 2009). We assume that abatement cost functions are quadratic so that the first-order conditions are linear and the model has an analytic solution. While this limits the generality of the model, it should not affect its qualitative behaviour. Closed-form solutions are considerably more insightful.

Countries act in a market for tradable emission reduction permits. Countries differ in the amount they would emit without regulation ($x_i$), their allocated permits ($z_i$) and the cost of their emission reduction activity ($k_i$). Emission reduction costs are quadratic in the required emission reduction, and $c_i$ is a country-specific cost coefficient. Emissions beyond the level of country $i$'s allocated permits must be accounted for by purchasing additional permits ($y_i$) or engaging in emission reduction activity ($\alpha_i$). Additional emissions permits must be purchased from other countries' allocations.

$$\alpha_i = x_i - y_i - z_i \tag{1}$$

$$\sum_i y_i = 0 \tag{2}$$

$$k_i(\alpha_i) = \frac{c_i}{2}\alpha_i^2 \tag{3}$$

Country $i$'s cost of engaging in this market consists of the cost of any emission reduction activity undertaken and the cost of any additional permits purchased at market price $p$.

$$C_i = k_i(\alpha_i) + py_i \tag{4}$$

Under efficient market conditions, all countries will act as price takers, and will trade permits to minimise their costs and achieve the efficient allocation of permits and emission abatement activities, resulting in permit purchases $y_i^*$ and permit price $p^*$.

$$y_i^* = x_i - z_i - \frac{p^*}{c_i} \tag{5}$$

$$p^* = \frac{\sum_i (x_i - z_i)}{\sum_i \frac{1}{c_i}} \tag{6}$$

A larger emission reduction requirement increases the number of permits a country should purchase, as does a higher cost of emission reduction activity. The market price of permits increases with the aggregate emission reduction requirement of all countries, and with the cost of emission reduction activities.

### *2.2. Permit trading with market power*

We now assume that, of the $N$ countries in the permit market, $M$ countries can act strategically (in such a way as to manipulate the market price to their advantage), while the remaining $F = N - M$ countries act as price takers in a competitive fringe. All countries act with full information of the optimisation problems facing all other countries. As before, the fringe countries (indexed by $f \in F$) purchase permits as given by:

$$y_f = x_f - z_f - \frac{p}{c_f} \tag{7}$$

Countries with market power (indexed by $m \in M$) choose the number of permits to purchase to minimise their total cost:

$$\min_{y_m} C_m = \frac{c_m}{2}(x_m - y_m - z_m)^2 + y_m p \tag{8}$$

Again, all permits purchased must come from another country's allocation:

$$\sum_{m \in M} y_m + \sum_{f \in F} y_f = 0 \tag{9}$$

$$\sum_{m \in M} y_m + \sum_{f \in F}(x_f - z_f) - p \sum_{f \in F} \frac{1}{c_f} = 0 \tag{10}$$

This gives us the permit price under conditions of market power:

$$p = \left( \sum_{m \in M} y_m + \sum_{f \in F}(x_f - z_f) \right) \frac{1}{\sum_{f \in F} \frac{1}{c_f}} \tag{11}$$

As in the efficient solution, the permit price under market power increases with the cost of emission reduction activities. Here, however, the price depends on the emission reduction requirement of fringe countries and the permit purchase decisions of countries with market power. This allows us to calculate permit purchases by a representative strategic country ($y_s$) and representative fringe country ($y_g$):

$$y_s = \frac{c_s(x_s - z_s) \sum_{f \in F} \frac{1}{c_f} - \left( \sum_{\substack{m \in M \\ m \neq s}} y_m + \sum_{f \in F}(x_f - z_f) \right)}{\left( 2 + c_s \sum_{f \in F} \frac{1}{c_f} \right)} \tag{12}$$

$$y_g = \frac{c_g(x_g - z_g) \sum_{f \in F} \frac{1}{c_f} - \left( \sum_{m \in M} y_m + \sum_{f \in F}(x_f - z_f) \right)}{c_g \sum_{f \in F} \frac{1}{c_f}} \tag{13}$$

Equations 12 and 13 show that the number of permits purchased by a particular country is determined by the activities in other countries through the permit purchases of strategic countries ($y_m$), the gap between projected emissions and allocated permits of fringe countries ($x_f - z_f$), and the emission abatement cost coefficients of fringe countries ($c_f$). A country's permit purchases are also determined domestically by the gap between its own emissions and permit allocation, and by its abatement cost coefficient. Fringe country $g$ purchases fewer emissions permits as the aggregate emission reduction requirement in the fringe and the aggregate permit purchases in the strategic sector increase. Intuitively, these both imply higher demand for the stock of permits, raising the price of permits for country $g$ and making emission abatement activities more cost efficient in comparison. Country $g$'s purchases also increase as its own cost of emission abatement increases, but decrease as the same costs increase in the fringe sector generally. Again, these affect the cost of emission abatement relative to permit purchases, and the aggregate level of demand for the stock of allocated permits. Strategic country $s$ also purchases fewer permits as the aggregate fringe emission reduction requirement increases, and as the purchases of *other* strategic countries increase.

Both permit purchase equations (equations 12 and 13) are independent of the absolute level of the cost coefficients. That is, a rescaling of all $c_i$ by a constant $k$ (so that $c_i \rightarrow kc_i, \forall i$) cancels out in the term $c_g \sum_{f \in F} \frac{1}{c_f}$ , which appears in both the numerator and the denominator for both fringe and strategic countries. Therefore such a rescaling will result in the same level of permit purchases by all countries. While the *relative* cost coefficients must change in order to impact the level of permit purchases, the permit price is sensitive to both the level and the distribution of cost coefficients, as in equation 11.

### *2.3. Effect of Market Power*

From equation 11, the net effect on permit price of a country ceasing to act strategically and instead joining the fringe depends on two opposing effects. If country $n$ acts strategically ($n \in M$), equation 11 takes the following form:

$$p = \left( \sum_{\substack{m \in M \\ m \neq n}} y_m + y_n + \sum_{f \in F} (x_f - z_f) \right) \frac{1}{\sum_{f \in F} \frac{1}{c_f}} \tag{14}$$

If country $n$ then joins the fringe ($n \in F$), equation 11 changes to:

$$p = \left( \sum_{m \in M} y_m + (x_n - z_n) + \sum_{\substack{f \in F \\ f \neq n}} (x_f - z_f) \right) \frac{1}{\frac{1}{c_n} + \sum_{\substack{f \in F \\ f \neq n}} \frac{1}{c_f}} \tag{15}$$

There are two changes to $p$.

First, for strategic sellers of emissions permits, $y_n$ is negative, while for most buyers and sellers, the emission reduction requirement $(x_n - z_n)$ is positive. For strategic buyers, $y_n$ is positive but less than $(x_n - z_n)$ (otherwise the country would be engaging in unnecessary costly emission reduction). Therefore, $y_n < (x_n - z_n)$ , so this change acts to raise the permit price regardless of whether a strategic buyer or seller of permits loses market power.

Second, the change from $\left(\sum_{f \in F} \frac{1}{c_f}\right)$ to $\left(\frac{1}{c_n} + \sum_{f \in F} \frac{1}{c_f}\right)$ acts to reduce the permit price in the case of any strategic actor losing market power, so the net direction of the change in $p$ is ambiguous. Intuitively, however, a country acting as a strategic permit buyer is one which attempts to lower the price of permits; a buyer ceasing to act strategically should result in an increased permit price, so we can expect the effect of the first change in $p$ to outweigh the second (resulting in a net increase in $p$), and vice-versa for a strategic permit seller joining the fringe.

From equation 12 we can see the effects on a country's permit purchases of country $n$ ceasing to act strategically and joining the fringe. With country $n$ acting strategically ($n \in M$), country $s$ buys or sells permits as given by:

$$y_s = \frac{c_s(x_s - z_s)\sum_{f \in F}\frac{1}{c_f} - \left(\sum_{\substack{m \in M \\ m \neq s \\ m \neq n}} y_m + y_n + \sum_{f \in F}(x_f - z_f)\right)}{\left(2 + c_s \sum_{f \in F}\frac{1}{c_f}\right)} \qquad (16)$$

With country $n$ in the fringe ($n \in F$), country $s$ buys permits as given by:

$$y_s = \frac{c_s(x_s - z_s)\left(\frac{1}{c_n} + \sum_{\substack{f \in F \\ f \neq n}}\frac{1}{c_f}\right) - \left(\sum_{\substack{m \in M \\ m \neq s}} y_m + (x_n - z_n) + \sum_{\substack{f \in F \\ f \neq n}}(x_f - z_f)\right)}{\left(2 + c_s\left(\frac{1}{c_n} + \sum_{\substack{f \in F \\ f \neq n}}\frac{1}{c_f}\right)\right)} \qquad (17)$$

Here there are three changes to the form of $y_s$.

First, the addition of $\frac{1}{c_n}$ in the numerator acts to increase $y_s$ regardless of whether the company joining the fringe was a strategic buyer or seller of permits. Second, the addition of $\frac{1}{c_n}$ in the denominator acts to reduce $y_s$. Third, replacing $y_n$ with $(x_n - z_n)$ in the numerator also acts to reduce $y_s$ as $y_n < (x_n - z_n)$. The same analysis can be performed for $y_g$, the permit purchases of a fringe country, instead of $y_s$, with similar results. Thus the change in permit purchases by a particular country due to another country joining the fringe is ambiguous in direction.

## 3. Numerical results

The analytical results for the permit price are ambiguous, and so are the results for individual trading positions. This is not surprising, as the strategic buyers push the market in the opposite direction than do the strategic sellers. We therefore populate the model with realistic numbers and evaluate the results.

### *3.1. Calibration*

The model is calibrated in two steps. First, abatement cost coefficients for each country ($c_i$) are derived from equation 3, using projections for GDP in 2020 (Capros et al. 2008) and the macroeconomic costs (as a percentage of 2020 GDP) associated with meeting the non-ETS emissions targets as in the EU impact assessment (CEC 2008a;CEC 2008b;CEC 2008c). Projections of emissions in 2020 ($x_i$) and allocated emissions permits ($z_i$) are as in four calibrations of (Tol 2009b): EUmax and EUmin use EU data for 2005 and 2020 with upper and lower bounds, respectively, for the share of ETS in total emissions. EUmid calculates the non-ETS share of emissions in 2020 from projections of total emissions and growth rates for ETS and non-ETS emissions from (Capros et al. 2008). The final calibration uses UNFCCC data for 2005 with growth rates for ETS and non-ETS emissions from (Capros et al. 2008). Second, the derived abatement cost coefficients are scaled according to the price of carbon in each calibration as in (Tol 2009b).

Figure 1 shows the profile of abatement cost coefficients ranked from lowest to highest in the four calibrations. In all calibrations, the profile spans a very wide range of values (note the log y-axis). Only the EUmin calibration diverges significantly from the others at high values of $c_i$. The ranking of individual countries also varies between calibrations, although they are broadly consistent (see Table 1). Figure 2 shows the gap between projected emissions ($x_i$) and allocated emission permits ($z_i$) for all countries under the four calibrations. The projected emissions and the size of the gap vary substantially for a number of countries, particularly the largest emitters.

We take the EUmid calibration as our base case, with the other three calibrations serving as tests for sensitivity to different cost coefficient profiles, emission projections and permit allocations. First we calculate the efficient solution of no market power. We then allow the three largest buyers and three largest sellers of permits in the efficient solution to act strategically, and we present the effects of this market power on the permit price and on the level of trade.

## *3.2. Results*

### 3.2.1. Efficient market

The model is calibrated to the carbon permit prices of between €27.40/t$CO_2$eq and €30.82/t$CO_2$eq as in (Tol 2009b). However, while the scaling of $c_i$ affects the absolute price level, the relative deviations from the efficient levels of price and trade due to market power do not depend on the level of $c_i$, but on the distribution of $c_i$ across countries. These relative deviations are the focus of this paper. Trade varies between 67 and 109 Mtonnes of emissions across the four calibrations. This represents approximately 3% of total allocated permits, or 18% to 23% of the total emission reduction requirement, implying a generally fair initial allocation of permits.

Table 2 present the outcomes for the permit price (in €/t$CO_2$eq) across the four calibrations. Table 3 shows the levels of permit trade (in Mt$CO_2$eq) under each scenario. The highest level of permit trade occurs in EUmin, in which the lower bound of possible emissions is attributed to the ETS. There are more emissions sources attributed to non-ETS sources, with higher initial permit allocations creating more scope for trade.

In all calibrations, the model results in more countries buying permits than selling them, with 14 or 15 countries buying permits. Germany and Italy purchase the most permits in all cases, while no country appears in the three largest permit sellers across all calibrations, although Bulgaria and Spain stand out as large sellers of permits. 13 countries buy permits in all calibrations, 10 sell in all calibrations, and 4 vary between acting as a buyer or a seller of permits.

### 3.2.2. Market power

Intuitively, introducing strategic trade by purchasers of permits lowers the resulting permit price, and introducing strategic trade by permit sellers raises the permit price. Strategic behaviour on either side of the market reduces the overall level of trade.

The results (in Tables 2 and 3) show that in most calibrations market power in the non-ETS emissions trading market is not a serious threat to the efficiency of the market. Across the EUmin, EUmax and UNFCCC calibrations, one country acting strategically cannot change the resulting permit price by more than 0.75%, nor reduce the level of trade in permits by more than 2.4%. The largest deviation from the efficient permit price is less than 1.9%, and this requires three strategic sellers of permits with only price takers on the demand side of the market (in the EUmin calibration).

The effects on trade are somewhat more severe, with a fall in permits traded of up to 12.4% in EUmin. However this requires three strategic actors on both sides of the permit market. Market power is unevenly distributed: in EUmax and UNFCCC calibrations the price effects of strategic permit buyers tend to overpower the effects of strategic sellers (e.g. a single strategic buyer and three strategic sellers results in a permit price below the efficient price in EUmax). In EUmin the balance of power favours strategic sellers. This is in part due to the proportion of the market controlled by the largest actors on both sides: In EUmax and UNFCCC calibrations, the three largest permit buyers account for almost 80% of trade in the efficient market scenario, with the three largest permit sellers accounting for only 50% of permit sales. This gives the permit buyers greater scope for manipulating prices. In contrast, in the EUmin calibration the three largest buyers and three largest sellers account for 67% and 60% of trades respectively – a considerable change in concentration of trades on both sides of the market, allowing permit sellers to exert greater influence.

The EUmid calibration suggests consequences of market power which are both more severe and more unevenly distributed than in the other calibrations. A single strategic buyer (Italy) can reduce the market price of permits by 0.76% and can reduce trade by 2.6%, both about the same as the largest single-country effects from the other three calibrations. A single strategic seller of permits (Spain), however, can increase the price by over 4%, and can reduce trade by 3.6%. Spain alone can overpower the price effect of the three largest permit buyers – Italy, Germany and the UK – acting strategically, resulting in a permit price which is above the efficient price. Three strategic sellers (Spain, Bulgaria and France) facing only price takers can increase the permit price by almost 7.7%, and reduce trade by over 6.6%. With three strategic buyers and three strategic sellers the level of trade in emissions permits can be reduced by almost 15.5%. Again the balance of market power is evident in the market shares of the largest buyers and sellers of permits, with 73% of purchases and 69% of sales concentrated in the three largest market buyers and sellers. This is substantially greater power for permit sellers than in any other calibration, leading to much greater price manipulation.

The introduction of additional strategic countries changes the permit purchase equations of all other countries. A country leaving the fringe to strategically purchase permits reduces the permit price by buying less than it would have had it been part of the fringe. This effect is partially compensated by the other countries, whose net change in purchases has the effect of raising the permit price. Whether the additional strategic country has the effect of moving the permit price towards or away from the efficient price depends on the pre-existing net market power of the other strategic countries. For example, in a market with only one strategic country, a buyer of permits, the introduction of a second strategic country will move the market price away from the efficient price if the second strategic country also buys permits, and towards it if the second country sells permits.

Table 4 shows the welfare implications for the four alternative calibrations. When there are only strategic buyers or strategic sellers, qualitatively, the results are as one would expect: Welfare falls as more sellers behave strategically, and as more buyers behave strategically. Strategic behaviour of both buyers and sellers leads to further welfare losses – although the interaction mitigates the impact on price (Table 2), there is a synergistic effect on trade (Table 3) and hence on welfare (Table 4).

Table 5 shows the welfare implications by actor for the EUmid calibration. Results for the other three calibrations, which are very similar, can be found in the appendix. When there are only strategic buyers or strategic sellers, qualitatively, the results are as one would expect:

The strategic actor(s) gain at the expense of the fringe. When there are both strategic buyers and strategic sellers, an intriguing pattern emerges: The welfare gains of strategic buyers (sellers) are primarily at the expense of strategic sellers (buyers). At the same time, there is safety in numbers: As there are more strategic buyers (sellers), adding strategic sellers (buyers) has a smaller effect on the strategic buyers (sellers). Indeed, the fringe is better off if there are both strategic sellers and buyers than if there are only strategic buyers or sellers.

## 4. Discussion and conclusion

We generalize Wirl's model of oligopsonistic-cum-oligopolistic trade in emission permits to the case of heterogeneous market actors. We apply the model to the nascent EU market for non-ETS emission reduction credits. The following results emerge. Strategic sellers suppress supply in order to drive up the price. Strategic buyers suppress demand in order to drive down the price. If there are both strategic buyers and strategic sellers in the market, the influence of either on the price is muted by the behaviour of the other. However, their effect on the volume of trade is reinforced and indeed super-additive. Welfare falls as there are more strategic actors in the market. However, strategic actors gain welfare at the expense of one another, while fringe actors benefit from the interaction between strategic buyers and sellers.

There are a number of caveats to these results. We use specific functional forms for convenience. We did not try to generalize this, although our findings suggest that unambiguous results are unlikely. It may be more profitable to replicate our model with alternative specifications and numerical solution techniques. We use a partial equilibrium model. We therefore ignore the interactions between power in the emission permit market and power in other markets (electricity, transport). We disregard the peculiarities of the Swedish market. Thinness and infrequent trade are likely features. These issues are deferred to future research.

We do not discuss possible instruments to counteract market power. As the structure and regulation of the market have yet to be decided, it is premature to argue for or against a particular intervention. The results presented here do indicate that regulation is needed to contain market power.

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Table 1. GDP projections, estimated increase in direct costs due to emissions targets, and abatement cost coefficient rankings (1: lowest $c_i$, 27: highest $c_i$)

| | GDP 2005 (2005€ bn) | GDP 2020 (2005€ bn) | Impact on GDP due to non-ETS target (% GDP) | EUmin cost coeff. rank | EUmid cost coeff. rank | EUmax cost coeff. rank | UNFCCC cost coeff. rank |
|---|---|---|---|---|---|---|---|
| Austria | 245.1 | 335.2 | 0.4 | 8 | 6 | 9 | 6 |
| Belgium | 298.5 | 409.2 | 0.5 | 6 | 7 | 5 | 4 |
| Bulgaria | 21.4 | 49.3 | 2.5 | 13 | 11 | 11 | 12 |
| Cyprus | 13.6 | 23.4 | 0.9* | 25 | 21 | 20 | 21 |
| Czech | 99.7 | 178.2 | 0.4 | 23 | 17 | 23 | 16 |
| Denmark | 208.3 | 281.3 | 2.2 | 20 | 16 | 18 | 19 |
| Estonia | 11.1 | 23.6 | 0.6 | 22 | 23 | 26 | 26 |
| Finland | 157.4 | 221.3 | 0.5 | 16 | 18 | 15 | 15 |
| France | 1710.0 | 2434.9 | 0.5 | 2 | 2 | 1 | 1 |
| Germany | 2241.0 | 2927.4 | 0.9 | 10 | 9 | 6 | 5 |
| Greece | 181.1 | 284.2 | 1.7 | 17 | 15 | 16 | 17 |
| Hungary | 88.8 | 147.4 | 0.3 | 18 | 19 | 17 | 18 |
| Ireland | 161.2 | 286.2 | 0.4 | 9 | 8 | 8 | 11 |
| Italy | 1417.2 | 1864.3 | 1.0 | 3 | 3 | 3 | 3 |
| Latvia | 12.8 | 31.8 | 1.0 | 11 | 14 | 13 | 13 |
| Lithuania | 20.6 | 44.7 | 0.6 | 26 | 22 | 24 | 23 |
| Luxembourg | 29.4 | 51.2 | 0.9* | 12 | 10 | 12 | 10 |
| Malta | 4.6 | 7.4 | 0.9* | 27 | 26 | 22 | 24 |
| Netherlands | 505.6 | 702.6 | 0.6 | 7 | 5 | 7 | 8 |
| Poland | 243.8 | 472.2 | 1.6 | 21 | 25 | 21 | 27 |
| Portugal | 147.8 | 212.8 | 0.4 | 19 | 24 | 19 | 22 |
| Romania | 79.3 | 185.1 | 2.6 | 15 | 20 | 25 | 20 |
| Slovakia | 38.1 | 77.6 | 1.7 | 24 | 27 | 27 | 25 |
| Slovenia | 27.6 | 43.5 | 0.7 | 14 | 13 | 14 | 14 |
| Spain | 905.5 | 1410.8 | 0.7 | 1 | 1 | 2 | 2 |
| Sweden | 287.7 | 421.2 | 0.3 | 4 | 4 | 10 | 7 |
| UK | 1792.0 | 2560.2 | 0.4 | 5 | 12 | 4 | 9 |

* (CEC 2008a) does not report figures for Cyprus, Luxembourg or Malta. These countries are assigned the average percentage cost of the other countries.

Table 2. Efficient price of permits (in €/$tCO_2$eq) and % change due to market power.

| EUmid | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **€27.40/$tCO_2$eq** | +4.14% | +4.25% | +7.66% |
| | 1 | -0.76% | +3.44% | +3.57% | +7.15% |
| | 2 | -0.87% | +3.31% | +3.44% | +6.95% |
| | 3 | -0.92% | +3.28% | +3.40% | +6.93% |

| EUmin | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **€30.82/$tCO_2$eq** | +0.75% | +1.54% | +1.86% |
| | 1 | -0.42% | +0.32% | +1.04% | +1.34% |
| | 2 | -1.10% | -0.32% | +0.36% | +0.68% |
| | 3 | -1.42% | -0.59% | +0.09% | +0.45% |

| EUmax | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **€30.68/$tCO_2$eq** | +0.31% | +0.36% | +0.49% |
| | 1 | -0.64% | -0.36% | -0.32% | -0.21% |
| | 2 | -1.39% | -1.15% | -1.11% | -1.03% |
| | 3 | -1.78% | -1.55% | -1.51% | -1.45% |

| UNFCCC | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **€29.34/$tCO_2$eq** | +0.10% | +0.50% | +0.77% |
| | 1 | -0.63% | -0.54% | -0.17% | +0.07% |
| | 2 | -1.44% | -1.35% | -1.03% | -0.83% |
| | 3 | -1.69% | -1.61% | -1.31% | -1.13% |

Table 3. Efficient trade of permits (in $MtCO_2eq$) and % change due to market power.

| EUmid | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **75 Mt** | -3.58% | -3.69% | -6.64% |
| | 1 | -2.64% | -7.68% | -7.86% | -13.35% |
| | 2 | -3.03% | -8.37% | -8.58% | -14.71% |
| | 3 | -3.21% | -8.73% | -8.95% | -15.49% |

| EUmin | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **109 Mt** | -1.67% | -3.43% | -4.14% |
| | 1 | -1.12% | -3.00% | -5.14% | -6.03% |
| | 2 | -2.94% | -5.31% | -8.40% | -9.76% |
| | 3 | -3.82% | -6.59% | -10.54% | -12.40% |

| EUmax | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **67 Mt** | -0.58% | -0.68% | -0.93% |
| | 1 | -2.37% | -3.19% | -3.34% | -3.76% |
| | 2 | -5.18% | -6.40% | -6.63% | -7.33% |
| | 3 | -6.62% | -8.16% | -8.45% | -9.38% |

| UNFCCC | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | **79 Mt** | -0.13% | -0.65% | -1.00% |
| | 1 | -1.92% | -2.10% | -2.86% | -3.41% |
| | 2 | -4.39% | -4.66% | -5.78% | -6.66% |
| | 3 | -5.17% | -5.47% | -6.75% | -7.78% |

Table 4. Total welfare changes (mln euro) due to market power.

| EUmid | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -14.73 | -15.11 | -26.66 |
| | 1 | -2.24 | -26.53 | -27.42 | -58.43 |
| | 2 | -2.63 | -28.77 | -29.76 | -65.90 |
| | 3 | -2.67 | -29.82 | -30.88 | -69.98 |

| EUmin | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -3.77 | -6.23 | -7.24 |
| | 1 | -2.55 | -7.92 | -13.34 | -15.82 |
| | 2 | -4.92 | -13.60 | -24.88 | -30.64 |
| | 3 | -6.10 | -17.66 | -34.98 | -44.70 |

| EUmax | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -0.60 | -0.69 | -0.87 |
| | 1 | -2.82 | -4.28 | -4.54 | -5.29 |
| | 2 | -4.79 | -7.40 | -7.90 | -9.41 |
| | 3 | -5.91 | -9.47 | -10.18 | -12.40 |

| UNFCCC | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -0.21 | -0.88 | -1.23 |
| | 1 | -2.72 | -3.15 | -4.82 | -6.04 |
| | 2 | -4.98 | -5.72 | -8.75 | -11.24 |
| | 3 | -5.51 | -6.37 | -9.96 | -12.98 |

Table 5. Welfare changes (mln euro) due to market power by group (on average); EUmid calibration.*

| Strategic Buyers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | - | - | - | - |
| | 1 | 2.44 (2.44) | -26.91 (-26.91) | -27.84 (-27.84) | -55.89 (-55.89) |
| | 2 | 7.64 (3.82) | -46.00 (-23.00) | -47.67 (-23.84) | -97.58 (-48.74) |
| | 3 | 10.81 (3.60) | -55.16 (-18.39) | -57.21 (-19.07) | -118.22 (-39.41) |

| Strategic Sellers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | - | 20.04 (20.04) | 31.26 (15.63) | 71.18 (23.73) |
| | 1 | - | 8.20 (8.20) | 17.42 (8.71) | 45.38 (15.13) |
| | 2 | - | 6.14 (6.14) | 14.97 (7.49) | 39.31 (13.10) |
| | 3 | - | 5.12 (5.12) | 13.83 (6.92) | 36.41 (12.14) |

| Fringe welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | - | -34.77 (-1.34) | -46.37 (-1.85) | -97.84 (-4.08) |
| | 1 | -4.69 (-0.18) | -7.82 (-0.31) | -17.00 (-0.71) | -47.91 (-2.08) |
| | 2 | -10.27 (-0.41) | 11.09 (0.46) | 2.93 (0.13) | -7.64 (-0.35) |
| | 3 | -13.48 (-0.56) | 20.21 (0.88) | 12.49 (0.57) | 11.83 (-0.56) |

* We show total welfare for the three types of actor; the groups vary in size; average welfare is shown in brackets.

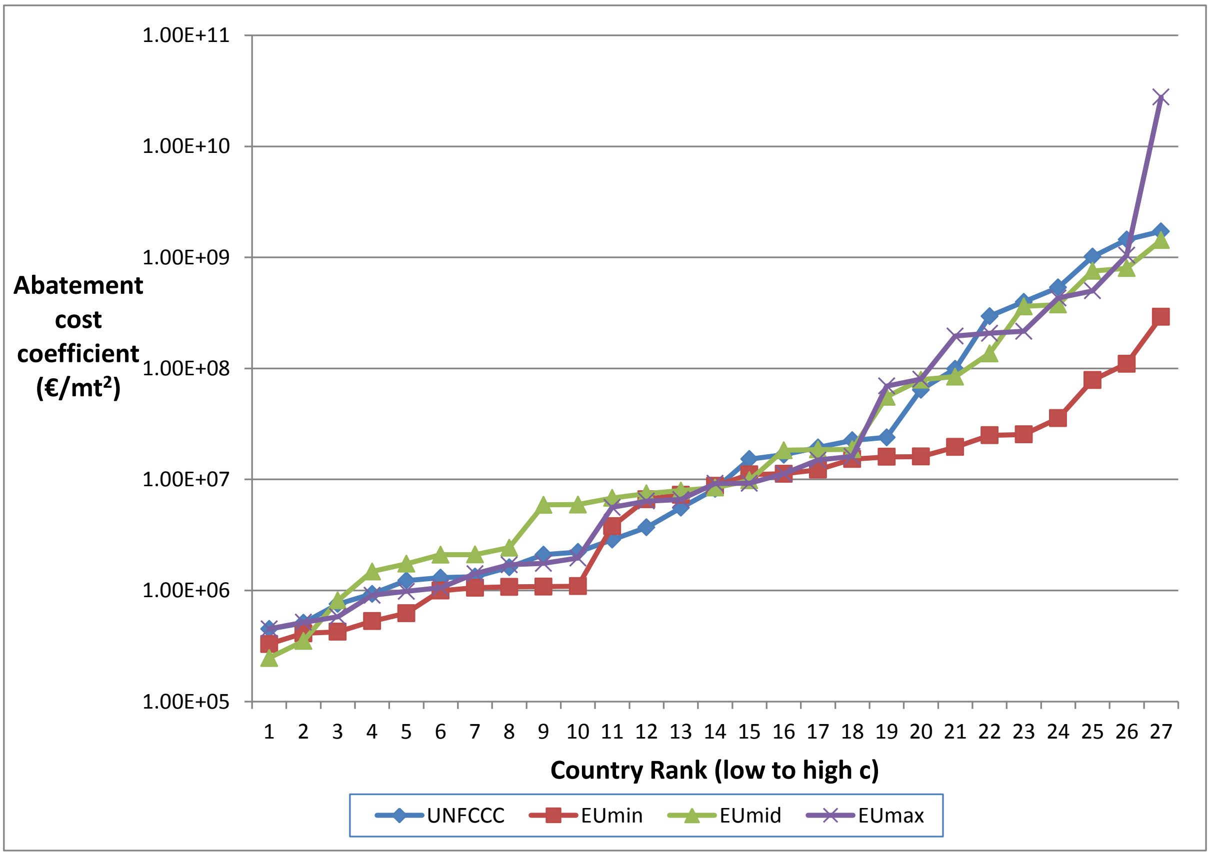


Figure 1. Abatement cost coefficient profiles under UNFCCC, EUmin, EUmid and EUmax calibrations

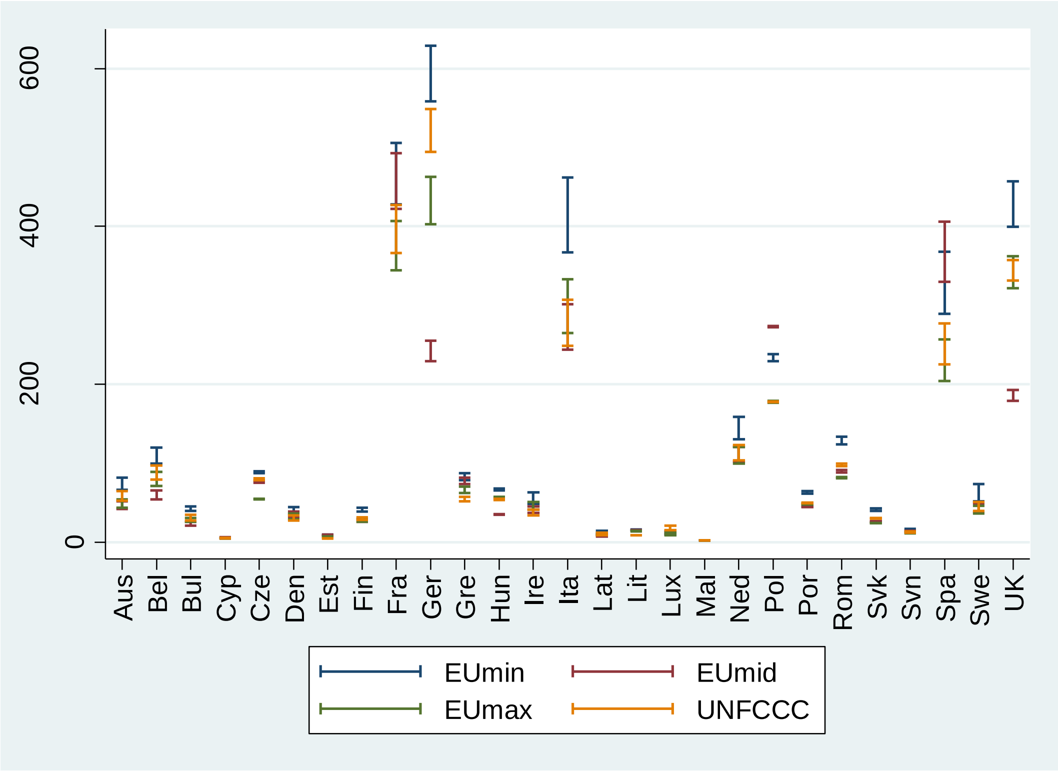


Figure 2. Emission reduction requirements under all calibrations

Table A1. Welfare changes (mln euro) due to market power by actor; EUmin calibration.*

| Strategic Buyers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | 0.00 | 0.00 | 0.00 |
| | 1 | 2.68 | -7.50 | -18.52 | -23.20 |
| | 2 | 15.86 | -1.20 | -19.12 | -27.67 |
| | 3 | 24.43 | 3.10 | -19.74 | -31.82 |

| Strategic Sellers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | 4.18 | 16.84 | 28.29 |
| | 1 | 0.00 | -1.05 | 7.69 | 16.18 |
| | 2 | 0.00 | -9.75 | -7.16 | -2.84 |
| | 3 | 0.00 | -14.39 | -15.82 | -13.91 |

| Fringe welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -7.95 | -23.06 | -35.53 |
| | 1 | -5.23 | 0.63 | -2.52 | -8.79 |
| | 2 | -20.78 | -2.65 | 1.40 | -0.13 |
| | 3 | -30.53 | -6.38 | 0.58 | 1.03 |

* We show total welfare for the three types of actor; the groups vary in size.

Table A2. Welfare changes (mln euro) due to market power by actor; EUmax calibration.*

| Strategic Buyers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic buyers | 0 | | 0.00 | 0.00 | 0.00 |
| | 1 | 3.03 | -0.13 | -0.68 | -2.13 |
| | 2 | 14.16 | 9.37 | 8.51 | 6.36 |
| | 3 | 21.76 | 16.06 | 14.99 | 12.43 |

| Strategic Sellers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | 0.65 | 1.99 | 4.02 |
| | 1 | 0.00 | -2.30 | -3.32 | -3.31 |
| | 2 | 0.00 | -5.84 | -9.62 | -11.98 |
| | 3 | 0.00 | -7.76 | -12.99 | -16.67 |

| Fringe | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -1.26 | -2.68 | -4.90 |
| | 1 | -5.85 | -1.86 | -0.55 | 0.15 |
| | 2 | -18.95 | -10.93 | -6.79 | -3.79 |
| | 3 | -27.67 | -17.77 | -12.19 | -8.16 |

* We show total welfare for the three types of actor; the groups vary in size.

Table A3. Welfare changes (mln euro) due to market power by actor; UNFCCC calibration.*

| Strategic Buyers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | 0.00 | 0.00 | 0.00 |
| | 1 | 2.79 | 1.82 | -2.09 | -4.84 |
| | 2 | 15.49 | 13.90 | 7.65 | 3.22 |
| | 3 | 24.42 | 22.50 | 15.07 | 9.85 |

| Strategic Sellers' welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | 0.21 | 3.22 | 7.43 |
| | 1 | 0.00 | -2.56 | -2.63 | -1.04 |
| | 2 | 0.00 | -6.14 | -10.17 | -11.93 |
| | 3 | 0.00 | -7.27 | -12.60 | -15.52 |

| Fringe welfare | | Strategic Sellers | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Strategic Buyers | 0 | | -0.42 | -4.10 | -8.66 |
| | 1 | -5.51 | -2.41 | -0.09 | -0.16 |
| | 2 | -20.47 | -13.48 | -6.24 | -2.53 |
| | 3 | -29.93 | -21.61 | -12.43 | -7.32 |

* We show total welfare for the three types of actor; the groups vary in size.