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# Grandfathering and the endowment effect

## An Assessment in the context of the Spanish National Allocation Plan

by

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## An Assessment in the context of the Spanish National Allocation Plan

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In this paper, we test the Coase theorem in the context of carbon emissions trading. We investigate whether generating firms were influenced in their operational decisions by the initial amount of grandfathered emissions in the trial period of the European Union Emission Trading Scheme (EU-ETS). Theory suggests that under certain assumptions, the initial allocation should not affect production outcomes. We exploit a non-linearity in the allocation rule of $CO_2$ allowances across coal plants in Spain to test for the relevance of the initial allocation to abatement outcomes. The evidence suggests no systematic relationship between the initial endowment and production decisions at the unit level.

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## 1. Introduction

One of the enduring issues in cap-and-trade systems is whether the free allocation of allowances to affected facilities distorts the operations of those units. It is clear that free allowances improve the profitability of the units so endowed, but as long as the endowment does not change according to the facility's output or emissions, the lump-sum endowment should have no effect on operations. Given that the allowances can be sold in the market, operators should recognize the full opportunity cost involved in emitting a unit of emissions in the same manner as they would if they had not been allocated allowances for free and had to purchase them in the market or at an auction

This independence of operations and allocation, first developed by Coase (1960), has enormous distributive implications. Among other things, it allows for considerations of equity and efficiency to be separated in cap-and-trade systems. Widely varying distributions that can respond to non-economic criteria can be implemented without harming economic efficiency. The counter-argument and the concern has always been that the initial allocation affects operational decisions. By this reasoning, allocating fewer allowances to an affected unit will lead to less production independently of the market price of allowances.

There are several reasons why the independence of the initial allocation of allowances and production decisions might not hold. For example, the presence of transaction costs and imperfections in the market for allowances might invalidate the independence result. A prominent example is the presence of market power in the permits market. Cost-of-service regulation can also lead to different results than those expected under the classical Coasian assumptions. Fowlie (2007) finds evidence of this latter regulatory effect in the context of the $NO_x$ cap-and-trade program.

Endogeneity has made testing the Coasian result of the independence of operations and allocation difficult, if not impossible, in most cases. The initial allocation tends to reflect past production or emissions, which are clear determinants of current output or emissions. Failing to control for the endogeneity of the allocation rule can lead to the misleading conclusion that the allocation has an impact on production decisions, given that past and current emissions are highly correlated. Fowlie and Perloff (2008) are able to overcome this problem by using a random factor in the allocation of allowances in the

$NO_x$ RECLAIM program for the Los Angeles Basin.[2] They are unable to find any endowment effect, thereby providing evidence that, at least in that particular market, the Coasian assumption applies.

The Spanish allocation of allowances in the EU-ETS offers a similar uncorrelated effect. Coal-fired electricity generating units were allocated allowances according to historical emissions, but with a quadratic adjustment that rewarded cleaner generating units. Those units with relatively lower emissions rates were given more allowances compared to similar units with higher than average emission rates. This quadratic term introduces a variation in the initial allocation to Spanish coal-fired generating units that is linearly independent of past emissions. Under some assumptions, this allows for another test of whether the initial allocation has an effect on operations.

In this case, it is also important to control for the effect of carbon prices on operational decisions. Given that cleaner units incur relatively lower cost of $CO_2$ emissions, they might be expected to produce more as a result of the introduction of the European Union's $CO_2$ Emissions Trading Scheme (EU-ETS), the same consequence that could be posited if allocation had an effect on operational decisions. In the case of Spain and given this particular allocation rule, failing to control for the price effect could lead us to conclude that there is evidence of an allocation effect.

The remainder of the paper is structured as follows. In section 2, we discuss in greater detail how the permits were allocated in Spain, and look at some other institutional details that are relevant for our analysis. In section 3, we describe the data used in our empirical application. In section 4 the model is presented and the results are discussed. Section 5 concludes with the main findings.

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[2] Fowlie and Perloff take advantage of the fact that facilities were randomly assigned to two different allocation cycles, which introduces temporal variation in the facility level permit allocations.

## 2. The allocation rule

The allowances in the trial period of the Emissions Trading Scheme were allocated mainly by a grandfathering mechanism. More than 95% of the permits were given for free to polluting units by each government, while less than 5% were auctioned. Therefore, a need arose to set the rules that would determine how many allowances each unit would be entitled. The National Allocation Plan (NAP) of each participating country established the amount of emissions that would be grandfathered to each industrial sector, as well as the allocation rule that would be used to distribute those permits across units, based on several criteria.

As in many other countries, Spain put a considerable weight of the reduction of emissions on the electricity sector, with a resulting initial allocation well below Business-As-Usual (BAU) projections. Not surprisingly, the electricity sector in Spain became a net demander of allowances, this being true for almost every type of thermal technology in aggregate. At the individual level, the balance was negative for most coal and oil units[3]. Combined cycle units had either excess or deficit of allowances[4].

The NAP in Spain was also characterized by an uneven allocation across thermal units, differentiated not only by the three broad types of technology -coal, oil and gas-, but also, to some extent, by the differential efficiency across units within the same technology. Coal units were given the allocation according to their production in the baseline period, corrected by their relative efficiency including a quadratic term based on the emissions rate. Oil units were given substantially less emission allowances than needed, based on their baseline emissions. Given that most combined cycle units were not constructed in the baseline period, they were given emission allowances according to a benchmark emissions rate of 0.365 tons of $CO_2$/MWh and expected production, taking into account their predicted available capacity. To sum it up, the initial allocation of permits to thermal plants in the electricity sector depended on baseline emissions in 2000-2002, the emissions rate and the available capacity of each unit.

[3] There are two units that got divested and thus did not use fully their allowances.

[4] Given the large amount of new entry in the combined-cycle sector, oftentimes the divergence arises due to a difference between the predicted time of construction of the unit and the actual time of initiation of operations.

### a. The non-linear allocation to coal

In this paper, we focus our attention on coal units and exploit a non-linearity in the allocation rule. As detailed in Del Rio (2007), the allocation to coal units was done using the following quadratic formula:

$$a_i = A_{coal} \times \frac{x_i / y_i^2}{\sum_j x_j / y_j^2} \tag{1}$$

where $a_i$ is the individual allocation, $A_{coal}$ the overall coal allocation, $x_i$ are baseline emissions and $y_i$ is the emissions rate. The allocation was further constrained to be at least 55% of the baseline emissions. The rationale behind this rule is that the government decided to reward those units that were more environmentally efficient by granting them more free allowances than dirtier plants.

We do not observe exactly the emissions rate that was used in the NAP, but we observe the baseline emissions of each plant, which allows us to compute their average emissions rate. Given our average emissions rates during the baseline period, we re-construct the rule to test how well we succeed in explaining the differences in the allocation rule. In figure 1, we represent our re-constructed rule against the actual allocation. According to our observed data, the rule was followed accurately by the authorities, taking into account that our data do not exactly match the ones used in the NAP.[5] Therefore, we can rely on the specification of the rule as the cornerstone to build our empirical strategy, and use the re-constructed rule as an instrument for the allocation itself.

The fact that there is a clear allocation rule for coal plants opens the door to potentially identify the endowment effect in this group of plants, as long as we succeed in controlling for other aspects of these plants that affect their production decisions and are correlated with their emissions rate, which enters the allocation rule non-linearly. Under appropriate identifying assumptions, we can consider part of the variation in the allocation rule to be exogenous and use this fact to explore whether the initial allocation systematically affected the production of the units.

[5] There are two observations that lie further away from our predicted rule. These are units that have measured emissions rates that are significantly different from benchmark estimates of their type of technology. It might be that the government used different estimates than the ones in our data set, or that the allocation differed due to some other unobserved factors.

The basic identifying assumption is based on the fact that the marginal cost of the allowances has a relationship that is primarily linear with the emissions rate. We assume that the non-linear effect of the emissions rate in the allocation rule affects production choices only through its influence on the initial allocation. Even though this is a strong assumption, it is common to treat the costs of pollution as being linear in the level of production, as emissions are strongly correlated with the use of inputs. In many instances, and absent actual measurements of emissions at the unit level, it is common to use benchmark emissions rates to compute an estimate of total emissions, by simply multiplying the emissions rate with total electricity produced in a linear fashion.

### *b. Other institutional details*

The particularities of the Spanish electricity sector make it relevant to consider other potential institutional features that might have affected the allocation decisions. Among these, we pay special attention to national subsidies to coal production. On the one hand, if the subsidized quota equals the annual production for most units, we might expect coal units not to react at all to the introduction of the EU-ETS, but rather to produce only their subsidized quantity.

For this reason, we have collected a data set containing the subsidized quotas of each plant, as well as their annual production. According to our data, the proportion of subsidized coal varies considerably across units. There are some plants that only operate with imported coal, which do not receive any subsidies. Other plants are given a subsidy of at most 60% of their potential annual production, and, on average, 35%. In practice, this implies that units cover on average around 50% of their actual production with the subsidies.

Still, the national subsidies to production can have an impact on the overall production decisions at the unit level. They represent a reduction of the cost of the units that receive those subsidies, which makes them more attractive relative to those plants that operate with imported coal and receive no subsidies at all. Therefore, we include the quota of each unit in the analysis.

## 3. The data

We use a newly constructed data set that contains daily electricity generation at the unit level for Spanish thermal technology from 2002 to 2006[6]. This data set contains both MWh produced at a given day, as well as unit available capacity net of forced outages and planned shut downs. We combine these data with other market outcomes, such as the day-ahead and final electricity prices, $CO_2$ prices and aggregate output by other types of technology. We also collect characteristics at the unit level: maximum available capacity, type of fuel used[7], vintage, generating company, geographic location, and subsidized national quota.

Together with production and characteristics at the unit level, we have annual information on $CO_2$ emissions at the plant level[8] from the National Register, for the years 2001-2004. These data are merged with the emissions data during the EU-ETS trial period 2005-2007. We estimate emissions rates at the plant level for each year, by dividing total emissions by total output at the annual level. Emissions rates do not fluctuate much at the unit level and are consistent with typical fuel benchmark emissions for the generation plants involved. Therefore, they are strongly correlated across units that use the same fuel. Among coal units, imported coal plants have the lowest emissions rate around 0.90 tons/MWh, whereas lignite units are the dirtiest with an emissions rate ranging 1.00 to 1.10 tons/MWh. We use the average emissions rate for each unit.

We focus on generation decisions for coal units in our empirical strategy to identify the effect of the initial endowment. We construct a measure that normalizes the grand-fathered allocation, to capture how the relative allocation across units differed. We do this so that the main source of endogeneity in the rule, the baseline emissions, is cancelled out. We define the relative allocation $\gamma_i$ as:

$$\gamma_i = \frac{a_i / \sum_{j=1}^{N} a_j}{x_i / \sum_{j=1}^{N} x_j} = k \times \frac{a_i}{x_i} = cons \times \frac{1}{y_i^2} \qquad (2)$$

6 Data are publicly available at the system and market operator websites, www.esios.ree.es and www.omel.es.

7 The input types are combined cycle, oil, imported coal, anthracite coal, black lignite and brown lignite, following the categorization in the Annual Statistics by Red Eléctrica Española.

8 A plant is composed by one or more units. In the data set, the largest plant contains four units.

where $a_i$ represents the allocated permits, $x_i$ stands for the total number of emissions in the baseline period 2000-2002 and $y_i$ is an emissions factor. Thus, if all plants had been given permits proportionally, then the relative allocation $\gamma_i$ would equal one for all units and we would have no variation in the data. We can also interpret this variable as a normalized ratio of how many permits a unit was given relative to the needed permits to produce as BAU, according to the baseline period. As highlighted by equation (2), $\gamma_i$ is inversely related to the emissions rate.

In figure 2 we can visually check that the data set reflects the quadratic nature of the allocation rule. We observe that cleaner units are given more pollution permits than if the rule had been proportional to baseline emissions, whereas dirtier plants are punished with less grandfathered permits. There are several reasons for the rule not fitting exactly into the non-linear pattern. On the one hand, we do not observe the exact baseline emissions that were used to compute the allocation, but have to reconstruct it from the observed data. On the other hand, there might have been some minor departures from the rule based on other criteria that we do not observe. We use therefore the re-constructed rule to instrument for the actual allocation, to address the possible endogeneity that might be left in the actual allocation rule.

Summary statistics for the coal units in our data set are presented in Table 1. In this table, we compare the characteristics of units with $\gamma_i$ either below or above one. There are eight plants with $\gamma_i$ smaller than one, and eleven plants that are given more permits than proportional, totaling 19 plants, which are composed by a total of 36 units. The type of coal that they use is correlated with their emissions factor. For example, lignite and anthracite units pollute more than imported coal units. Given the nature of the rule, the emissions rate of units with gamma lower than one, which are dirtier, is considerably higher than the one for clean coal plants. We also observe that the efficiency of the units is related to other characteristics. Cleaner units are smaller in size and produce less on average. However, their utilization rate is higher. In our econometric specification, we control for these aspects mainly in the form of a unit-specific fixed effect.

# 4. Model and Results

## a. Model

We model the choice of a coal unit deciding whether to produce or not on a given day. We represent generating utilities providing supply of electricity in a day-ahead wholesale electricity market on a daily basis. Given that generating units produce on those days in which their opportunity cost are below the market price, the decision to produce or not on a given day is a function of the expected average price for that day as well as the opportunity costs that the unit incurs in doing so.

The decision can be represented with the following inequality:

$$on_{it} = \begin{cases} 1 & \text{if} \quad p_t \geq c_{it} + e_i EUA_t + \theta\gamma_i + u_{it} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

where

$p_t$ = daily electricity price

$c_{it}$ = marginal cost for a given unit

$e_i$ = emissions rate at the plant level

$EUA_t$ = daily cost of the $CO_2$ allowances weighted by unit emissions rate

$\gamma_i$ = relative allocation variable at the unit level

$u_{it}$ = other opportunity costs for a given unit

A given unit switches on as long as its total opportunity cost is below the price in the market. The opportunity cost depends on the cost of the inputs, as well as some other factors that could affect decisions at the unit level. Note that if agents internalize the cost of the emissions, this opportunity cost also includes the cost of the emissions, as highlighted by the above expression. Therefore, we expect daily production decisions to be correlated with the pollution costs of the units, as well as the market price in the market. We also include our initial allocation variable to see how it affects production choices. Under the Coasian assumptions, it should have no effect on the opportunity cost, which implies $\theta = 0$.

If agents are rational, one should observe firms fully internalizing the cost of the emissions. This is a necessary condition for the Coase theorem to hold, given that the market mechanism will lead to an efficient outcome as long as the units internalize the costs of the environmental externality. Because the market for $CO_2$ permits is European wide, the permits market can be considered to be perfectly competitive. Under the additional assumption of no transaction costs and rational agents, production choices should not be affected by the initial allocation of permits.

The presence of transaction costs could affect the production decisions and thus break the independence between the initial allocation and the final outcome. In this sense, the opportunity cost of using a particular unit is relatively higher if the firm has to acquire the permits in the market, and does not have them for free. The transaction cost is going to be negatively related to the initial amount of grandfathered emissions, and could effectively increase the output of units that benefited the most from the grandfathering process.

If firms internalize the transactions costs when using their grandfathered permits, the presence of transaction cost increases the average cost of the emissions, and this increase is correlated with the size of the initial allocation. In this case, a firm incorporates the expected transaction costs since the beginning of the year, as it understands that by using grandfathered permits today it will not be able to use them in future stages of the year. Units with a more favorable allocation then face a relatively lower opportunity cost than the others overall.

Other theories that break the Coasian equivalence result, such as a behavioral endowment effect, predict similar results. The general conclusion is that, if the initial allocation matters, it tends to increase the production of those units that benefited the most from the initial endowment, in detriment of the production generated by other units. Given that $\gamma_i$ is a relative measure that is positively related to the amount of grandfathered allowances, an endowment effect in our model is captured by $\theta < 0$ in equation (3): units with a more favorable allocation face a relatively smaller opportunity cost than other units, all else equal[9].

[9] Following the example with transaction costs, a more generous initial allocation diminishes part of the transaction costs of acquiring permits in the market, thus lowering the relative opportunity cost of the unit.

Re-writing expression (3), we derive the following relationship when a unit switches on:

$$\beta_1 p_t + \beta_2 e_i EUA_t + \beta_3 \gamma_i \geq \xi_{it} \tag{4}$$

where $\xi_{it}$ represents the variable cost of the unit without the effects of the EU-ETS, which equals $c_{it} + u_{it}$ in expression (3).

The implications of the model on the parameters above are twofold:

$$\begin{cases} H1: \;\; \beta_1 \approx -\beta_2 \Rightarrow \text{Price effect or cost internalization} \\ H2: \;\; \beta_3 \approx 0 \quad\;\; \Rightarrow \text{No endowment effect } (> 0 \text{ otherwise}) \end{cases}$$

In the first hypothesis *H*1, firms internalize the cost of the emissions fully and incorporate the cost when choosing their production decisions. As explained above, this is a necessary condition for achieving the efficient abatement outcome, but not sufficient. In the second hypothesis *H*2, we test whether the initial allocation had a significant effect on production outcomes, by assessing whether it significantly increased or decreased the opportunity cost of using a given unit over all the EU-ETS period.

### b. Base case specification

We model the production decisions in reduced form, as depending on several variables that might determine the usage of a given plant, as suggested by the model above. We observe production outcomes at the unit level on a daily basis. From the outlined model, we expect a particular unit to switch on if the average price for a particular day is sufficiently high. In the presence of the EU-ETS, this probability is going to be correlated to the cost of the emissions if firms internalize this cost appropriately, implying that higher costs of emissions makes switching on a dirty coal plant less likely.

In our baseline specification, we evaluate a linear probability model in which we represent the probability of a unit being switched on as follows:

$$on_{it} = \beta_1 p_t + \beta_2 e_i EUA_t + \beta_3 \gamma_i + \beta_4 q_{it} + \mu_i + \varpi_t + \varsigma_t + \varepsilon_{it} \tag{5}$$

where

$p_t$ = daily electricity price

$e_i$ = emissions rate at the plant level

$EUA_t$ = daily cost of the $CO_2$ allowances weighted by unit emissions rate

$\gamma_i$ = relative allocation variable at the unit level

$q_{it}$ = relative quota of at the plant level

$\mu_i$ = unit fixed-effect

$\varpi_t$ = weekday fixed-effect

$\varsigma_t$ = year-month fixed-effects

Note that the time fixed-effects are important to capture other elements that affect production decisions and are not included in the model. One of the most relevant omitted variables is the price of gas and coal, which affects the relative order of coal units in the supply curve. Other relevant variables such as rainfall, which affects the production frontier of hydraulic units and, thus, might affect production strategies of each firm, are also captured by these controls. Monthly and yearly controls capture the variation in these variables, given that input prices and rainfall seasonality do not tend to fluctuate abruptly within a month.

The results for two different specifications are presented in table 2.1. We observe that the coefficients on the price and the cost of the allowances are very similar, with opposite sign. We cannot reject the null hypothesis that both coefficients are of the same magnitude. The F-test values for this test are below 1 in all of the specifications, which corresponds to a p-value around 0.75. These results provide evidence that firms did internalize the cost of the emissions fully during this period, passing it through to the prices in the electricity market, as one would expect from profit-maximizing agents.

The results also show that there is no strong evidence that the initial allocation variable had an effect on production outcomes. The effect is positive in the two specifications, albeit not significant. These results suggest that there is no strong or clear relationship between the initial allocation and production outcomes. The national subsidies do significantly increase the probability of a firm running in a given day. This variable is significant in all specifications and has the expected sign. The subsidy effectively reduces the opportunity cost of the units, which produce more often than units with relatively lower production subsidies, all else equal.

In table 2.2, we instrument for the allocation rule with the re-constructed rule. We observe that the instrument reduces the effect of the initial allocation. This is an intuitive result. If there is some endogeneity left in the allocation rule, which is unobserved, it will tend to be correlated with production at the unit level. This will overestimate the endowment effect. Using the instrument reduces the coefficient on the endowment variable towards zero, as the endogenous part of the allocation is removed.

### *c. Instrumental variables*

Given the possible endogeneity of electricity prices, we construct a series of instruments based on weather data. The effect of weather on price is driven by its impact on electricity consumption, which we capture by looking at weather data in capital cities in Spain in different regions of the Peninsula. Electricity prices are correlated with weather data, which provides a valid first stage for the wholesale price. Our exclusion restriction is that production choices respond to weather changes only through its effects on price.

In regression 3.1 we present results from a first stage regression of prices on these weather data, in which we use temperature and humidity levels in the city of Madrid[10]. The price at the electricity market is regressed on daily mean temperatures, as well as maximum and minimum temperatures and humidity, after partialling out the rest of the regressors in our base case specification. Weather is effectively a strong predictor of prices, as presented in table 3.1., with an F value of 13.41. This provides a clean instrumental variables strategy to address the endogeneity concerns in our base case regression. One can see that the relationships are as expected. Extreme temperatures increase the market price, whereas average temperature has a negative impact on price[11]. Humidity does not seem to separately explain the variation in prices.

The results for the two specifications of the base case using instrumental variables are presented in table 3.2., in which we also instrument for the allocation rule. The coefficient on price is very close to the one on the cost, with the opposite sign. Again, we cannot reject that those coefficients are equal, supporting the hypothesis that firms internalized the cost of the emissions fully. The coefficient on the initial allocation is

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[10] Including weather measures from other cities does not change the results of our estimation.

[11] In Spain, electricity demand is higher in average in the winter season than in the summer season.

closer to zero than in the previous specifications, and the national subsidies are still significant and of the expected sign. In our preferred specification, in which we instrument for both prices and the initial allocation, the coefficient on gamma is very close to zero, providing evidence that the grandfathered permits did not affect production choices of electric utilities.

## 5. Conclusions

In this paper we have addressed the question of whether generating firms in the Spanish electricity wholesale market were affected by their initial allocation of allowances. Given the endogeneity of the allocation rule, we have focused on the coal units, for which the allocation design, which rewarded cleaner units proportionately more, introduced some variation. After controlling for the price effect of the carbon price on production choices, a re-constructed allocation rule could be used as an instrument for the actual initial allocation. We have looked at how the initial allocation affected production decisions by looking at how it induced deviations in the utilization of the units with a linear probability model.

We presented two hypotheses. Under a Coasian framework, firms should internalize the cost of the emissions fully ($H1$). Furthermore, the initial allocation should not matter ($H2$). Under the alternative hypothesis, firms would internalize the cost of the emissions partially and the initial allocation could have a positive impact on production decisions, the so-called endowment effect. The evidence shows that there is not a strong relationship between the initial allocation and production decisions. Furthermore, we cannot reject that firms internalized the cost of the emissions fully.

The implications of this finding are in line with previous results in the literature, as we do not find evidence against the validity of the Coase theorem in this permit market. Results suggest that, under certain conditions such as a functioning competitive trading mechanism and profit-maximizing firms, a separation between efficiency and distributional aspects when designing a cap-and-trade program is feasible.

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## Tables

**Table 1:** Characteristics of plants depending on their relative allocation in 2001-2007

| Values | Dirty $\gamma < 1$ | Clean $\gamma > 1$ | Overall |
|---|---|---|---|
| Average emissions factor ($tCO_2/MWh$) | 1.04 | 0.92 | 0.97 |
| Primary type of coal used | HA, LN, LP | HA, LN, CI | - |
| Average max available capacity (MW) | 633 | 581 | 603 |
| Average annual production (GWh) | 4101 | 3631 | 3829 |
| Average running percentage (%) | 71 | 76 | 74 |
| Average availability (%) | 88 | 91 | 90 |
| Observations at the unit level | 16,060 | 22,995 | 78,511 |
| Observation at the plant level | 8,395 | 12,045 | 20,440 |

Notes: HA = Anthracite, LN = Black Lignite, LP = Brown Lignite, CI = Imported Coal.

**Table 2.1:** Base case On/Off linear probability model

| | (1) | (2) |
|---|---|---|
| **price** | 0.046 | 0.046 |
| | (5.53)** | (5.52)** |
| **e*EUAt** | -0.042 | -0.042 |
| | (2.71)* | (2.71)* |
| **gamma** | 0.169 | 0.103 |
| | (0.68) | (0.58) |
| **rquota** | | 0.665 |
| | | (2.87)** |
| **Weekday FE?** | YES | YES |
| **Month FE?** | YES | YES |
| **Year FE?** | YES | YES |
| **Observations** | 65,736 | 65,736 |
| **Number of id** | 36 | 36 |

Robust t statistics in parentheses clustered at the unit level
* significant at 5%; ** significant at 1%

**Table 2.2:** Base case with re-constructed rule as instrument

| | (1) | (2) |
|---|---|---|
| **price** | 0.046 | 0.046 |
| | (5.64)** | (5.64)** |
| **e*EUAt** | -0.043 | -0.043 |
| | (2.87)** | (2.85)** |
| **gamma** | 0.104 | 0.055 |
| | (0.39) | (0.37) |
| **rquota** | | 0.670 |
| | | (2.85)** |
| **Weekday FE?** | YES | YES |
| **Month FE?** | YES | YES |
| **Year FE?** | YES | YES |
| **Observations** | 65,736 | 65,736 |
| **Number of id** | 36 | 36 |

Robust t statistics in parentheses clustered at the unit level
* significant at 5%; ** significant at 1%

**Table 3.1:** IV On/Off linear probability model – First stage

| | price | |
|---|---|---|
| **Temp** | -0.126 | (6.79)** |
| **Max_temp** | 0.081 | (6.38)** |
| **Min_temp** | 0.042 | (3.65)** |
| **Humidity** | -0.002 | (0.82) |
| **Observations** | 1,793 | |
| **F** | 13.41 | |

Other exogenous variables are partialled out
Robust t statistics in parentheses clustered at the unit level
* significant at 5%; ** significant at 1%

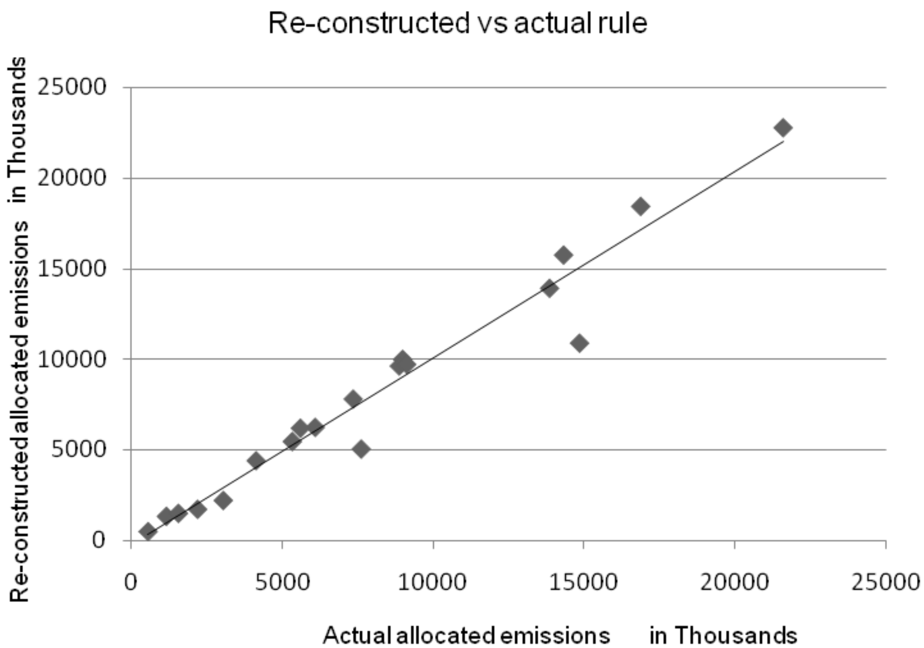
**Table 3.2:** IV On/Off linear probability model

| | (1) | (2) |
|---|---|---|
| **price** | 0.088 | 0.088 |
| | (5.94)** | (5.95)** |
| **e*EUAt** | -0.083 | -0.083 |
| | (4.72)* | (4.71)* |
| **gamma** | 0.043 | -0.007 |
| | (0.16) | (0.05) |
| **rquota** | | 0.665 |
| | | (2.88)** |
| **Weekday FE?** | YES | YES |
| **Month FE?** | YES | YES |
| **Year FE?** | YES | YES |
| **Observations** | 64,548 | 64,548 |
| **Number of id** | 36 | 36 |
| **Instruments** | rule, temp, temp_max, temp_min, humid in MAD | |

Robust t statistics in parentheses clustered at the unit level
* significant at 5%; ** significant at 1%

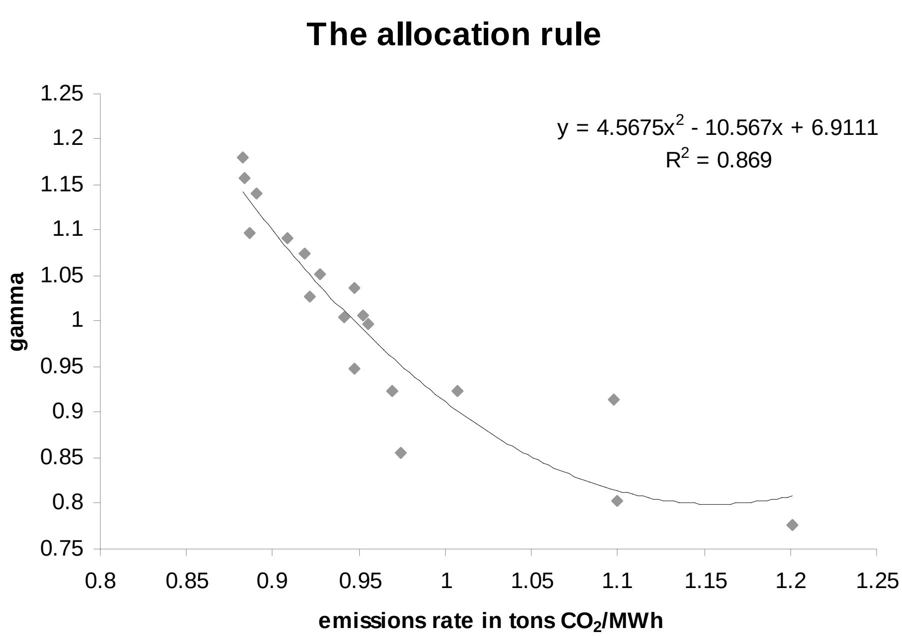
# Figures

**Figure 1:** The fit of the theoretical rule to the actual allocation




Source: Own elaboration.

**Figure 2:** The non-linearity in the grand-fathered permits




Source: Own elaboration.