"Industrial Emissions Abatement: Untangling the Impact of the EU ETS and the Economic Crisis"

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Abstract

In this study we use historical emission data from installations under the European Union Emissions Trading System (EU ETS) to evaluate the impact of this policy on industrial greenhouse gas emissions during the first two trading phases (2005-2012). As such the analysis seeks to disentangle two causes of emission abatement: that attributable to the EU ETS and that attributable to the economic crisis that hit the EU in 2008/09. Using a panel data approach the estimated emissions reduction attributable to the EU ETS is about 21% of the total emission abatement during the observation period. These results suggest therefore that the lion's share of abatement was attributable to the effects of the economic crisis, a finding that has serious implications for future policy adjustments affecting core elements of the EU ETS, including the distribution of EU emission allowances.

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1. Introduction:

The impact of climate change, including rising sea levels and the melting of the polar ice caps, is today well known, as is its principal cause, the emissions of manmade greenhouse gases (GHG). Indeed, this causality has been acknowledged by several national governments and various treaties have been signed to counter the trend. For example, under the Kyoto Protocol (KP), the European Union (EU) agreed to cut its 1990 levels of GHG emissions by 8% in the first commitment period (2008-2012) and by 20% in the second commitment period (2013-2020) (United Nations 2008).

To achieve these goals the EU Emissions Trading System (EU ETS) was launched to cut the costs of industrial GHG emissions by relying on market mechanisms. Since its introduction the policy has developed considerably, experiencing a number of turbulent phases as well as the impact of the 2008/09 economic crisis. Undoubtedly, the economic downturn has also affected industrial GHG emissions. However, it is unclear how great this impact has been and what share of the reduction in emissions can be attributed to the EU ETS and what share can be attributed to the economic crisis. Untangling the effects of the EU ETS from those of the economic crisis on industrial emissions abatement is the first contribution made by this paper.

With this objective in mind, this study adopts a panel data approach to untangle the respective impacts. What distinguishes this paper from previous studies is that, instead of relying on estimated emission data, we use the verified emission data reported by each installation under the policy. As such our results are not dependent on forecasts that are subject to a certain degree of uncertainty but rather are based on actual historic data. This constitutes the second contribution of this paper.

The study is organized as follows. First, we describe the EU's system for trading emissions and review the literature dealing with its impact on emission reduction. We then present the data used in the regression, along with an overview of GHG emissions. This section is followed by an outline of the model's specifications and the estimation technique. We then present and discuss our results. Finally, we draw the main conclusions and identify the primary policy implications for the EU ETS.

2. Policy description:

The EU ETS was officially launched in 2005. It was the first and largest market-based regulation mechanism to reduce GHG emissions and can be considered the "flagship" policy of the European Commission (EC) in its fight against climate change. To date, it operates in the 28

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member states of the EU, plus Lichtenstein, Norway, and Iceland. The main principle of the EU ETS is "cap and trade", where cap refers to an EU-wide cap for GHG emissions set by the EC that is progressively reduced each monitoring period. Companies under the cap are required to cover their emissions with EU emission allowances (EUAs), which are handed out free of charge or auctioned. EUAs, however, can be traded among facilities or countries enabling those that run short of allowances to purchase additional EUAs and so avoid penalization in the event of non-submission. More specifically, installations subject to the policy have to surrender one allowance for every tonne of CO_2 that they emit; otherwise, they are subject to heavy fines.

Currently, over 11,000 installations are covered by the policy, accounting for around 45% of the participating countries' total GHG emissions (European Commission 2013). Since the main aim of the policy is to cut industrial GHG emissions only the major emitting sectors (including, oil refineries, steel works and producers of iron, aluminum, metals, cements, lime, glass, ceramics, pulps, cardboards, acids, and bulk organic chemicals) and the energy sector are subject to the policy. However, energy production and electricity/heat production account for the lion's share of GHG emissions at around 32% of the EU-27's total GHG emissions (European Environment Agency n.d.).

EUAs are distributed by auctioning or are handed out for free. In the first two phases of the EU ETS (2005-2012) EUAs were typically given away for free with just a small number being auctioned off; however, today auctioning has become the default method for allocating allowances. This applies particularly to the power generation sector,[1] which from 2013 on is required to buy all of its allowances, because previously the sector was able to pass on its emission costs to final consumers despite receiving allowances for free creating windfall profits (Fabra & Reguant 2013; Point Carbon 2008). In other sectors, such as manufacturing, the number of free allowances has been reduced gradually from a free-of-charge share of 80% in 2013 to a scheduled 30% in 2020. Allowances that are not given away for free are auctioned at the European Energy Exchange (EEX) or ICE Futures Europe (ICE) which serves as the United Kingdom's platform.

Since its launch in 2005, the EU ETS has gone through a number of changes each marking the beginning of a new phase in EU policy. The first phase of the EU ETS (2005-2007) was a pilot period of "learning by doing" (The European Commission 2014). The main achievements during this phase were the creation of an EU-wide database recording GHG emissions from all

[1] Under Article 10c of the revised EU ETS Directive Bulgaria, Cyprus, the Czech Republic, Estonia, Hungary, Lithuania, Poland, and Romania can hand out a certain number of their EUAs free of charge through to 2020, albeit in a progressively decreasing manner.

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participating installations. This was essential for calculating the number of EUAs to be handed out free of charge in the following phase. Given the absence of reliable emission data prior to 2005, the initial emissions cap and the corresponding amount of allowances were based on historical emission data (Georgiev et al. 2011). However, emission forecasts greatly exceeded actual emissions, which resulted in an oversupply of EUAs and meant that in 2007 the price of the EUAs fell to zero (Griffin 2009).

In the second phase (2008-2012) the EU ETS underwent several changes. First of all, Lichtenstein, Norway, and Iceland joined the system increasing the number of participants to 30[2]. The cap was tightened by 6.5% with respect to 2005 to counter the price deterioration while EUAs from the first phase could not be transferred to the second, thus tackling the same problem. Moreover, a certain proportion of EUAs (around 10%) were auctioned off among the installations. From 2008 onwards, the policy adhered to the goals set by the Kyoto Protocol, namely, cutting its 1990 levels of GHG emissions by 8% in the period through to 2012. However, designed as it is to cut industrial GHG emissions, the EU ETS was strongly influenced by the economic crisis that began in late 2008. The crisis led to an oversupply of EUAs and a fall in their price (see below for a more detailed discussion).

The EU ETS is currently in its third phase (2012-2020), characterized by even more radical policy changes than was the case in the transition from phase I to II. In the third phase a single EU-wide cap has been set as opposed to national caps. As discussed above, the number of allowances being auctioned has increased sharply. Finally, the cap on emissions is reduced annually by 1.74% so as to achieve an emission abatement of 21% in 2020 compared to 2005 level.

3. Literature Review:

The literature discussing the EU ETS examines many facets, including evaluations of investment incentives in low-carbon technology (Martin et al. 2011; Rogge et al. 2010), competitive analyses (Graichen et al. 2009), and appraisals of its impact on profits and product prices (Point Carbon 2008; Sijm et al. 2006). Several studies also evaluate its impact on GHG abatement and, given that this is the specific focus of the present study, only papers dealing with this question are discussed in detail below.

One of the first attempts at evaluating the effectiveness of the EU ETS in reducing GHG emissions was conducted by Ellerman and Buchner (2008). The authors artificially create a counterfactual (hypothetical emissions without the EU ETS) and compare these emissions to real

[2] Romania and Bulgaria joined the EU ETS on accession to the EU in 2007

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emissions from sectors under the policy. They do this by using emissions from 2002 as a baseline and projecting these figures through to 2006 taking into account such factors as real GDP growth, energy intensity of the EU economy and single sectors, energy prices and the carbon intensity. The authors conclude that emissions were reduced by 130-200 megatonnes (MgT) in 2005 and by 140-220 MgT in 2006 by the EU ETS.

Anderson and Di Maria (2010) also seek to identify the abatement achieved by the EU ETS. In line with Ellerman and Buchner (2008), the authors forecast business-as-usual (BAU) emissions, and compare forecasts with observed emissions from participating installations for the first phase of the EU ETS. However, their approach differs from that adopted by Ellerman and Buchner as they estimate BAU-emissions using a dynamic panel approach with the baseline emission data being taken from Eurostat and matched to the participating sectors of the EU ETS. By comparing BAU-emissions to real data for the first phase, the authors estimate a GHG abatement of 247 MgT and, moreover, a year-on-year decrease in the rate of abatement.

The two studies reviewed above only examine the first phase (2005-2007) of the EU ETS. Georgiev et al. (2011), however, extend Ellerman and Buchner's (2008) approach to the first two years of the second phase (2008-2009). The main difference is that they use emissions from the first phase of the EU ETS as a baseline; specifically, they draw on the first three years of the policy as BAU-conditions for the forecast. But, as discussed in Georgiev et al. (2011), the resulting projection and, hence, the GHG abatement should be treated with caution given that the number of observations in the projection is insufficient to be robust and, moreover, they question the reliability of the BAU conditions owing to the impact of the 2008/09 economic crisis.

As the three studies discussed above evaluate the EU ETS before the 2008/09 economic crisis or by employing BAU-conditions that do not capture the impact of the latter, their results fail to account for the major economic changes experienced by the EU and obvious impacts on industrial GHG emissions. Accordingly, the BAU conditions for the emission projections need to be adjusted to ensure forecast reliability.

Taking the influence of the economic recession into account, Declercq et al. (2011) set up a counterfactual scenario by forecasting the GHG emissions for the power sector to determine 2008 and 2009 abatement under the EU ETS. As determinants they consider the demand for electricity, the CO_2 price, and fuel prices. The estimated effect of the economic downturn results in an abatement of 150 MgT of CO_2 for the power sector over the years 2008 and 2009, with the reduction in demand for electricity accounting for a major share of abatement.

The most striking characteristic of any evaluation of the literature assessing the EU ETS and its effect on GHG emissions is that nearly all the studies[3] create counterfactuals artificially using BAU forecasts. As Ellerman and Buchner (2008) point out, there are "better and worse" estimates for the counterfactual, but ultimately the results are obtained from a "what-would-have-been" analysis as the counterfactual can never actually be observed. In contrast to the evaluations reviewed above, the analysis reported here uses historical data to evaluate the impact of the EU ETS and of the economic crisis on emissions reduction. We exploit the fact that, since its introduction in 2005, the EU ETS has developed considerably and that a good body of ex-post data is now available. In this respect, and to the best of our knowledge, this study is the first attempt to analyze the performance of the EU ETS in emission reductions based on ex-post historical data and to account for the effects of the 2008/09 economic crisis.

4. Data and Sources:

The original data sample used in this analysis includes 30 countries and covers a time span from 2005 to 2012. With the exception of Norway, Lichtenstein, and Iceland, all countries in the EU ETS belong to the European Union. However, a full data set is only available for 25 countries, since Bulgaria and Romania did not join the EU and become participants in the EU ETS until 2007[4]; hence, reliable emission data are only available from 2007 onwards. Likewise Norway, Lichtenstein, and Iceland did not become members of the EU ETS until 2008 and so data are only available for the second phase of the policy. Thus, our eventual sample includes data representing the EU 25 (that is, the EU 28 minus Bulgaria, Rumania and Croatia).

The data sources for this study are Eurostat and the Community Independent Transaction Log (CITL). The latter provides the verified emissions of all national stations under the regulatory system. All other data were extracted from Eurostat.

Table 1 provides an initial description of the evolution in the GHG emissions of the EU 25 countries and the impact of the economic crisis. Total GHG abatement is calculated as the difference between the 2005 and 2012 emissions. Accordingly, there was an average reduction of 11.778 MgT of GHG emissions per country during the observation period, equivalent to an average percentage reduction of 14.21% for each member state. The most striking revelation however is the impact of the economic downturn on industrial GHG emissions, with an average

[3] One exception is the firm-level research conducted by Abrell et al. 2011. To assess the impact of the EU ETS on emissions at the firm level the study uses panel data from more than 2000 participating firms for the years 2005-2008. However, the study was conducted before the economic crisis and so does not assess the effect of the recession on CO_2 emissions.

[4] Croatia has only been an official member of the EU ETS since 2013 and so no emission data are yet available.

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reduction per country of 10.174 MgT of GHG emissions in sectors under the EU ETS between 2008 and 2009, that is a reduction of 10.48%. Yet, percentage changes as high as 23.36% were also observed. This reduction, achieved in just one year, is equivalent to 86.38% of the total GHG abatement achieved in the first and second phase of the EU ETS. Subsequently, most countries in the EU 25 experienced an economic upturn that led to a recovery in the GHG emission rates in the following year. The last column in Table 1 illustrates this by reporting a negative average abatement of -5.66% for 2010; in other words, an increase in emissions.

(Insert Table 1 around here)

However, this 'rebound' in GHG emissions is much lower than the impact of the 2009 economic crisis, suggesting that the economic downturn continued to have an impact on industrial emissions after 2009. This is particularly true of countries such as Portugal and Spain that continued to present reduced rates in 2010. Unsurprisingly, the reduction in emissions not directly attributable to the EU ETS led to an oversupply of emissions certificates, which are at the heart of the efficient operation of the EU ETS (see below for a more detailed discussion). Yet, the above calculation fails to untangle the impact of the EU ETS on emissions and only reveals that emissions suffered a strong external shock (the economic crisis). Clearly, any regression that seeks to capture the effect of the policy needs to bear this shock in mind.

5. Empirical Strategy:

In line with the above reasoning we present the following regression equation. The model specification is inspired primarily by Anderson & Di Maria (2010), who use a flow adjustment model. In such models the dependent variable is described using a lagged variable, prices and other explanatory variables. The main difference is that, instead of using electricity, gas, coal, and oil prices, we employ the respective consumption of these commodities.[5] Hence, the EU ETS GHG emissions can be estimated with the following equation:

$$CO2_{i,t} = \beta_i + \beta_1 CO2_{i,t-1} + \beta_2 nace\_d_{i,t} + \beta_3 c\_gas_{i,t} + \beta_5 c\_coal_{i,t} + \beta_6 c\_elec_{i,t} + \beta_7 crisis_{i,t} + \beta_6 policy_{i,t} + \varepsilon_{i,t}$$

[5] The main reason for this adjustment is that sufficient price data could not be obtained. While data for gas/electricity prices can be extracted from Eurostat, prices for oil and coal are not available. One source for these prices is the International Energy Agency, though the data are not available free of charge. Nevertheless, oil and coal prices can be obtained at an average level for the EU. Similar model specifications were estimated as was done for the reference model in this study but using prices. However, the overall statistical quality of these regressions was much worse than that obtained from the alternative specification. For this reason they are not discussed any further in this paper. The resulting regressions are included in the appendix (Table 1A).

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where the dependent variable $CO2_{i,t}$ is the GHG emissions taken from CITL, β_i is the constant in the model, $CO2_{i,t-1}$ are the lagged GHG emissions, $nace\_d_{i,t}$ is the economic industry index for the electricity sector, $c\_gas_{i,t}$, $c\_coal_{i,t}$,and $c\_elec_{i,t}$ are the consumption of gas, coal, and electricity, respectively, $crisis_{i,t}$ is the dummy variable describing periods of economic downturn, $policy_{i,t}$ is the difference between the GHG emissions from the ETS and non-ETS sectors to capture the effect of the policy, and $\varepsilon_{i,t}$ is the error term. The subscripts i, t define the cross-section and the time dimensions, respectively. As indicated by the regression equation a country fixed-effect approach is used since both the Hausman test for fixed or random effects and the Breusch-Pagan Lagrangian multiplier test for random effects suggest the use of country fixed-effects. We use cluster-robust standard errors to correct for potential problems caused by autocorrelation following Drukker D. M. (2003) and Wooldrige J.M. (2002).[6]

The variables included in the model fulfill different objectives. One of these is to control for the economic activity of the sectors under the EU ETS. Hence, variables accounting for industry specific characteristics are introduced in the model; these can be seen as "classical" control variables. In our model these variables are sector-specific economic activity variables and consumption of energy, gas and fossil fuels.

Following Anderson & Di Maria (2010), annual production indices are used to model the economic activity of the different sectors under the EU ETS. These indices are given in working days adjusted so as to measure the actual days worked to achieve the output of the observation unit during the observation period (Eurostat 2014b). This index was collected for the main sectors under the EU ETS in line with Eurostat's NACE-classification. These sectors are Mining and Quarrying (NACE B), Manufacturing (NACE C), and Energy (NACE D). All the indices were normalized and 2010 was selected as a baseline and given a value equal to 100. It should be noted that the only economic industry index used in the regression is that of the electricity sector, $nace\_d_{i,t}$. This is because neither the industry index for the manufacturing sector nor that for mining and quarrying contributed to explaining industrial emissions in this study. However, by including electricity consumption in the equation, emissions from the manufacturing sector are indirectly accommodated in the regression since the main cause of emissions stemming from this sector is precisely electricity consumption (International Energy Agency 2007).

As shown by Apergis & Payne (2009) and Chang (2010), there is evidence that energy, gas, and fossil fuel consumption is linked to GHG, mainly CO_2, emissions. Additionally, as discussed earlier in the literature review, Declercq et al. (2011) found that a reduction in electricity demand

[6] Statistical results available upon request.

was the main driver of GHG abatement in the years 2008 and 2009. To account for this fact, data for the electric energy, gas, and coal consumption of the various member states have been extracted, where consumption in each case refers to gross inland consumption. The consumption of all the commodities is measured in thousands of tonnes of oil equivalent to facilitate data comparison.

A second objective of the regression equation is to account properly for the effects of the economic crisis. As discussed, the 2008/09 economic crisis had, and in some parts of the EU continues to have, a strong influence on economic performance and, hence, industrial GHG emissions. This means that the analysis needs to control for any market disturbances.

In this paper, the economic crisis is modeled by creating a dummy variable that takes a value of 1 if a country shows a negative annual GDP growth rate and 0 otherwise. In this way, on 53 occasions the variable takes the value 1 and on 147 the value 0. This definition has the additional advantage that the coefficient can be interpreted as the CO_2 abatement attributable to periods of economic downturn, thus facilitating our untangling of the respective impacts of the ETS policy and the recession.

A third objective for introducing a variable into the equation is to capture the effect of the EU ETS on industrial GHG emissions. In the above regression, the variable $policy$ is designed for this purpose. This policy variable in general has to fulfill two objectives: first, it has to capture the impact of a policy on outcomes and, second, it should cancel out all other influences on outcomes. In this instance, the policy variable should only capture the abatement of GHG emissions due to the EU ETS and not those due to other influences.

Thus, the policy variable was created as follows. Given that GHG emissions across different sectors suffer the same external shocks, a comparison of GHG emissions from sectors under the EU ETS and those from sectors not covered by the policy should enable us to capture nothing but the effect of the EU ETS. Fortunately, this comparison is feasible because Eurostat provides emissions data for sectors that do not form part of the trading system. These data include emissions from road transport, building, agriculture, and the waste sector. Emissions produced by land use, land use change and forestry, international shipping, and international aviation are not, however, included in the data. Thus, non-ETS emissions are calculated as the difference between total GHG emissions and verified emissions under the ETS (Eurostat 2014a). To make the data for non-ETS and ETS sectors comparable, data were first standardized with 2005 emissions representing the baseline year and given a value of 100. In a subsequent step the standardized emissions from the ETS were subtracted from the emissions of the non-ETS

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sectors. Accordingly, the resulting measure shows the different evolution taken by GHG emissions and, supposing similar trends in emissions, these differences can be interpreted as the impact of the EU ETS.

However, to constitute a valid measure for capturing the impact of the policy on emission abatement the validity of this transformation has to be tested. In a first step it should be possible to check if the policy variable actually captures an emission reduction attributable to the ETS. In this regard the differences between emissions emanating from ETS and non-ETS sectors should be positive, assuming that is that the policy has a negative impact on industrial emissions. As the figures in Table 2 show, the design of the policy variable captures this assumption since over 60% of the observations of the variable "policy" are positive as is its mean.

(Insert Table 2 around here)

Yet this is insufficient to provide robust proof of the validity of the policy variable. In a second step, we tested whether emissions from sectors under the EU ETS present similar trends to those emanating from non-ETS sectors. In other words, we sought to determine whether the external effects have similar impacts on emissions emanating from the two sectors so that a comparison of their respective emissions might be deemed valid. In so doing we performed two auxiliary regressions to determine whether similar emission trends might be assumed (Table 3). The first regression (column "co2_nonets_stand") estimates the effect of the crisis on emissions from sectors not forming part of the EU ETS. The second regression (column "co2_stand") estimates the effect of the crisis on emissions from sectors under the EU ETS and so takes into account the impact of the policy on these emissions. By comparing the coefficients of the variable "crisis" in the two regressions we are able to verify whether emissions emanating from the two sectors behave similarly or not.

(Insert Table 3 around here)

The comparison is then completed by calculating the ratio of the two coefficients of the variable "crisis", where a value equal to 1 means that the impact of the economic crisis on the different rates of emission is the same. Here we obtained a ratio of 0.841, which can be considered as evidence that external effects have a similar impact on the respective rates of emission and, so, we can assume the policy variable to be valid. However, the effect of the crisis on emissions

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emanating from the EU ETS is slightly greater than that on emissions outside the trading system which could create a possible upward bias[7] in the effect of the policy.

Finally, we turn our attention to the dependent variable, namely, industrial GHG emissions under the EU ETS. As discussed above, annual industrial GHG emissions are reported by CITL. Overall, more than 11,000 heavy emitting installations in the power generation sector and from manufacturing industry are obliged to report to this authority under the EU ETS. GHG emissions are given in tonnes of CO_2 equivalents, since in addition to the emission of CO_2 other gases such as nitrous oxide, used in the production of acids (European Commission 2013) and perfluorocarbons (PFCs), resulting from aluminum production, are covered by the policy. CO_2 equivalent in this sense refers to the amount of CO_2 emissions that is equal to the global warming potential of the emission, for example, of one tonne of nitrous oxide.

6. Results

In line with the strategy outlined above, we performed three different estimations (Table 4).The first two equations (Eq.1; Eq.2) omit either the variable accounting for the impact of the economic crisis or the variable designed to capture the effect of the EU ETS on GHG emissions ($crisis$and $policy$respectively). In the third equation (Eq. 3) both variables, $crisis$ and $policy$, are introduced jointly. This procedure allows us to make two important observations. First, we are able to verify whether the ETS policy or the economic crisis was primarily responsible for the reduction in GHG emissions and, second, we can narrow the range of abatement shares attributable respectively to the policy and the economic crisis. The overall fit of the different specifications can be stated since the R^2 ranges around 0.72.

(Insert Table 4 around here)

The significance of the lagged endogenous variable is unsurprising as the finding is in line with the literature (Anderson & Di Maria 2010; Kamerschen & Porter 2004); however, its magnitude is somewhat smaller. The economic activity index for the electricity sector is not significant in any of the regressions, but as it appears to follow the right trend the variable is retained. The same is true of the gas consumption coefficient. Although it is not statistically significant, it appears to account for the switching from coal/oil to gas which took place in the energy sector in order to

[7] The comparison of emissions emanating from non-ETS sectors and sectors under the EU ETS might be considered in terms of substitution effects, which would result in a bias in the creation of the policy variable. However, these effects would only become manifest in the long-run and, accordingly, do not affect the policy variable here.

cut emissions[8]. This effect was also observed by Delarue et al. (2008). The coal consumption coefficient[9] is not statistically significant. However, it is retained in the regression since, as before, is seems to account for the fact that the burning of fossil fuels is a major source of GHG emissions, especially CO_2. The electricity consumption estimate presents highly significant values (1%) across the different specifications. This points to a clearly positive influence on rates of emission and its magnitude does not vary significantly over the four equations. This effect is in line with the theory described above in the literature review.

Drivers of GHG emissions abatement and the effect of the EU ETS

In order to identify the main drivers of emission reduction, we calculated all three equations. As can be seen in Table 4, the coefficient of the policy variable in Eq.1 is statistically significant (at 5%) and it presents the right sign. This suggests that the EU ETS is effective and, as such, is an appropriate tool for cutting industrial GHG emissions. In Eq. 2, in contrast to Eq.1, we focus on the impact of the economic crisis on emissions. As expected, the impact is clearly negative and statistically significant, which leads us to conclude that the economic downturn among the EU 25 was a main driver of the reduction in emission rates. Viewed separately, both the policy and the crisis played a major role in cutting emissions. However, when introduced jointly into the regression (Eq. 3), the statistical significance of the policy variable falls (to 10%), whereas the variable measuring the impact of the economic crisis remains statistically significant at 5%. Additionally, the fact that both variables present smaller absolute values means that they absorbed reduction-shares of each other. These results suggest that the policy variable absorbed a considerable amount of economic activity in Eq. 1 and, hence, an interpretation of the impact of the policy without taking into account the effects of the economic downturn would be misleading in the sense that this might result in an overestimation of the effectiveness of the EU ETS in its ability to reduce emissions.

The way in which the policy variable has been constructed here does not allow us to provide a direct interpretation of the coefficient in Eq.3. However, there are two ways in which the effect of the EU ETS on GHG emissions might be disentangled. First, we can compare the coefficient for the economic crisis before and after introducing the policy variable into the equation. Accordingly, a comparison of the coefficient of $crisis$ in Eq.2 and Eq.3 is provided, where we focus on the percentage change in the magnitude of the coefficient from one equation to the

[8] Since the unit of measure is the megatonne, the coefficient of gas consumption has a zero value. Using a smaller scale its value ranges between -53 and -62 tonnes.
[9] Similarly, given the measurement scale the coefficient of coal consumption has a zero value, but when increasing the scale values range between 175 and 194 tonnes.

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other. In this case the coefficient of $crisis$ is equivalent to a 20.99% reduction following the introduction of the policy variable into Eq.3. This result suggests that the coefficient of the economic crisis variable in Eq.2 captures something in addition to the effect of the crisis, namely, the impact of the EU ETS on emission abatement. By approaching the problem of untangling the abatement effect of the policy in this way, the impact of the EU ETS can be considered as representing 20.99% of the total GHG emission reduction during the observation period.

A second way in which we can account for the impact of the EU ETS on emissions is as follows. The interpretation of the coefficient of the policy variable indicates that a one unit increase in the policy variable leads to an additional abatement of 0.168 MgT of GHG, ceteris paribus. Bearing this in mind, the policy variable can be examined further. As can be seen in Table 1, its mean equals 2.016, which suggests that on average emissions under the EU ETS are around 2 index points lower than those from sectors not covered by the policy. This would be equivalent to an average index of 16.128 points between 2005 and 2012. If we return to the effect of a one unit increase of the policy variable and multiply this effect by the accumulated index over the eight-year period, we obtain an average total abatement of 2.709 MgT of GHG attributable to the EU ETS, ceteris paribus. This indicates that 23%[10] of total average abatement is due to the EU ETS.

However, as discussed in the description of the policy variable above, the impact of the economic crisis on emissions emanating from sectors under the EU ETS was greater than that on emissions from non-ETS sectors. This bias results in an overestimation of the effects of the policy on emission abatement. To account for this bias, the percentages obtained have to be multiplied by the ratio of the coefficients $crisis$ taken from Table 2. As a result the average share of abatement attributable to the EU ETS falls to 20.67%.

Interestingly, regardless of how the impact of the EU ETS on emission abatement is calculated, the methods yield similar results, which is indicative of their robustness. The results obtained suggest that the share of emission abatement attributable to the EU ETS is around 21%. Table 5 summarizes the results for the various methods presented.

(Insert Table 5 around here)

Robustness and stability of the estimates

Having estimated the impact of the crisis and the EU ETS on industrial GHG emissions, we now need to test the robustness of these estimates to guarantee their validity. Problems might well

[10] This value is obtained by dividing the average total abatement under the EU ETS by the average total abatement for the EU 25 countries taken from Table 1.

arise if there are any structural breaks in our sample of 25 countries over the eight-year period. For this motive, two different Chow tests were performed. The first of these was designed to capture a structural break between countries, namely, between the EU 15 and its extension east in 2004 when ten new member states joined the EU. The second was designed to capture any structural break in the time dimension, more specifically, if there was any break in the transition from the first to the second phases of the EU ETS. Both tests showed there to be no structural breaks in either the time dimension or the cross-sections, suggesting that the sample can be estimated as a whole and does not have to be split.[11]

7. Conclusions

In this paper we have used historical emission data from installations under the EU ETS to evaluate the impact of the policy on industrial GHG emissions during the first two trading phases (2005-2012). According to the results obtained, the total share of emission abatement due to the EU ETS is about 61 MgT of the 294 MgT of the total reduction recorded by the EU-25 Member States from 2005-2009. This seems to indicate that most of the reduction in emissions is due to the economic recession rather than to the EU ETS. Moreover, the estimated reduction attributable to the EU ETS here is well below the reductions forecast in the pre-crisis literature. In general, the latter studies overestimated the capacity of the EU ETS to reduce GHG emissions. Clearly, the market environment suffered a strong external shock with the economic crisis. This could not be foreseen ex ante, but it changed the BAU-conditions, and these need to be accounted for.

However, a comparison of our results with those in the post-crisis literature – most obviously Declercq et al. (2011) – reveals a higher degree of consistency. Recall that the authors estimated a 150-MgT abatement for the European power sector due to the impact of the economic crisis. If we subtract this estimate from the total rate of emissions between 2004 and 2012, then 233 MgT of the reduction in total emissions cannot be attributed to the EU ETS. Likewise, by multiplying the electricity sector's share of GHG emissions (≈ 0.71), we find that 165.43 MgT of the reduction in emissions in this sector cannot be attributed to the EU ETS. A comparison of these outcomes with those reported by Declercq et al. (2011) reveals a close similarity, providing further validation for the estimates reported here.

These results illustrate the severe impact of the economic downturn on GHG emissions for sectors under the EU ETS. Moreover, this reduction in emissions not attributable to the EU ETS has major implications for the successful operation of the system. Given that installations under the EU ETS were able to save a significant number of EUAs thanks to the economic crisis (and

[11] Statistical test results available upon request.

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not because of their abatement efforts), the market for allowances was oversupplied. The consequences of this are complex, but clearly the price for allowances fell, which reduced participants' incentives to invest in low-carbon technology. Hence, the effectiveness of the EU ETS was seriously compromised.

The results obtained in this study provide robust estimates of the magnitude of emission abatement attributable to the EU ETS, and can serve as the basis to increase the effectiveness of the system in its attempts to cut GHG emissions. The main limitation however in evaluating the EU ETS remains the availability of data and the quality of those data.

One key feature that would facilitate future evaluations would be for firms under the policy to record, in addition to their emission data, economic performance data. In this way any reduction in GHG emissions could be traced back to their origin more effectively and thus improve the accuracy of estimates. Future research would benefit greatly from the availability of micro-level firm data as this would allow a more precise quantification of the reduction in emissions attributable to the EU ETS.

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Table 1: GHG Emissions Overview

Country	Total Abatement in MgT	Total Abatement in %	Abatement from 08-09 in MgT	Abatement from 08-09 in %	Abat. 08-09 / Total Abat.	Abatement from 09-10 in MgT	Abatement from 09-10 in %
Austria	-4.986095	14.94%	-4.719141	14.71%	94.65%	3.559878	-13.01%
Belgium	-12.356252	22.32%	-9.255089	16.69%	74.90%	3.897041	-8.43%
Cyprus	-0.694979	13.68%	-0.215013	3.86%	30.94%	-0.305413	5.70%
Czech Rep.	-13.138166	15.93%	-6.614269	8.23%	50.34%	1.799522	-2.44%
Denmark	-8.290168	31.31%	-1.087439	4.10%	13.12%	-0.194762	0.76%
Estonia	0.922055	-7.31%	-3.162545	23.36%	342.99%	4.136044	-39.85%
Finland	-3.60174	10.88%	-1.809195	5.00%	50.23%	6.943508	-20.21%
France	-27.63695	21.05%	-13.037252	10.50%	47.17%	4.478226	-4.03%
Germany	-22.465655	4.73%	-44.559032	9.42%	198.34%	26.570097	-6.20%
Greece	-9.827367	13.79%	-6.192321	8.86%	63.01%	-3.721576	5.85%
Hungary	-4.898679	18.72%	-4.835351	17.75%	98.71%	0.590452	-2.64%
Ireland	-5.545017	24.71%	-3.166499	15.54%	57.11%	0.15779	-0.92%
Italy	-46.895929	20.75%	-35.794723	16.22%	76.33%	6.607937	-3.57%
Latvia	-0.114479	4.01%	-0.253113	9.23%	221.10%	0.750367	-30.14%
Lithuania	-46.895929	20.75%	-35.794723	16.22%	76.33%	6.607937	-3.57%
Luxembourg	-0.613812	23.58%	0.082799	-3.94%	-13.49%	0.070968	-3.25%
Malta	0.081172	-4.12%	-0.121472	6.02%	149.65%	-0.018806	0.99%
Netherlands	-3.92537	4.89%	-2.479882	2.97%	63.18%	3.704899	-4.57%
Poland	-6.513296	3.21%	-12.93317	6.34%	198.57%	8.552658	-4.47%
Portugal	-11.18151	30.70%	-1.64968	5.52%	14.75%	-4.09477	14.49%
Slovakia	-4.298866	17.04%	-3.741497	14.77%	87.03%	0.103416	-0.48%
Slovenia	-1.109958	12.73%	-0.793082	8.95%	71.45%	0.06284	-0.78%
Spain	-47.992625	26.14%	-26.526546	16.23%	55.27%	-15.452293	11.28%
Sweden	-1.209659	6.24%	-2.588651	12.89%	214.00%	5.169326	-29.55%
U.K.	-11.271546	4.65%	-33.119481	12.50%	293.83%	5.397695	-2.33%
SUM:	**-294.46082**		**-254.36636**			**65.372981**	
EU 25 Average	**-11.778433**	**14.21%**	**-10.174654**	**10.48%**	**86.38%**	**2.61491924**	**-5.66%**

Source: CITL and own calculations

Table 2:

Variable	Obs	Mean	# of positive values	% of pos. values	# of negative values	% of neg. values
Policy	200	2.0158	125	62.5	75	37.5

Table 3: Auxiliary Regressions

	co2_nonets_stand	co2_stand
Crisis	-3.328	-3.959
	(0.835)***	(0.883)***
Policy		-0.899
		(0.049)***
_cons	97.987	97.952
	(0.417)***	(0.414)***
R^2	0.08	0.73
N	200	200

* p<0.10; ** p<0.05; *** p<0.01

Table 4: Regression Results

	Eq. 1	Eq. 2	Eq. 3
lag_CO2	0.566	0.599	0.584
	(0.062)***	(0.061)***	(0.064)***
nace_d	0.111	0.138	0.069
	(0.109)	(0.084)	(0.099)
c_gas	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
c_coal	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
c_elec	0.010	0.010	0.010
	(0.002)***	(0.002)***	(0.002)***
Policy	-0.198		-0.168
	(0.084)**		(0.082)*
Crisis		-2.948	-2.329
		(1.054)***	(1.093)**
_cons	-74.155	-77.054	-66.580
	(24.251)***	(20.620)***	(23.076)***
R^2	0.72	0.71	0.72
F	49.96***	84.45***	100.03***
N	175	175	175

Note: Values in parenthesis representing standard errors

* p<0.10; ** p<0.05; *** p<0.01

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Table 5: Results Overview

	Method: Comparison of coefficients "*crisis*"	Method: Calculation using the mean and coefficient estimate of the policy variable
Percentage due to the EU ETS	20.99%	20.67%
Average abatement for the EU 25 due to the EU ETS	2.4726 MgT	2.4346 MgT
Total Abatement for the EU 25 due to the EU ETS	61.815 MgT	60.865 MgT

Source: Own calculations

APPENDIX:

Table 1A: Alternative regression using price instead of consumption of the commodities (where oil, gas, coal, and electricity representing the prices of each commodity)

Table 1A: Alternative specification using prices

	Eq.1	Eq.2	Eq.3
lag_CO2	0.589	0.610	0.603
	(0.082)***	(0.080)***	(0.079)***
nace_d	0.228	0.238	0.157
	(0.123)*	(0.108)**	(0.111)
oil	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)
gas	0.048	0.125	0.365
	(0.753)	(0.648)	(0.755)
Coal	0.011	0.016	0.009
	(0.013)	(0.015)	(0.015)
electricity	-69.280	-55.971	-53.725
	(47.194)	(38.880)	(42.909)
Policy	-0.260		-0.214
	(0.115)**		(0.107)*
Crisis		-4.457	-3.663
		(1.459)***	(1.316)***
_cons	13.584	13.031	19.167
	(11.170)	(10.455)	(10.598)
R^2	0.56	0.56	0.58
F	40.62***	30.39***	31.38***
N	175	175	175

Note: Values in parenthesis representing standard errors

* $p<0.10$; ** $p<0.05$; *** $p<0.01$

Table 2A: Collinearity Statistics

Table 2A: Collinearity Statistics

Variable	VIF	
lag_CO2	3.21	2.94
nace_d	1.16	1.15
c_gas	1.90	1.85
c_oil	34.04	-
c_coal	1.99	1.96
c_elec	31.46	2.84
crisis	1.09	1.08
Mean VIF	10.69	1.97

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