[¿Qué variables económicas determinan las emisiones del sector eléctrico? Empresas españolas en el EU ETS]

Autores y e-mail de la persona de contacto:
L. Ferruz[a], P. Gargallo [b] and M. Salvador [b] S. Segura[a,*],

*ssegura@unizar.es

Departamento: [a] Contabilidad y Finanzas. [b] Estructura e Historia Económica y Economía Pública.

Universidad: Universidad de Zaragoza

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Resumen:
El European Union Emissions Trading Scheme (EU ETS), o mercado de carbono, entró en funcionamiento en 2005 y es la pieza clave para la reducción de emisiones de CO_2. Este mercado está integrado por 11000 instalaciones eléctricas e industriales así como de aerolíneas de 31 países europeos. Alrededor del 10% de estas instalaciones, se encuentran en territorio español siendo las instalaciones eléctricas las que tienen un mayor peso en la cifra de emisiones total (aproximadamente un 60%).

Durante el periodo 2005-2012, a todas las instalaciones se les asignaban anualmente derechos de emisión de manera gratuita por parte del Gobierno. A partir de 2013, el sistema de asignación cambia: se mantiene la asignación gratuita solo para determinados sectores industriales, quedando excluidas las empresas energéticas.

Este cambio se traduce en un coste adicional para las empresas eléctricas lo que, dada la dependencia del resto de sectores en la energía, se traduce a su vez en un incremento de los costes de todo el tejido industrial.

En este contexto, el objetivo de este trabajo es analizar las variables económicas empresariales que determinan el montante de emisiones de CO2. Para ello, empleamos una regresión cuantil en la que tomamos la variación interanual de emisiones como variable dependiente y como independientes: el incremento anual de los ingresos, el incremento anual del capital industrial y un conjunto de variables control. La muestra la integran las empresas eléctricas españolas que han formado parte del EU ETS durante el periodo 2005-2012.

Los resultados de este trabajo facilitan, por una parte, el diseño de políticas macroeconómicas en materia medioambiental y, por otra, la toma de decisiones del gestor empresarial en materia de reducción de emisiones de manera óptima desde el punto de vista económico.

Palabras Clave: *EU ETS, sector eléctrico, regresión cuantil*
Clasificación JEL: Q51, Q52, Q43

I. Introduction

The European Union Emissions Trading Scheme (EU ETS) is defined by the European Commission as the cornerstone of EU policy on climate change. It was launched in 2005 and its implementation was planned in three phases: Phase I in 2005–2007, Phase II in 2008–2012, and Phase III beginning in 2013 and extending to 2020.

As the European Commission stated in Directive 2003/87/EC, the objective of the EU ETS is "to promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner". Thus, when evaluating this market's efficacy, we should focus not only on the reduction of company CO_2 emissions, but also on finding out whether this reduction has been carried out in a cost-effective and economically efficient manner.

The European Union Allowances (EUA) play the main role in achieving this target, as discussed by authors such as Egenhofer (2007), Braun (2009), and Mackenzie (2009). Given the importance of this issue, some researchers have studied the drivers of EUA prices (see e.g. Chevallier, 2012, Aatola et al., 2013).

The prices must be sufficiently high to provide an incentive for companies to take steps to reduce their emissions, such as investing in more efficient technology or using a less carbon-intensive energy source, rather than purchasing emissions allowances to release CO_2. Unfortunately, current prices are too low to provide an incentive to invest in new technology. Prior studies have already highlighted this issue, as in Dietz and Fankhauser (2010), who stated that EUA prices during 2008 and the first part of 2009 were too low to achieve the emissions reduction objective. Similarly, Abadie and Chamorro (2008) examined trigger allowance prices, above which it is optimal to make green investments, and concluded that EUA prices should be near €55, which is well below the current level of around 5€[1].

Oversupply of allowances, in studies such as Ellerman and Buchner (2007) and World Bank (2007, 2011), has been pointed to as one of the main reasons why current EUA prices are low. For the first two Phases of the EU ETS, member countries were required to design a National Allocation Plan (NAP) to determine the total supply of allowances available for each, and to devise a procedure to distribute the allowances among their domestic companies. If these allocations were "severe", that is, they provided lower emissions allowances compared to existing emissions, the supply of allowances would decline, causing prices to rise. If these allocations were more "generous", the price of EUAs would fall due to excessive supply, thereby jeopardizing the objective of spurring companies' green investments. For this reason, the European Commission (2009) stated that the allowance allocation for a company should be no higher than the amount of CO_2 it is expected to emit. Obviously, when NAPs were designed, this quantity was still unknown, so it had to be estimated. Taking into account that allowance oversupply occurred, clearly, companies emitted less CO_2 than predicted.

It is possible, then, to conclude that the EU ETS works well because it has led companies to emit CO_2 within the cap, but this can lead to a misinterpretation of its efficacy.

Despite the importance of this issue, when focusing on EU ETS efficacy, much research has been carried out analyzing the source of the emissions reduction and, more specifically, the link between green innovation and the existence of the EU ETS (Calel and Dechezleprêtre, 2012; Rogge et al, 2011; Sandoff and Schaad, 2009), whereas, to the best of our knowledge, very few studies in the literature have analyzed whether the reduction of emissions has been carried out in a cost-effective and economically efficient manner. One exception is Segura et al. (2014), who explored the relationship between companies' surplus allowances (SA) and business performance (BP) by using quantile regression techniques. Using data corresponding to Spanish firms in the period 2005-2010, a non-increasing link between SA and BP was found, especially after 2008, when the economic crisis broke out.

That paper assumed that quantiles of BP were linear functions of SA, although the lack of normality of both variables could make this hypothesis unrealistic. Clearly, more flexible statistical tools are necessary in order to capture the relationship between these factors. In this paper, we complete the study presented in Segura et al. (2014) by using copulas (Kroenker and Hallock (2001)) which, as Trivedi and Zimmer (2005) show, provide a set of models to capture dependence in a broader context, and have been widely used in the field of finance (Patton, 2006, 2009; Heinen and Valdesogo, 2008; Jondeau and Rockinger, 2006) and in environmental contexts (Denault et al, 2009; Grothe and Schnieders, 2011). In this way, we obtain more robust results and, as a consequence, we reach more accurate conclusions. This not only has implications for policymakers but also for the companies that belong to the EU ETS, when designing action guidelines.

The paper is organised as follows: Section 2 describes the data used in the paper, Section 3, the statistical methodology, Section 4 shows our results, and Section 5 describes the policy measures we propose, according to those results. Finally, Section 6 sets out our conclusions.

II. Data

We selected a sample of Spanish installations whose emissions were traded in the EU ETS during the period 2005-2010, including combustion plants, oil refineries, coke ovens, iron and steel and factories producing cement, glass, lime, bricks, ceramics, and pulp and paper.

The list of Spanish installations was obtained from the "*Registro Nacional de Derechos de Emisión de Gases de Efecto Invernadero*" (RENADE)[2], the Spanish national registry, containing all Spanish firms participating in the EU ETS. We focused on those companies in the registry as of July, 2011, giving a total of 1,131 installations corresponding to 839 companies. Due to data unavailability[3], our sample was reduced to 745 companies.

Spanish installations represent 10% of the EU ETS. Spain provides an excellent context for our study, as it has been severely impacted by the financial crisis.

For each firm, two variables were considered: surplus of allowances (SA) and business performance (BP).

Data related to SA were taken from the Community Independent Transaction Log (CITL), an online database where accounts of companies and physical persons holding these allowances were listed. Each installation held an account in the CITL where the allowance allocation, verified emissions, and compliance status were tracked.

The allowances assigned to, and the verified emissions from, installations owned by the same company were aggregated, having, as a consequence, a unique assigned (A) and verified (E) emission figure for each firm.

For each company and each period t, SA was calculated using the expression:

$$SA_{i,t} = \frac{A_{i,t} - E_{i,t}}{A_{i,t}}; \; i = 1,\ldots, N_t; \; t = 1, \ldots, T \qquad (1)$$

where $A_{i,t}$ represents the assigned emissions to company i; $E_{i,t}$ represents the verified emissions of company i, in period t; N_t is the number of firms with observed data in period t, and T is the number of periods. SA may have either a positive or negative sign, in such a way that a positive (negative) sign indicates a surplus (deficit) of allowances.

In order to measure company business performance (BP), we select Return on Assets (ROA), which is a profitability ratio widely used in the literature.

$$ROA_{it} = \frac{\text{Operating income}_{i,t}}{\text{Assets}_{i,t}};\ i = 1,\dots, N_t;\ t = 1, \dots, T \qquad (2)$$

Data were taken from SABI, a database that provides 1,250,000 Spanish and 400,000 Portuguese company reports. These reports include, among other information: company financial profile, summary of company industrial activities, Balance Sheet, Profit & Loss account, and financial ratios.

Descriptive statistical analysis

In our case we have N = 745 firms and T = 6 periods. We provide a descriptive analysis, year by year, of SA and ROA, separately.

Table 1 shows, for each period, the main statistics for SA variables. Two different periods stand out: 2005-2007 and 2008-2010, corresponding to Phase I (2005-2007) and Phase II (2008-2010[4]) of the EU ETS.

Table 1. Descriptive analysis of SA

	Year					
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
Observations	533	649	615	626	622	559
% firms with SA≥0	75	75	72	80	84	84
Minimum	-2.54	-2.71	-1.60	-1.77	-1.66	-3.01
Mean	0.08	0.14	0.12	0.20	0.32	0.33
Median	0.08	0.12	0.12	0.19	0.32	0.32
Maximum	0.95	0.99	0.99	0.99	0.99	0.99
Std.deviation	0.26	0.31	0.32	0.33	0.36	0.40
Skewness	-2.46**	-1.72**	-1.10**	-1.17**	-0.85**	-1.50**
Kurtosis	25.69**	17.51**	8.09**	8.60**	6.03**	12.35**
Jarque Bera	11754**	5925.6**	774.01**	946.05**	309.18**	2207.90**

As has been pointed out in Section I, the quantity of allowances received by each installation must not be higher than the level of CO_2 emissions it is likely to emit, in order to create the scarcity needed for trading and, therefore, to ensure a high EUA price. The allowance allocation and the emissions estimation for Phase I (2005-2007) were carried out in 2004 and for Phase II (2008-2012), in 2006. In this way, the better the emissions estimation, the more appropriate the allocated quantity, to ensure a high EUA price.

First, allowances were distributed at the sector level and, second, among installations within each sector. This allocation of allowances was done according to the estimated emissions for each sector and, then, for each installation. In the case of NAP I, these predictions were based on the level of emissions in prior years, and in NAP II, not only on the level of emissions but also on the production levels of prior years. As can be observed in Table 1, both mean and median have a positive sign over the whole sample period, indicating a surplus of allowances.

In the case of NAP I, as stated in Order PRE/2827/2009, the maximum number of allowances per year assigned to EU ETS sectors was 182.17 Metric Tonne Carbon Dioxide Equivalent (Mt). As stated in Spanish Government (2007), at the end of Phase I, the Spanish companies as a whole had a deficit of 22.49 Mt CO_2. However, as can be observed in Table 1, on average, companies had a surplus of 8%, 14% and 12% in years 2005, 2006 and 2007, respectively.

The difference between both results is due to the fact that around 75% of the companies had a surplus of allowances during Phase I. Although the country as a whole emitted more than expected, the majority of companies tended to emit less CO_2 than expected. These kinds of measure are appropriate when analyzing the state of compliance from a macro-economic point of view, but they omit extremely relevant information. Looking at the macro-economic figure, one could conclude that the Spanish cap during Phase I was severe. Nevertheless, if we focus on micro-economic figures, we see that, in fact, individual caps were not as severe since most companies (75%) emitted less CO_2 than assigned.

In the case of NAP II, the maximum level of allowances per year in Spain was 152,250 Mt CO_2 (Order PRE/2827/2009). Following the line of the European Commission, who cut the volume of emission allowances permitted in Phase II to 6.5% below the 2005 level, the Spanish cap for Phase II was more stringent than for Phase I. Specifically, the total Spanish Phase II cap was 16% less than in Phase I. In spite of this, in period 2008-2010 there was a surplus of 33.23 Mt CO_2 (Spanish Government, 2010).

Despite the fact that NAP II was more severe than NAP I, the higher SA levels in the second period (See Table 1) suggest that the deviation from what was expected was more marked than in the first phase.

According to data in the Spain GHG Inventory 1990-2010, during the period 2005-2007, CO_2 emissions were 49.43% above 1990 levels, due to considerable economic and population growth, as was pointed out in Royal Decree 1370/2006. During the period 2008-2010, emissions were only 29.53% above 1990 levels due to the economic crisis.

The results of Table 1 indicate that normality of the SA variable is rejected in all periods, due to a significant negative asymmetry and leptokurtosis, which tended to decrease from 2008 onwards. This arises from the existence of a low percentage of firms with strong negative SA values, i.e., CO_2 emissions much higher than the allowance allocations, which are responsible for the fact that Spain as a whole had a deficit of CO_2 emissions, as mentioned above.

Table 2 shows the main descriptive statistics of ROA. Again, two different periods stand out: 2005-2007 and 2008-2010. On average, companies have a positive ROA during the period 2005-2007 and it is relatively stable over this period. Values corresponding to period 2008-2010 are much lower. The break point took place in 2008, when the global crisis began. According to data from the Spanish National Statistics Institute, while in 2005, 2006 and 2007 the annual growth of GDP was around 4%, in 2008 this was reduced to 1%, and to -3.7% in 2009 and -0.3% in 2010.

Table 2. Descriptive analysis of the Return on Assets

	Year					
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
Observations	533	649	615	626	622	559
Minimum	-31.72	-66.77	-120.02	-155.89	-81.4	-59.11
Mean	4.86	2.57	4.04	0.17	0.38	1.7
Median	3.59	2.59	3.65	10.67	0.49	1.51
Maximum	79.08	58.32	52.64	73.99	100.63	52.24
Std. deviation	10.57	12.58	14.47	16.53	14.89	11.96
Skewness	1.38**	-0.62**	-2.72**	-3.21**	0.22**	-0.41**
Kurtosis	12.46**	8.12**	26.75**	28.88**	12.19**	7.78**
Jarque-Bera	2116.8**	739.21**	14969**	18255**	2156.5**	557.46**

Normality is, again, rejected for all the considered variables. The data of both phases is heavily skewed to the left (with the sole exception of 2009) and kurtosis is considerably pronounced. This is due to the presence of a set of firms with higher absolute levels of ROA, with very strong negative values.

Taking into account that normality of SA and ROA is rejected for all 6 years of our sample, these findings suggest that the relationship would not be effectively treated in the normal multivariate context. This is why we choose a copula approach to model the relationship between both variables, which, as Trivedi and Zimmer (2005) stated, is an adequate tool when capturing dependence in a broader context than the standard multivariate normal.

III. Methodology

Given that our statistical methodology is based on the use of copulas, we first provide a brief review of the main concepts and results related to copulas, and then describe the selection and estimation of the model procedure used in this paper. We only consider the bivariate case, which corresponds to our problem. (Good introductory texts on copulas are Cherubini et al. (2004) and Nelsen (2006).)

Definition

A copula C: $[0,1]^2 \to [0,1]$ is a cumulative distribution of a bi-dimensional random vector on $[0,1]^2$ with uniform marginals:

$$C(u_1, u_2) = P(U_1 \leq u_1, U_2 \leq u_2) \qquad (3)$$

where U_1 and U_2 are uniformly distributed on [0,1].

The importance of copulas in the modelling of dependence between variables arises from Sklar's Theorem (Sklar, 1959), which provides the theoretical foundation for their application. This theorem states that a bivariate cumulative distribution function $F_{1,2}(x_1, x_2)$ of a random vector (X_1, X_2) with marginals $F_1(x_1)$ and $F_2(x_2)$, can be written as

$$F_{1,2}(x_1, x_2) = C(F_1(x_1), F_2(x_2)) \qquad (4)$$

where C is a copula. This copula is unique on Ran(F_1) x Ran(F_2), which is the cartesian product of the ranges of the marginal cdf's, if the marginals $F_1(x_1)$ and $F_2(x_2)$ are continuous, and can be obtained from,

$$C(u_1, u_2) = F_{1,2}(F_1^{-1}(u_1), F_2^{-1}(u_2)) \qquad (5)$$

The converse is also true: given a copula C: $[0,1]^2 \to [0,1]$ and margins $F_1(x_1)$ and $F_2(x_2)$ then $C(F_1(x_1), F_2(x_2))$ defines a bi-dimensional cumulative distribution function $F_{1,2}(x_1, x_2)$.

Notable copulas

Researchers use a number of parametric copula specifications. Two of the most frequently used copula families are elliptical and Archimedean, which we review briefly below.

Elliptical copulas are those of elliptically contoured (or elliptical) distributions. The most commonly used elliptical distributions are the multivariate normal and Student-t distributions. The normal copula is flexible, in that it allows for equal degrees of positive and negative dependence. However, it assumes that there is no dependence in the tails of the distribution, which can be unrealistic in some situations as, for instance, in financial markets. Unlike the Gaussian copula, the t-copula has symmetric tail dependence, which makes it very useful in models of the joint movements of financial returns.

An Archimedean copula is constructed through a generator function φ as

$$C_\varphi(u_1,u_2)=\varphi^{-1}(\varphi(u_1)+\varphi(u_2)) \tag{6}$$

where φ^{-1} is the inverse of the generator φ. In order for this expression to be a copula, the generator needs to be a complete monotonic function (see, for example, Nelsen, 2006, Theorem 4.6.2). Three of the more frequently-used families of Archimedean copulas are Gumbel, Clayton, and Frank, whose expressions and generator functions are given in the following table.

Table 3. Copulas.

Family	**Parameter Space**	**Bivariate Copula** $C_\varphi(u,v)$
Gaussian	-1<ρ<1	$\int_{-\infty}^{\phi^{-1}(u_1)}\int_{-\infty}^{\phi^{-1}(u_2)}\frac{1}{(2\pi)\sqrt{1-\rho^2}}\exp\left\{\frac{-\mathbf{u}'\begin{pmatrix}1&\rho\\\rho&1\end{pmatrix}^{-1}\mathbf{u}}{2}\right\}d\mathbf{u}$
Student-t	η>0, -1<ρ<1	$\int_{-\infty}^{t_\eta^{-1}(u_1)}\int_{-\infty}^{t_\eta^{-1}(u_2)}\frac{\Gamma\left(\frac{\eta+2}{2}\right)\left(1+\frac{\mathbf{u}'\begin{pmatrix}1&\rho\\\rho&1\end{pmatrix}^{-1}\mathbf{u}}{\eta}\right)^{-\frac{\eta+2}{2}}}{\Gamma\left(\frac{\eta}{2}\right)(\pi\eta)\sqrt{\begin{pmatrix}1&\rho\\\rho&1\end{pmatrix}}}d\mathbf{u}$

Gumbel	$\alpha \geq 1$	$\exp\left(-\left((-\ln u)^{\alpha}\right)+\left((-\ln v)^{\alpha}\right)^{1/\alpha}\right)$
Frank	$\alpha \in (-\infty, \infty) \setminus \{0\}$	$-\frac{1}{\alpha}\ln\left(1+\frac{(e-^{\alpha u}-1)(e^{-\alpha v}-1)}{e^{-\alpha}-1}\right)$
Clayton	$\alpha > 0$	$\max\left(\left(u^{-\alpha}+v^{-\alpha}-1\right)^{-1/\alpha},0\right)$

The Gumbel copula is an asymmetric copula that has non-linear positive dependence throughout the data and exhibits greater dependence in the positive tail than in the negative. The Frank copula describes situations of symmetric tail independence and is an appropriate option when modelling strong positive or negative dependence throughout the data. The Clayton copula is an asymmetric copula describing situations of non-linear positive dependence throughout the data, but, in contrast to the Gumbel copula, exhibits greater dependence in the negative tail than in the positive.

Quantile Regression with copulas

Copulas can be used to calculate quantile regression curves (see Kroenker and Hallock, 2001) without imposing unjustified linearity restrictions that can reduce the flexibility of the analysis. With that aim, we use the following definition.

Definition.- Let X_1 and X_2 be random variables and $p \in (0,1)$. For x_1 in Ran X_1, let $\tilde{x}_{2,p}(x_1)$ be a solution to the equation $P(X_2 \leq x_2 \mid X_1 = x_1) = p$. Then $x_2 = \tilde{x}_{2,p}(x_1)$ is the *p-quantile regression curve of X_2 on X_1.*

In particular, if X_1 and X_2 are continuous, with marginal distribution functions $F_1(x_1)$ and $F_2(x_2)$, respectively, and copula $C(u_1, u_2)$, the p-quantile regression curve of X_2 on X_1 is given by (Nelsen, 2006):

$$\tilde{x}_{2,p}(x_1) = F_2^{-1}\left(\tilde{u}_{2,p}(F_1(x_1))\right) \text{ where } \frac{\partial C\left(F_1(x_1), \tilde{u}_{2,p}(F_1(x_1))\right)}{\partial u_1} = p \qquad (7)$$

Estimation procedure used in the paper

Thus, copulas unite one-dimensional marginal distribution functions into a bi-dimensional distribution and describe the dependence structure between variables. The task of modelling the entire joint distribution of two random variables can be carried out in two steps: first, we model the marginal distributions F_1 and F_2, and then we select a copula C for the U(0,1) transformed variables, $U_1 = F_1(X_1)$ and $U_2 = F_2(X_2)$.

We have used a semi-parametric method of inference functions (IFM) procedure (see more in Joe, 2001), where the marginal distributions of SA and ROA have been estimated using non-parametric kernel density estimators, and the copula has been selected using the AIC criterion from a predetermined set of families. The procedure consists of the following steps, where, with the aim of simplifying the notation, we have omitted the subscript corresponding to the period.

Step 1. Fit marginal distributions to ROA and SA using non-parametric kernel estimators of the corresponding univariate densities $\hat{f}_{ROA}(.)$ and $\hat{f}_{SA}(.)$.

Step 2. Use the corresponding marginal distribution functions, $\hat{F}_{ROA}(.)$ and $\hat{F}_{SA}(.)$ to transform ROA and SA to U(0,1) distributions, that is to say, $U_{ROA} = \hat{F}_{ROA}(ROA)$ and $U_{SA} = \hat{F}_{SA}(SA)$.

Step 3. For each family of copula, use the maximum likelihood procedure to fit a copula to U_{ROA} and U_{SA}. So, if the copula C belongs to a family of copulas indexed by a parameter θ: C = C(u_1, u_2; θ), then the maximum likelihood estimator $\widehat{\theta}_d^{MLE}$ of the parameter θ corresponds to the maximization of the log-likelihood

$$\widehat{\theta}_d^{MLE} = \arg\max_\theta L(\theta) = \arg\max_\theta \sum_{j=1}^{n} \log c\left(\hat{F}_{ROA}(ROA_i), \hat{F}_{SA}(SA_i), \theta\right) \qquad (8)$$

where $c(u_1, u_2; \theta) = \dfrac{\partial C(u_1, u_2; \theta)}{\partial u_1 \partial u_2}$ is the density of the copula $C(u_1, u_2; \theta)$.

Step 4. Selection of the appropriate family of copula using the AIC criterion.

Step 5. Calculation of the quantile regression curve of SA on ROA for a set of values of p. To that end, we have used the expression (7).

IV. Results

Tables 4 to 6 and Figures 1 and 2 show the results obtained for each period using the procedure described in Section III. All the calculations were made using MATLAB 7.9.0 (R 2009 b).

Table 4 shows, for each year, the AIC value for each family of copulas considered in the paper. Table 5 shows the estimation of the dependence parameters of the selected copula: the α parameter in the case of the Frank copula, and the correlation coefficient r_{12} of the joint distribution of (U_{ROA},U_{SA}) in the case of the Gaussian copula. Additionally, and for comparative purposes, the intercept and the coefficient of a robust linear regression line, estimated by weighted linear squares obtained by means of the *robustfit* procedure of MATLAB 7.9.0 are also included. Figure 1 shows, for each year, the scatter plot of ROA versus SA, the marginal histograms, the robust linear regression line, and the regression curves of SA on ROA, corresponding to the 2.5%, 50% and 97.5% quantiles whose limits delimit a 95% predictive interval of SA for a given value of ROA. Figure 2 shows the derivative curves corresponding to the median regression curve and the 95% confidence interval limits of the linear regression coefficient.

It can be seen that, with the sole exception of year 2007, the Frank copula was the family selected. This selection is explained by the existence of a significant inverse relationship between ROA and SA (see Table 4) that eliminates the Gumbel and Clayton copulas, which assume that this dependence is positive.

Table 4. AIC values corresponding to the compared families of copulas

	Year					
Family	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Gaussian	-9.1255	-11.5835	**-16.8527**	-22.4037	-152.0216	-84.2185
Student's t	-7.1255	-10.4207	-14.8527	-27.6624	-151.5056	-84.705
Frank	**-10.6817**	**-14.498**	-16.8362	**-28.4261**	**-177.1785**	**-104.2428**
Gumbel	2.0003	2.0004	2.0004	2.0002	2.0011	2.0008
Clayton	2.0002	2.0002	2.0002	2.0003	2.0006	2.0004

In fact, the estimated parameters corresponding to copulas and the linear coefficient regression (Table 5) are significantly negative for the whole sample period, and the regression curves are non-increasing (see Figures 1 and 2). That is to say, the greater surplus of allowances a company has, the weaker its business performance, and vice-versa. Thus, the more a company reduces its emissions with respect to its allocation, the lower its business performance, which may indicate that the reduction of allowances has not been done in an economically efficient manner.

Table 5. Parameter estimations of the selected copulas and the linear regression model

	Year					
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
	Selected family					
	Frank	Frank	Gaussian	Frank	Frank	Frank
Parameter of the copula	-0.9804 **	-1.0144 **	-0.1738 **	-1.4122 **	-3.6411 **	-2.9030 **
Linear regression intercept	0.1074**	0.1495**	0.1570**	0.2192**	0.3485**	0.3744**
Linear regression coefficient	-0.0025**	-0.0024**	-0.0029**	-0.0034*	-0.0107**	-0.0118**

** Statistically different from zero at the 1% significance level

The strength of the relationship between SA and ROA is not constant over time, however. As happened with SA and ROA individually, the dependence between both variables can also be divided into two periods: 2005-2007 and 2008-2010, in such a way that, in the second period, the dependence between SA and ROA was more intense than in the first. Table 6 shows the Spearman and Pearson coefficients implied by the selected copulas whose analysis confirms that the dependence between SA and ROA has increased during the second period (2008-2010), reaching its maximum value in 2009.

The link between SA and ROA becomes more intense when the surplus of Spanish companies as a whole increases. The great surplus of allowances coincided in time with both the onset of the global financial crisis that broke out in 2008, and the beginning of Phase II of the EU ETS.

Indeed, the estimated linear regression coefficients and the values of the derivative curves (Figure 2) show that the relationship between ROA and SA increased after the economic crisis (year 2008).

A significant number of companies for whom the crisis had a major impact show how their production activity was reduced due to a drop in their demand for their products, resulting in lower CO_2 emission levels than those assigned by the EU ETS, as well as negative values of profitability. This suggests that the extremely high surplus in Phase II is especially a feature of an economically inefficient environment.

Nevertheless, in the period 2005-2007, when Spanish GDP was in a bull phase, the link between surplus allowances and ROA, although not as strong as in the period 2008-2010, was also negative. That is, companies reducing their emissions are less competitive than those who surpass the limit.

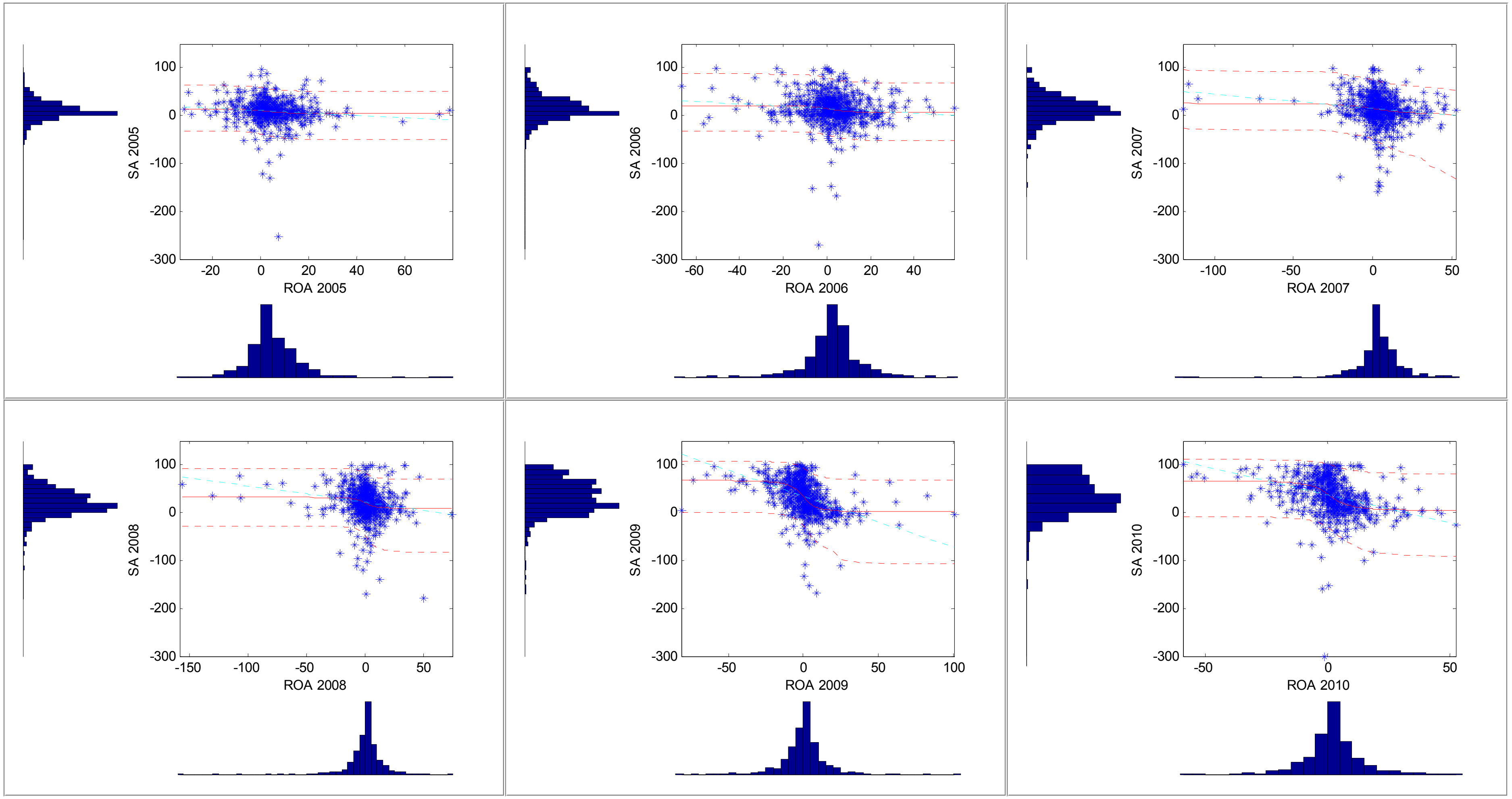

Figure 1. Regression curves. Dotted lines (2.5% and 97.5% quantile of the selected copula); continuous line (median of the selected copula); dashed line (robust linear regression)

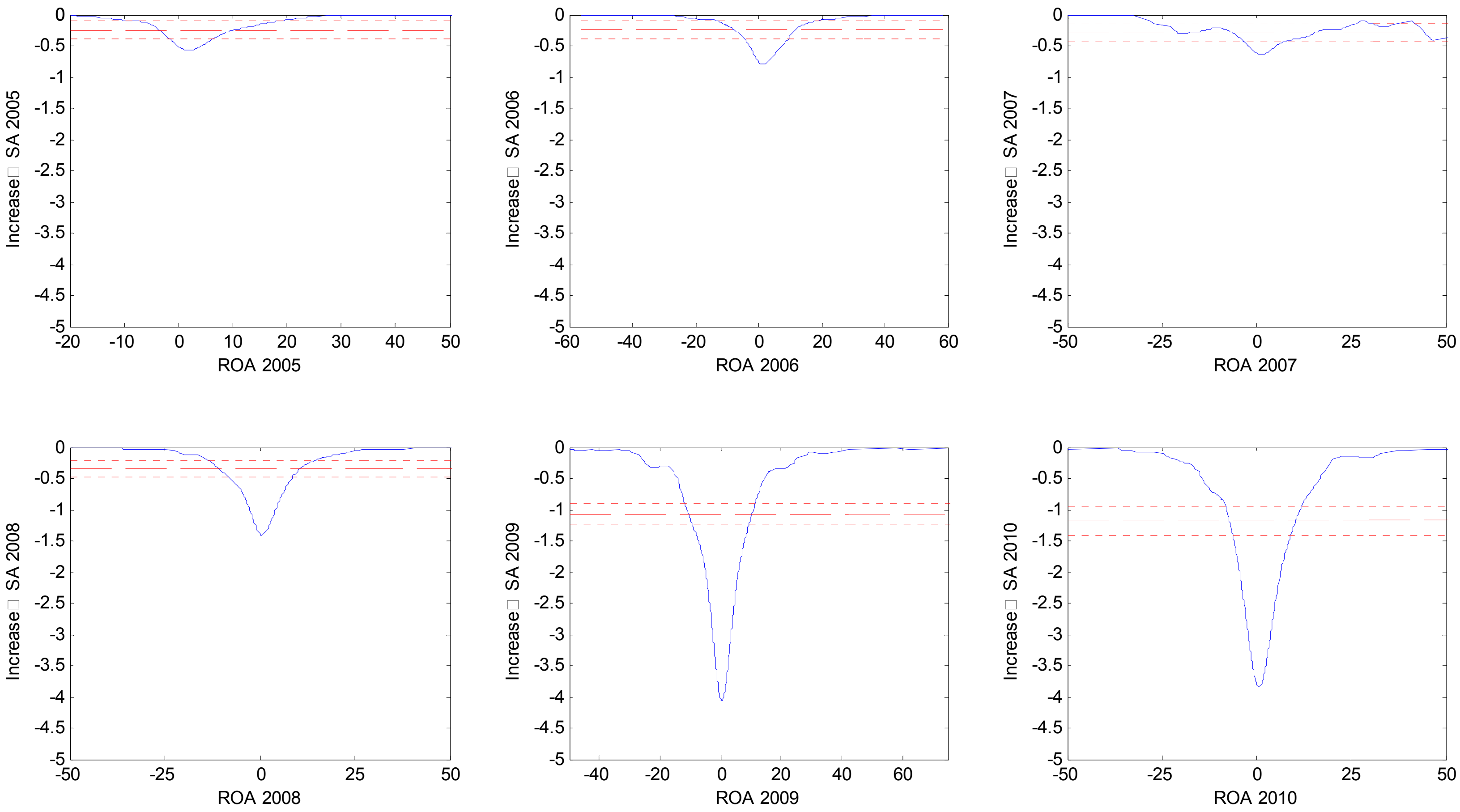

Figure 2: Derivatives of the median (blue continuous line) regression curve of the selected copula and point estimation of the regression linear coefficient (red dashed line) and 95% confidence interval limits (red dotted lines)

The relationship captured by the copulas is non-linear, as is highlighted in Figure 2, where we can see that the derivative curve of the median regression estimated by the copula is not constant for all the values of ROA.

The families selected (Frank and Gaussian) highlight the existence of weak tail dependence between both variables, with the strongest effects centered in the middle of the distribution, as can be appreciated in the regression curves (Figure 1), and their derivatives (Figure 2). Thus, SA and ROA tend to be independent in both tails of their distribution, where the least and the most profitable firms lie and, for this reason, t-copulas are not selected.

This behaviour is due to the existence of a natural upper limit (1) to the SA values and a lower limit (0) that most firms respect, because their CO_2 level emissions $E_{i,t}$ are lower than their assigned allowances. This leads to a decrease in the SA growth rate when we look at companies with extreme ROA values (See Figure 2). Indeed, the strongest link between ROA and SA corresponds to companies with ROA close to 0; approximately one third of the companies in our sample are integrated in the interval ROA € [-10%, +10%].

In Table 6, the goodness of fit of the selected models is analyzed. To that end, and in order to avoid the impact of outliers on the goodness of fit evaluation, we calculate the Mean Absolute Deviation (MAD) and the corresponding $\mathbf{R}^2_{abs}$ correlation coefficients of the selected copulas, and the linear regression lines. These criteria are given by the expressions:

$$\mathrm{MAD}_t = \frac{1}{N_t}\sum_{i=1}^{N}\left|SA_{i,t} - \hat{S}A_{i,t}\left(ROA_{i,t}\right)\right| \qquad (9)$$

$$R^2_{abs,t} = 1 - \frac{MAD_t}{MAD_{t,reference}} \qquad (10)$$

where

$\hat{S}A_{i,t}\left(ROA_{i,t}\right)$ is the value of $SA_{i,t}$ predicted for the median quantile curve of the selected copula (in the case of the copula model) or the linear regression line (in the case of the linear regression model)

$MAD_{t,reference} = \frac{1}{N_t}\sum_{i=1}^{N}\left|SA_{i,t} - Med_t\right|$ where Med_t is the median of $\{SA_{i,t};\ i=1,\ldots,\ N_t\}$, i.e., the mean absolute deviation with respect to the median taken as reference.

It can be seen that copula models have a better goodness of fit to data than linear regression models, especially after the financial crisis, reflecting more appropriately the dependence between the two variables.

Table 6. Goodness of fit of the selected copulas and the linear regression model

	Year					
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
	Selected family					
Goodness of fit measures	Frank	Frank	Gaussian	Frank	Frank	Frank
Spearman coefficient of the copula	-0.1613	-0.1668	-0.1661	-0.2293	-0.5201	-0.4369
Pearson coefficient of the copula	-0.1298	-0.1127	-0.1624	-0.1538	-0.3853	-0.3487
MAD of the copula	0.1607	0.2068	0.2211	0.2261	0.2306	0.2652
MAD of the regression lineal model	0.1611	0.2086	0.2215	0.2286	0.2462	0.2730
$\mathbf{R}^2_{abs}$ **of the copula**	0.0076	0.0141	0.0093	0.0325	0.1856	0.1270
$\mathbf{R}^2_{abs}$ **of the regression lineal model**	0.0055	0.0057	0.0075	0.0216	0.1302	0.1013

V. Proposed Policy measures

According to our results, and, in order to improve EU ETS efficacy, we have identified three main climate policy initiatives:

Green investment information disclosure.

As we have seen, SA is negatively related to ROA. As stated by the European Commission, by putting a price on each tone of carbon emitted, the EU ETS is driving investment in low-carbon technologies. A good way to help those companies investing in green technology to increase their ROA would be that the European Commission request, from each company within the EU ETS, information about their low-carbon investments and publish it on a yearly basis.

The utility of this measure would be two-fold. First, the Commission would know whether a company has reduced its emissions because of a decrease in its production figure, or due to its investment in green technology. In this way, the Commission could evaluate EU ETS efficacy more efficiently.

Second, and given that the number of investors and costumers who care about environmental issues when making their financial decisions is increasing day by day, companies investing in green technology would be rewarded by the market (e.g. positive response of share prices, reputation enhancement) and, in turn, would improve their financial performance. This would also represent an incentive for those companies who have still not made the investment.

The European Commission should reduce the frequency of cap revisions.

The beginning of Phase II in 2008 was marked by the onset of the global financial crisis. Companies show a decrease in their industrial activity, resulting in lower emissions levels than those assigned by the EU ETS. Our conclusions are in line with those of the European Commission, which has recently announced that the growing surplus of allowances during Phase II is due largely to the economic crisis that began in the fall of 2008, resulting in a larger than anticipated emissions decrease.

If no policy measures are taken, the surplus will continue to grow through 2014, and it will then remain constant until the end of Phase III in 2020, which the EC have stated is expected to endanger the effectiveness of the EU ETS, in both the short and the long term.

Thus, we consider that to postpone the auctions of certain allowances, planned for 2013, 2014, and 2015, proposed by the European Commission (2012), is sound short-term policy. Nevertheless, we believe that decisions regarding the emissions cap must be taken on a year-to-year basis in order to reduce the levels of surplus.

The unexpected financial crisis caused excessive supply because companies emitted less than forecast and the allowance allocation was drawn up several years in advance – before the crisis had taken hold. For this reason, the EU ETS did not achieve its target and thus, when making changes in the design of this market, the European Commission should reduce the frequency of cap revisions to adapt to the evolving economic situation.

Companies with ROA in the interval [-10%, +10%]

Apart from the market-based mechanisms, the Kyoto Protocol states that each country must meet its targets through the implementation of national policies. From our viewpoint, national policies should be oriented to providing financial assistance to companies to make investments to reduce their CO_2 emissions and to preserve their economic competitiveness. These policies should be oriented especially toward those firms with ROA around zero where, as we have seen in Section IV, the negative relationship to SA is more intense.

VI. Conclusions.

Policymakers and researchers have been rightly concerned about the efficiency of the EU ETS. According to the European Commission, EU ETS could be considered efficient if it drove a reduction in companies' CO_2 emissions without undermining their business performance.

This article provides an analysis of how surplus allowances and business performance at the firm level are related, by improving the prior results of Segura et al. (2014) using an approach based on copulas. In order to undertake our empirical study, we selected those Spanish companies that were part of the EU ETS during the period 2005-2010. We took into account the difference between assigned and verified emissions for the country as a whole, and we distinguished between two different periods, 2005-2007 (Phase I) and 2008-2010 (Phase II), in order to analyze the impact of the Spanish economic crisis on the emission process.

According to our results, EU ETS was not effective in Spain during the period 2005-2010 since it did not lead to companies reducing their CO_2 emissions in an economically effective manner. Although in both Phases I and II companies emitted less than expected, the surplus of allowances was negatively linked to business performance, i.e. companies that emitted less than expected had low business performance figures. This link sharply increased in Phase II, when there was a huge surplus.

In order to increase the efficiency of EU ETS, we propose three policy measures:

(i) The European Commission should gather and publish information about low-carbon investments on the part of each company within the EU ETS. This would serve as a register and a point of reference for investors interested in green investments. Additionally, it could be used as a tool to assess whether a decrease in CO_2 emissions is due to a downturn in industrial activity, or to an increase in green investment.

(ii) When making changes in the design of this market, the European Commission should reduce the frequency of cap revisions to adapt to the evolution of the economic situation.

(iii) National policies should be oriented to providing financial assistance to companies to make investments to reduce their CO2 emissions. These policies should be especially oriented toward those firms with ROA close to zero, where the relationship to SA is more intense.

Our study is not without its limitations and thus warrants future research. First of all, it would be interesting to consider how firm characteristics, such as sector, size, and risk, influence the relationship between surplus allowances and business performance. Another interesting future line of research would be to consider company R&D expenditures in order to analyze the relationship between surplus allowances and such expenditures, and hence evaluate EU ETS efficacy. These are some of our current lines of research, whose results will be published elsewhere.

VII. References.

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