Energy efficiency determinants: An empirical analysis of Spanish innovative firms

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Abstract
This paper examines the extent to which innovative Spanish firms pursue improvements in energy efficiency (EE) within their innovation objectives. The increase in energy consumption and its impact on greenhouse gas emissions justifies the greater attention being paid to energy efficiency and especially to industrial EE. The ability of manufacturing companies to innovate and improve their EE has a substantial influence on reaching the objectives regarding climate change mitigation. Despite the effort to design more efficient energy policies, the EE determinants in manufacturing firms have been little studied in the empirical literature. From an exhaustive sample of Spanish manufacturing firms and using a probit model, we examine the energy efficiency determinants to those firms that have innovated. To carry out the econometric analysis, we use a panel data coming from CIS (*Community Innovation Survey*) for the period 2008-2011 that includes 4,458 manufacturing firms. Among firm characteristics, the empirical results underline the importance of size in facilitating the adoption of technology that improves energy efficiency; while among the factors related to companies' behavior, the favorable influence of organizational innovations and innovations related with the reduction of environmental impacts stand out as the main factors in carrying out innovations with the objective of increasing energy efficiency.

Keywords: energy efficiency, corporate targets, innovation, Community Innovation Survey

JEL Classification: Q40, Q55, O31

1. Introduction

The increase in energy consumption and its influence on greenhouse gas emissions justifies the greater attention being paid to energy efficiency (EE) and especially to industrial EE. There is a global consensus on the correlation between energy consumption increases and rising greenhouse gas emissions. EE is the most advantageous way to enhance both the security of the energy supply and decrease greenhouse gas emissions and other pollutants (EC, 2011). Specifically, it is estimated that around 60% of the reduction of greenhouse gas emissions necessary to achieve the 2020 targets defined by the International Energy Agency (IEA) can be obtained through EE improvements (IEA, 2009). The economic literature has also contributed to underlining the role that technological improvements can play in the reduction of carbon emissions and lowering the cost of this reduction (Jaffe et al, 2004; Popp et al, 2009).

The problem arises when EE improvements at the current level are not enough to ameliorate the effects of increasing worldwide energy demand. However, industrial sector reports show that the implementation of existing technology and best practices on a global scale can lead to savings of between 18% and 26% of current industrial primary energy consumption (IEA, 2008). At the same time, a large number of studies of EE potential indicate that EE cost-effective measures are often not carried out in the industrial sector because of the existence of market failures and market barriers, bounded rationality and organizational problems, among other things (Hirst and Brown, 1990; Brown, 2001; Jaffe et al, 2004; Palm and Thollander, 2010; Cagno and Trianni, 2012; Backlund et al, 2012). The contributions on this question help to solve the problems that limit EE and to make progress towards the Climate Change Mitigation objectives.

As has been already pointed out EE, in general, and even more so in the industrial sector, is an important way to reduce the threat that global warming represents (IPCC, 2007), bearing in mind that industry is one of the main energy consumers (IEA, 2013). The European Commission (EC) promotes industrial EE through new energy requirements for industrial capital goods, improvements in the provision of information to SMEs, and measures to encourage the introduction of energy audits and energy management systems (EMS). Moreover, the EC is considering efficiency improvements in power and heat generation, ensuring that plans include EE measures throughout all the supply chain (EC, 2011).

The literature is not unanimous with regard to the influence EE has in terms of business performance. Neither does a single criteria exist on the optimal level of EE (Jaffe and Stavins, 1994). Conversely, besides their impact on greenhouse gas emission mitigation, it seems to have been demonstrated that EE investments are associated with improvements in technological development and innovation in firms. The debate centered exclusively on cost savings derived from EE improvements now turns out to be a very limited approach. For the reasons given above, EE is part of the environmental agenda (Worrell et al, 2009). The contributions from the literature on the impact of eco-innovation and environmental policy on company innovation decisions widen the scope of analytical procedure to more than that exclusively focused on cost savings. Porter and Van der Linde's (1995) article, which introduced a new approach based on the existence of a positive relationship between environmental policies and innovations that enhance product quality, cost savings, and finally company competitiveness, facilitates the study of EE from a new perspective. In as far as EE is located at the center of these stated policies, these contributions, even though partially questioned (Lanoie et al, 2011), help progress to be made in the interpretation of corporate decisions and the role of environmental regulation in EE decision-making. EE improvement has internal effects, in cost terms, and external effects, in as far as they directly affect emission reduction and Climate Change Mitigation. Nidumolu et al. (2009) maintain that it has been demonstrated that companies that work with environmental targets achieve reductions in costs to the extent that they reduce the inputs they use. This thesis is also defended by a part of the literature (Worell et al, 2009; Segarra-Oña et al, 2011).

One of the challenges for the study of EE is to identify the characteristics of firms that drive the adoption of EE improvements in order that policy can be correctly designed. This should become an important objective for the Spanish economy, where energy intensity has risen 10% between 1990 and 2006 while in the EU15 it has done the opposite in the same period (Mendiluce et al, 2010). Although in recent years this trend has improved in apparent terms, basically because of the economic crisis, Spain is still in the lead among EU countries in energy intensity (IDAE, 2013). Existing studies corroborate the possibility that the reduction of inequalities in energy intensity between countries could be attributed to the adoption of EE improvements (Greening et al, 1997; Duro et al, 2010).

Despite the importance of EE in reaching the economic and environmental sustainability objectives of the *Climate Energy Package*, the results obtained to date are not very encouraging. Between 1990 and 2006, the energy intensity of Spain remained stable without any reductions being seen that would indicate substantial efficiency improvements (Marrero and Ramos-Real, 2008). The large share of final energy consumption taken up by Spanish industry, 34,5% of final consumption in 2008, together with the limited incentives that companies receive to incorporate process innovations meant to improve EE, explains the poor progress registered at macroeconomic level.

This paper examines the characteristics of the Spanish manufacturing firms related with innovations in EE. In order to do so, an exhaustive sample of innovative firms from the Innovation Technology Panel (PITEC) is used, which offers access to a wide sample of Spanish innovative companies. The questions included in the survey allow key determinants for the achievement of EE improvements to be estimated. The paper pursues two objectives. On the one hand it goes in depth into the profile of firms that carry out process innovation and pursue improvements in EE levels among their objectives. On the other the paper analyses whether the behavior of firms around organizational innovations and environmental impact control are related to the EE objectives that Spanish manufacturing firms are trying to achieve. By EE we understand action taken by firms that has the objective of reducing the amount of energy consumption per unit output.

After this introduction, the paper is organized as follows. Next section briefly reviews the literature and the empirical studies. Section 3 describes the data employed in the empirical analysis and the variables used for the estimations. Section 4 illustrates the econometric strategy and presents the results. Section 5 concludes.

2. Literature review and empirical studies

There is a broad debate in the economic literature about the benefits attributed to EE. Several contributions affirm, with varying emphasis and evaluation of results, that a large proportion of the industrial sector has not implemented EE improvements despite the fact that these changes are associated with greater profits rather than costs (Hirst and Brown, 1990; Brown, 2001; Palm and Thollander, 2010; Cagno and Trianni, 2012; Backlund et al, 2012). On the other hand there is a current of thought that argues that EE improvements, far from reducing energy consumption, increase it – 'Jevons' Paradox' -, the so called 'Rebound Effect', that leads to a lowering of prices, at first, and then a subsequent increase that removes the cost savings (Khazzom, 1980; Greening et al, 2000; Sorrell, 2009).

The differences between the EE improvements actually achieved and those considered to be socially optimal have been defined by the literature, from different points of view, as the 'Energy Efficiency Gap' (Jaffe and Stavins, 1994). The most widespread formulation maintains that the 'Gap' appears when EE investment is below the socially optimal, in economic and environmental terms (Gillingham et al, 2009). Another reformulation of the same idea considers the 'Gap' can be explained as the uses of high 'implicit'[1] discount rates to evaluate EE investment decisions, greater than those that are accepted as optimal by the market for other investments with the same risk (Jaffe and Stavins, 1994).

The 'Energy Efficiency Gap' is considered to be the consequence of the existence of numerous market failures, which are understood as deviations from the assumptions of perfect competition, such as barriers associated with economic, organizational and behavioral obstacles and the lack of adoption of organizational innovations in EE management (Backlund et al, 2012).

The debate focuses on the distinction between market failures and market 'barriers'. The economic approach, which is lead by Sutherland (1991) and Jaffe and Stavins (1994), argues that public policy can only try to face market failures like imperfect information, R&D spillovers or principal-agent problems, among other things. On the other hand the technological approach maintains that public policy should attempt to remove all the barriers, whether they are market failures or not[2] (Hirst and Brown, 1990; Brown 2001). Those favoring the economic approach are against employing public policies to overcome this kind of barrier, because the cost of their implementation exceeds the gains in EE that can be obtained. From more extreme positions it is argued that if it is accepted that private agents take their own investment decisions seeking their own interest (complete rationality), it would be understandable that when they observe the existence of market failures and market barriers they use higher discount rates to evaluate investment decisions as they are faced with greater risk or uncertainty, and this would lead us to the conclusion that no paradox exists in the 'Energy Efficiency Gap' (Sutherland, 1996).

[1] The 'implicit' discount rate refers to the expected rate of return required for an investment to be considered cost-effective.

[2] Considered to be non-market failures are uncertainty about future energy prices, uncertainty about expected savings from the adoption of new technology, the qualitative characteristics of new technologies that make it less desirable, adoption costs not included in investment cost-effectiveness calculation or the heterogeneity of the consumers, and inertia, among others.

The most recent literature highlights, nevertheless, the importance of the technological-organizational approach in the design of policies for dealing with barriers (Backlund et al, 2012; Chay and Yeo, 2012). The increasing concern about the environmental agenda has converted EE and reducing the 'Gap' into fundamental targets, not only in economic terms (cost savings), but also in the fight against climate change (Worrell et al, 2009; Worell, 2011). In this context the EU agrees with the technological approach in the debate about the 'Gap'. The definition of the Energy Services Directive (ESD) is an example, which defends the idea that it is only possible to reach the social optimum of EE by applying strict policies to ameliorate market failures as well as market 'barriers' (EC, 2006; Backlund et al, 2012).

Several authors have attempted to determine the barriers that affect EE investments and establish different taxonomies (Blumstein et al, 1980; Jaffe and Stavins, 1994; Sorrell et al, 2000; Golove and Eto, 1996; Rhodin and Thollander, 2006; Hirst and Brown, 1990; Reddy, 1991; Sudhakara Reddy 2013; Chai and Yeo, 2012; Cagno et al, 2013). The number of barriers that have been identified is very high. In accordance with the scope of this study, only those that concern the industrial sector are analyzed, placing special emphasis on innovative companies.

The classification of barriers compiled by Sorell et al. (2000) offers a wider view than that considered by mainstream economic analysis. These authors distinguish three groups of barriers: economic, behavioral and organizational. The economic perspective associates barriers with market failures related, on the one hand, to rational behavior such as heterogeneity, hidden costs, risk, access to capital, and on the other to market or organizational failures such as imperfect information, externalities, split incentives, adverse selection and principal-agent problems. Sorell et al. (2000), in line with the literature closer to behavioral analysis and institutionalism, introduce a second group of barriers linked to 'bounded rationality', that is, to cognitive limitations and to behavior (Shogren and Taylor, 2008). Equally, the way in which information is presented, the credibility and trust of the sources of EE information, inertia in the way to proceed and the firm's environmental protection awareness are other barriers related to behavior. Finally, power (understood as conflicts of interest inside the firm) and the company culture are considered to be organizational barriers.

Other barriers not included in Sorrell et al. (2000) are failures in innovation markets (R&D spillovers and learning by doing) and in energy markets (environmental externalities) (Gillingham et al, 2009). The contribution of Sorrell et al. (2000) has opened up the field of analysis about the 'Energy Efficiency Gap'. Recent research has assumed a wider view of the concept of barriers (Chai and Yeo 2012). The data obtained from new sources such as energy audits (Fleiter et al, 2012; Triani and Cagno, 2012) or surveys (De Marchi, 2012; Segarra-Oña et al, 2011; Horbach et al, 2012) looking for the existence of different barriers from those conventionally associated with market failures, has broadened the information and the capacity of analysis, involving other technical and social disciplines and identifying new barriers in the industrial sector.

In empirical analysis the literature has attempted to identify barriers that hinder the adoption of EE investments (Rohdin and Thollander, 2006; Sardinou, 2008; de Groot et al, 2001; Trianni and Cagno, 2012; Fleiter et al, 2012). However, the number of contributions that study the link between EE and innovation is still small, and even more so with regard to the factors that influence the adoption of EE improvements by innovative firms (Trianni et al, 2013; De Marchi, 2012; Horbach et al, 2011; Segarra-Oña et al, 2011; Rennings and Rammer, 2009). Some of these studies use data coming from CIS (Community Innovation Survey) and tend to search for explanations for the decisions of innovative companies about investing in eco-innovation and/or EE, in some cases using logit and probit models or matching approach techniques.

The estimations carried out tend to identify a group of variables that influence EE improvement. Size is a significant variable in almost all the studies; institutional support for R&D in the form of subsidies and fiscal credits (Luiten et al, 2006; Luiten and Block, 2003), the ability to export and the export orientation of the country in which the firm is located (Urpelainen, 2011), and the sectorial characteristics associated with the energy intensity of the productive process (de Groot, 2001; Sardinou, 2008; De Marchi, 2012) explain EE investment decisions. It should be pointed out that in empirical studies focused on SMEs size is not significant due to the formation of the sample (Fleiter et al, 2012; Anderson and Newell, 2004). It is also considered that determining innovation factors, such as the number of registered patents held by the firm and spending on technology are also determining factors in the adoption of eco-innovation (Segarra-Oña et al, 2011). In this sense it has been found that regulation and cost savings (Horbach, 2012), and the introduction of environmental management systems and organizational changes (Khanna et al, 2009) favor innovation in environmental improvement.

The literature shows that certain characteristics of firms influence the adoption of innovative environmental technologies (Uhlaner et al, 2011). For example, to mitigate the problem of barriers it is crucial to determine the characteristics that differentiate eco-innovative companies. To have this information available could facilitate the discovery of the origin of the barriers and could be considerably useful for the companies themselves and for policy-makers when attempting to overcome existing limitations to the introduction of EE improvements. However more effort in this direction is required by researchers to identify these characteristics when the adoption of technology for EE improvements is being considered (Trianni et al, 2013).

Some empirical studies analyze the specific characteristics of eco-innovative firms in the field of EE. In an early approach, DeCanio and Watkins (1998) argued that the characteristics of each firm itself (such as the size, capital cost, expected future incomes and sector) influence decisions to invest in EE improvements. Rennings and Rammer (2009) attempt to explain the differences between innovative firms that introduce EE improvements in comparison with other innovative firms. In order to do this they use data from the Community Innovation Survey (CIS) from Germany, and they obtain the following results related to firms that introduce innovations in EE: i) they are more productive, ii) assign a larger share of sales to R&D, iii) obtain greater cost savings from the innovation process, iv) use more sources of information, v) cooperate more with the firms in their group, and vi) perceive innovation barriers more intensely.

The most recent studies on this topic are those by Horbach et al. (2012) and De Marchi (2012). The first, despite studying the determinants of eco-innovation in general, establishes a distinction according to the areas of impact of the innovation, which allows the identification of the determinants of EE innovations. The results show that the reasons that lead companies to adopt EE innovations are mainly focused on cost savings; but there is still an important component of environmental impact reduction. Other characteristics of eco-efficient innovative firms that emerge from this paper are changes in the organization of work to improve EE and cooperation with universities in the innovative process. At the same time future regulation and market demand are key factors that stand out in introducing more EE in the final product. The study by De Marchi (2012) that attempts to explain the link between cooperation and eco-innovation also includes eco-efficiency in a part of the model. The results obtained show that cooperation, continuity in carrying out R&D, firm size and investment in capital goods also benefit EE innovation.

3. Data sources and variables

The data source used in this research is the Technological Innovation Panel (PITEC). This data panel was the outcome of a cooperative project undertaken by the National Institute of Statistics (INE), the Spanish Foundation for Science and Technology (FECYT) and the COTEC Foundation. The INE has been carrying out a Community Innovation Survey (CIS) since 1994. The Spanish version of the survey includes sections on the introduction of innovations, expenditure on innovation, barriers to innovation and the results that firms obtain when they innovate, amongst other topics.

The main objective of the PITEC Project is to provide researchers with direct access to anonymized data. At the moment, PITEC supplies information that covers the period 2003-2011. The CIS for Spain has included over time new questions that were not formulated in the first editions in order to address more innovative lines of work and analysis. In particular, in 2008 firms were asked for the first time what goals they were pursuing when they introduced innovation into product or processes, offering for the first time the chance to make an independent analysis of energy efficiency-related objectives[3]; in 2009, the twelve objectives added to the previous year were expanded with three new objectives relating to employment. Also in 2009, the question of when the firm was founded was posed for the first time.

[3] The 2008 questionnaire introduces a significant change in relation to the previous years. The usual section about innovative activity results, which proposed among its alternatives one that brought together effects related with less material and energy per output unit, was replaced by a new section related to firms' objectives for their product and process innovations. The new item asks '*How important were each of the following objectives for your activities to develop product or process innovations during the three last years*? In addition, the survey asked to identify the importance of each objective to be identified *(High, Medium, Low or Not relevant)*', and distinguishes between the reduction of material cost per unit product and the reduction of energy cost per unit product. Other few OECD countries also included these questions. For instance, in 2009, the German CIS introduced a specific question about the objectives that firms pursue when they innovate in process or product. In this case firms indicate if a particular objective has high, medium, or low importance or whether it is not relevant for the company. In all cases the question is addressed to firms that innovate in process or product (see Birgit Aschhoff et al., 2013).

One of the main advantages of the PITEC database compared with sources containing cross-sectional data is its time dimension. This characteristic allows researchers to address with more precision the behaviour of the company and the level of heterogeneity between firms making up the samples. On the other hand, one of the limitations of the CIS survey is the subjective nature of many of the questions addressed to the firm's management or those responsible for R&D departments. Nevertheless, the comparisons made by Mairesse and Mohnen (2005) suggest that subjective assessments concerning business innovation tend to be consistent with more objective evaluations.

Our definitive database is the result of a prior filtering process. The most important filtering criteria were as follows: a) the survey data cover the period 2008-2011, given that the INE's CIS survey included a section on the objectives pursued by innovative firms in 2008; b) the sample cover those Spanish manufacturing firms which innovated in processes or products, given that the question '*How important were each of the following objectives for your activities to develop product or process innovations during the three last years?*' was aimed only at those firms. Of the 5,721 companies identified as Spanish manufacturing firms, after applying the relevant filters, the final sample comprised 4,458 firms which innovate in processes, products or both.

Table 1

As shown in Table 1, 66.2% of Spanish manufacturing firms made some kind of process innovation, while 77.9% of firms made innovations in products and/or processes. These data demonstrate that innovations in products and processes have high levels of complementarity, and the benefits of undertaking them both together are higher than those achieved by pursuing product or process innovations separately (Tirole, 1988, De Marchi, 2012). This evidence highlights the presence of indivisibility in the tangible and intangible assets associated with innovation processes and the prominence of economies of scope and scale. In our sample, 81.9% of the firms that made product innovations also made process innovations, while only 18.1% of the firms that innovated in products failed to innovate in processes; meanwhile, among the companies that innovated in processes, 79.8% also innovated in products, while the remaining 20.2% failed to do so.

Table 2 presents the variables that were used. The determining variable is dichotomous and takes the value of 1 when the firm seeks energy efficiency as an objective of innovation (with a medium or high level of importance) and zero when this objective has a low or insignificant level of importance. Currently, the number of firms actively pursuing improvements in energy efficiency levels, in terms of a reduction in energy costs per unit of production, is lower than those of other countries. For example, if the volume of innovative Spanish firms is compared with German firms based on CIS data from 2009, in high-tech industries 72% of Spanish innovative firms included improvements to their levels of energy efficiency with a moderate, medium or high importance as part of their objectives, as opposed to 86% of innovative German firms; while in mature industries, 69% of Spanish firms had energy efficiency among their objectives, as opposed to 83% of German firms (Aschhoff et al, 2013).

The determining factors of energy efficiency in manufacturing firms can be broken down into two groups. Firstly, there is a set of variables related to the individual characteristics of firms such as size, age, exports, whether or not it belongs to a group of companies or nationality. Secondly, there is another set of variables associated with the behaviour of the firm which the literature frequently considers as facilitators of the adoption of strategies related to energy efficiency – investment in R&D, investment in tangible assets, organizational innovations and access to public subsidies.

Table 2

The profile of firms giving a high level of importance to energy efficiency-related innovations differs significantly from those whose most important objectives do not include energy efficiency. The 1,467 innovative firms which gave a medium-to-high value to objectives related to improving their energy efficiency compared to the 1,723 firms which ascribed a low or even zero value to them showed notable differences, many of which offer a substantial level of statistical significance. The first group present greater sensitivity to environmental improvements and compliance with current legislation, they have a higher number of employees, invest more intensively in tangible assets, are more likely to belong to Spanish or foreign business groups and, finally, along with their technological innovations also practiced organizational innovations in terms of their working methods, internal logistics, incentives and quality systems, amongst other factors.

The values reflected in the different approaches of the two subgroups (firms that demonstrate little interest in pursuing energy efficiency compared to those that place energy efficiency among their main objectives), together with the substantial significance of the test, show the presence of structural differences. Indeed, the profile differences between the two subgroups greatly conditions the behaviour that determines the probability of each firm adopting the reduction of energy cost per unit of product as a strategic objective.

Table 3

4. Econometric analysis and results

Considering that the dependent variable, as we have defined it above, is a binary type, a probit model is used. Specifically, the next equation is estimated:

$$\text{Prob}\ (EE)_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 INN_{it} + \alpha_t + \varepsilon_{it} \qquad (1)$$

where EE_{it} is the importance given to energy efficiency innovation. The explanatory variables, as we have mentioned above, include a set of firm characteristics (X) and another set of variables associated with innovation strategies and behaviour of the firm (INN). The estimations have been carried out for the manufacturing industry and, individually, for the four sectors with a higher degree of energy intensity and that are also affected by the 2005 emissions reduction and trading directive (paper industry, chemicals, nonmetallic minerals and metals and metal products).

In the estimations for the whole sample fixed effects have been included by industry with the maximum level of disaggregation that the database allows (20 industry dummies). The sectorial divergences with respect to energy efficiency are notable. With the inclusion of these fixed effects any specific industry characteristic that can affect the firm's likelihood of considering energy efficiency innovation to be of high or medium importance is controlled for. In all the estimations time dummies are also included to control for cyclical effects.

Even though a panel of data is available, a pooled probit estimation has been carried out for the whole period. The time period for which dependent variable data is available is short (four years) and the relevant variation in the data is cross-sectional, while there is little variation over time. In the estimations, robust standard errors clustered at firm level have been used to control for intra-firm serial correlation.

The results of the estimations (Table 4) show that certain firm characteristics influence innovations connected with energy efficiency. In the first place, size and export propensity have positive and significant parameters, a result that coincides in the case of size with the results obtained in other studies (DeCanio and Watkins, 1998; De Marchi, 2012; Veugelers, 2012), but not in the case of export propensity, which has been little studied and has not been found to be significant (De Marchi, 2012). In spite of that, both are considered to be structural variables in eco-innovation processes (Segarra-Oña et al, 2011; De Marchi, 2012). The results obtained in this estimation for exporting, unlike those of De Marchi (2012), indicate that those firms that are more competitive and have a greater international market presence have more propensity to introduce energy efficiency related innovations. However, in the individual estimations for more energy intensive sectors, neither of the variables, size or export, are significant, which suggests that all types of firms in these sectors consider energy consumption reduction per output unit to be very important.

Other characteristics of firms such as age are not significant in explaining the introduction of energy efficiency innovation. These results coincide with other studies (Horbaach, 2012; Veugelers, 2012). In contrast, being part of a group of companies is significant and favors innovation with an energy efficiency objective. The exploitation of synergies between companies in the group is useful in overcoming existing barriers to eco-efficiency innovation.

Secondly, for innovation in the field of energy efficiency, capital goods investment is important, a result that coincides with that obtained by De Marchi (2012), while neither internal R&D nor external R&D are significant in the estimations. Consequently the type of process innovation that is carried out does not seem to need a great R&D effort while the introduction of tangible assets that permits process innovation resulting in reduction of energy consumption per output unit is required. By sectors, these results are also obtained for the paper, metal and metal products industries. In other applied studies on energy efficiency the results are along the same lines as those obtained, in Horbaach et al. (2012) and De Marchi (2012) neither internal nor external R6D are significant in the introduction of greater eco-efficiency.

Table 4

Thirdly, there is no relation between public R&D subsidies and energy efficiency innovation. The estimations by sectors show the robustness of these results and in none of the four cases is a significant parameter obtained. The existing literature also confirms this result, and in the studies of both eco-innovation and eco-efficiency models the public funds variable is only significant in the first whereas if the analysis is limited to energy efficiency innovation no positive effect is found (Horbaach et al, 2012; De Marchi, 2012).

Finally, energy efficiency innovation is closely related to other innovation objectives. The parameters for the innovation objectives “reduce environmental impact” and “to meet legal requirements” are positive and highly significant, especially regarding environmental objectives. Other empirical studies also show evidence of this close link (Horbaach et al, 2012). Additionally, there is also a positive relation between organizational and energy efficiency innovations, suggesting that this type of innovation goes together with changes in firm practice and procedures in the production area. For instance, the introduction of energy management bodies inside companies offers energy efficiency improvements new potential (Backlund et al, 2012). The same result is also obtained for the individual estimations by sectors, except in the case of the paper industry, where the legal requirement fulfillment innovation objective is not significant.

5. Conclusions

From the climate change mitigation perspective, to improve energy efficiency in the manufacturing sector is an important way to reduce the threat that global warming represents. In Spain, one of the main challenges that the economy faces is to reduce its energy dependence and the negative impact on the environment. Despite the importance of energy efficiency and the differences that distinguish the Spanish economy from neighbouring scenarios, the determinants of energy efficiency at firm level have scarcely been addressed.

This gap in firms’ behaviour in the field of energy efficiency may originate from the various incentives generated by the firm’s situation, in terms of social movements and the design of environmental policies, or from the differences in firms’ profiles and behaviour. The empirical evidence of this paper shows that a firm’s profile stands out as a key factor when it comes to introducing innovations aimed at improving energy efficiency levels. Thus the differences in corporate behaviour are, to a large extent, to be found in structural differentials linked to firms’ profiles. For the manufacturing sector, the empirical results show that in Spanish firms which focus on foreign markets, this plays an important role in a firm’s capacity to improve its energy efficiency. The results also show that the size of the firm is a relevant variable.

On the other hand, variables relating to the firm’s behaviour produce revealing results. Investment in tangible assets has a direct relationship with a commitment to energy efficiency, while investments in R&D per employee do not directly affect the firm’s capacity to improve its energy efficiency. The low profile of R&D as a facilitator of the adoption of technologies and practices that incorporate improvements in the firm’s energy efficiency levels should not be surprising, given the very nature of innovation in processes. In fact, improvements in energy efficiency are associated with the introduction of more efficient machinery, the adoption of the use of sustainable materials and the development of processes that are less reliant on the intensive use of technology, all of which are associated with investment in tangible assets and have little to do with R&D activity *per se*. Accordingly, the results obtained show the importance of investment in tangible assets as a factor that facilitates and accelerates the adoption of innovations in which energy efficiency plays a significant role.

Additionally, the econometric estimations show that environmental and energy efficiency objectives complement each other and that it is often the case that the innovative firm addresses them together, either as a result of the firm's own sensibilities or through the retroactive effects generated by the firm pursuing both objectives. Along with this result, it is worth highlighting the importance of organizational innovations as a key factor when it comes to overcoming the internal barriers that cause resistance to change and energy efficiency improvements.

The results obtained demonstrate that the profile of manufacturing firms, along with their adoption of specific strategies – especially investment in tangible assets, organizational innovations and measures relating to the environment – increase the probability that an innovative company will place energy efficiency among its objectives. These results highlight the need to design cross-cutting policies that generate incentives for innovative firms in the Spanish manufacturing sector to jointly tackle the challenges associated with energy efficiency and environmental sustainability without compromising the firm's competitiveness.

Empirical evidence highlights the fact that in Spanish manufacturing firms, organizational innovations and innovations in processes related to environmental objectives stand out as factors that encourage the kind of private investment that seeks energy efficiency, amongst other objectives. Given that there is a gap between the optimum levels of energy efficiency and those that are actually achieved, a wide-ranging series of public measures should be called for to encourage the adoption of technology and working patterns which not only improve firms' energy efficiency but also increase the productivity and competitiveness of manufacturing firms.

Policies to encourage EE are placed on a higher level than cost savings. Their objectives are to help to establish a more rational energy demand, reduce its growth, turn EE into an innovation and technological development tool, pursue sustainability and, in short, to be able to reach the main target of climate change mitigation. To implement these policies and to advance in our understanding of the factors that explain the gap between the optimal and the current level of energy efficiency requires a more detailed analysis of the barriers that firms face in reducing their energy costs. Therefore, further research should complement the analysis of the characteristics of the firms carried out in this paper with analyses regarding the obstacles that may hamper the introduction of innovations that have the objective of increasing energy efficiency. While the literature has described the different barriers related to energy efficiency and proposed some taxonomies, the few empirical analyses carried out to date do not allow definite conclusions to be drawn.

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Table 1
Innovative firms in the Spanish manufacturing sector

	Yes	No	Total
Firms innovating in products or processes	4,458 (77.9%)	1,263 (22.1%)	5,721 (100.0%)
Firms innovating in products	3,694 (64.6%)	2,027 (35.4%)	5,721 (100.0%)
Firms innovating in processes	3,788 (66.2%)	1,933 (33.8%)	5,721 (100.0%)

Table 2
Definition of variables

EE	Dichotomous variable: 1 if the firm considers the objective of innovation "energy efficiency (reducing energy consumption per unit output)" of medium or high importance (0 if the objective has only a low importance or it is not relevant)
Independent variables	
LSIZE	Number of employees in the firm (in log)
LAGE	Age of the firm in years (in log)
RDINT	Investment in internal R&D per employee (in thousands of euros). Delayed variable
RDEXT	Investment in external R&D per employee (in thousands of euros). Delayed variable
INVEST	Gross investment in tangible assets per employee (deflated)
GROUP	Categorical variable: 1 if the firm belongs to a group; 0 if not
PRIVNAC	Categorical variable: 1 if the firm is private with no foreign shareholding; 0 if not
EXPORT	Exports as percentage of total sales
FINANCE	Dichotomous variable: 1 if the firm gets public funding from a regional, national or European government for R&D activities; 0 if not
ECOINN	Dichotomous variable: 1 if the firm considers the objective of innovation "lower environmental impact" of medium or high importance
REGINN	Dichotomous variable: 1 if the firm considers the objective of innovation "meet legal requirements" of medium or high importance
INNORG	Dichotomous variable: 1 if the firm has introduced organizational innovations (new business practices for how work is organized and new company procedures); 0 if not
TIME DUMMIES	Years 2008 to 2011
INDUSTRY DUMMIES	Sectors 15 to 36 (CNAE93)

Note: R&D expenditure and investments in tangible assets were deflated with the Industrial Price Index of the INE.
Source: PITEC

Table 3
Profiles of innovative firms which have either a medium-high or low-insignificant Energy Efficiency objective

Variables	EE objective low or insignificant	EE objective medium - high	Mean difference
SIZE	121.9917 (348.7059)	234.0364 (673.6638)	112.04* (9.279)
AGE	28.7287 (19.4621)	31.1025 (20.6704)	2.3738* (0.3567)
RDINT	4287.268 (10685.41)	4727.863 (8954.64)	440.59* (177.280)
RDEXT	941.4136 (6024.747)	870.0461 (3003.758)	71.36 (87.397)
INVEST	9283.781 (100885.8)	11017.89 (43345.06)	1734.10 (1431.34)
EXPORT	10.1544 (17.5237)	11.2686 (18.1379)	1.1142* (0.3173)
GROUP	37.66% (0.4846)	49.87% (0.5000)	12.20* (0.0087)
ECOINN (% firms)	31.63% (0.4651)	81.42% (0.3889)	49.79%* (0.0077)
REGINN (% firms)	37.86% (0.4851)	80.92% (0.3930)	43.05%* (0.0079)
INNORG (% firms with organizational innovations)	42.19% (0.4939)	64.33% (0.4791)	22.14%* (0.0086)

Note: Comparison of the two samples by the statistical t-test; *significant at 1%.
Source: PITEC

Table 4. Innovation objective: Increase energy efficiency (EE). Probit estimations					
VARIABLES	(1) TOTAL (15…36)	(2) PAPER (21)	(3) CHEMICALS (24)	(4) NONMETALLIC MINERAL (26)	(5) METALS AND METAL PRODUCTS (27-28)
LSIZE	0.0976***	0.150	0.111	-0.181	0.00638
	(0.0300)	(0.268)	(0.0993)	(0.126)	(0.0984)
LAGE	-0.0198	-0.0881	-0.197*	0.333*	-0.0378
	(0.0419)	(0.274)	(0.110)	(0.193)	(0.133)
RDINT_1	0.628	14.85	-2.324	-6.715*	2.858
	(0.627)	(17.15)	(3.198)	(3.765)	(3.206)
RDEXT_1	0.0611	-33.56	-0.716	-5.895	-5.068
	(0.876)	(21.92)	(3.175)	(6.649)	(3.787)
INVEST	1.64e-09*	6.47e-08*	3.89e-09	3.60e-08**	-9.85e-09
	(8.90e-10)	(3.89e-08)	(3.01e-09)	(1.66e-08)	(4.30e-08)
EXPORT	0.00291*	-0.00226	0.00388	0.0120	0.00511
	(0.00157)	(0.0212)	(0.00361)	(0.0125)	(0.00512)
GROUP	0.121*	-0.154	0.267	0.432	0.270
	(0.0710)	(0.449)	(0.198)	(0.297)	(0.218)
PRIVNAC	-0.104	-0.250	0.0475	0.208	0.324
	(0.0835)	(0.578)	(0.208)	(0.326)	(0.323)
FINANCE	-0.0114	0.613	-0.0297	0.202	0.124
	(0.0549)	(0.418)	(0.145)	(0.241)	(0.181)
ECOINN	1.593***	2.382***	1.186***	1.364***	1.905***
	(0.0708)	(0.565)	(0.213)	(0.335)	(0.214)
REGINN	0.928***	0.338	1.037***	1.272***	0.852***
	(0.0701)	(0.507)	(0.206)	(0.308)	(0.216)
INNORG	0.391***	0.478	0.316**	0.509**	0.380**
	(0.0555)	(0.385)	(0.150)	(0.241)	(0.166)
Constant	-2.618***	-1.906	-1.546***	-2.625***	-2.345***
	(0.351)	(1.252)	(0.534)	(0.774)	(0.640)
Observations	14,872	306	1,946	790	1,621
Wald Chi-squared	1807.46	76.72	178.99	115.62	239.06
Pseudo R_squared	0.228	0.335	0.158	0.262	0.258

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
All the estimations include year dummies (3) and the total estimation includes also a set of industry (20) dummies