ENVIRONMENTAL POLICIES AND ENERGY EFFICIENCY INVESTMENTS. AN INDUSTRY-LEVEL ANALYSIS

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Abstract:

Energy efficiency is considered a very cost-effective way to mitigate air emissions and improve the economic performance of manufacturing industries. Many countries have implemented measures to increase energy efficiency in industry. These measures include command-and-control and market-based interventions, and they may be specific to a particular firm or sector. Although these policies may have benefits, the results of the empirical analyses of the effects of these interventions on the adoption of energy-saving technologies are not conclusive. The main objective of this paper is to examine the role of different environmental policy measures on energy efficiency investment. We construct a database from several sources for Spanish industries for the period 2010-2017. This gives us information on a broad range of factors and policy instruments that may drive energy efficiency investments. We consider four different instruments: regulation, taxes, subsidies, and tax credits.

Keywords: energy efficiency, environmental policy, climate change, industry-level.

JEL: Q48, Q53, Q55

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1. INTRODUCTION

Energy efficiency has been explicitly recognized by the International Energy Agency (IEA) from the "hidden fuel" to the "first fuel" of a sustainable global energy system. Putting energy efficiency at the top of policy and science agendas at an international and national level can only be explained by its significant and growing advantages in all economic sectors (European Commission, 2018). Beyond traditional measures to reduce energy consumption, save costs and decrease air emissions, policies aimed at increasing energy efficiency also have multiple economic and social benefits (Ryan and Campbell, 2012). From an energy supply perspective, energy efficiency contributes significantly to energy security by reducing dependence on imported energy. In addition, decreasing energy consumption through enhanced efficiency reduces inflationary tensions caused by the rise in international prices of energy raw materials. Finally, productivity gains at a sector level by increasing operation and process reliability can generate positive macroeconomic impacts, from boosting economic activity to generating more employment or having a positive impact on health and well-being.

The European Union set ambitious energy efficiency targets for 2020 and 2030 to reduce primary and final energy consumption (at least 20.0% and 32.5% improvements in energy efficiency compared to a baseline, respectively). To achieve these targets, all energy consumption sectors have to make contributions, including the industrial sector, which is responsible for one-quarter of final energy consumption and global air emissions (IEA, 2020). Although there may be incentives for firms to invest in energy-efficient technologies to reduce costs and go green, the literature shows that there is a difference between the socially optimal level of investment in energy-saving technologies and the amounts actually invested, which is referred to as the energy efficiency gap (Jaffe and Stavins, 1994). After reviewing the empirical literature about the drivers of energy efficiency in manufacturing firms, Solnordal and Foss (2018) affirm that the main reasons that firms invest in energy efficiency are still unclear, due to the heterogeneity of the literature. The authors mention that the multidisciplinary focus applied among researchers leads to scant consensus about the main drivers of energy efficiency.

Countries have implemented different policies to increase energy efficiency (Tanaka, 2011). However, there is still significant potential for improvement in energy efficiency policies (Abadie et al., 2012). These policies use different instruments, such as specific regulations, pricing policies, subsidies, tax deductions, cheaper loans and taxes, that can be market-based or command-and-control or, as Tanaka (2011) classifies them, prescriptive, economic or supportive.

The main objective of this paper is to examine the role of different policy instruments on energy efficiency investment in industries. While many papers have, in accordance with the Porter hypothesis (Porter and van der Linde, 1995), examined the effects of environmental policies on green innovation and business performance, very few have analysed the specific effects on investment in energy-efficient technologies. In addition, the results of these studies, which in many cases only consider a specific instrument, are not conclusive (Solnordal and Foss, 2018; García-Quevedo and Massa-Camps, 2019). Many energy-efficiency policies are already in place and assessing and evaluating their effects should be a high priority in research in this field (Gerarden et al., 2017).

To perform the empirical analysis, we have constructed a database for Spanish manufacturing industries for the period 2010-2017 with information from the Spanish Institute of Statistics (INE). The sources used are the Environmental Protection Activities Survey, the Innovation in Companies Survey, the Industrial Companies Survey, the Air Emissions Account and the Energy Consumption Survey. This gives us information on a broad range of factors and policy instruments that may be driving energy efficiency investments. It is worth mentioning that industry-level analyses have been carried out to examine energy efficiency (Pardo Martínez, 2010), environmental technology investments (del Río et al., 2011), environmental R&D (Costa-Campi et al., 2017) and air emissions (Agnolucci and Arvanitopoulos., 2019; Cole et al., 2005).

The rest of the paper is organised as follows. Firstly, we review the literature on the drivers of energy-efficient investments and particularly on the effects of policies and regulation. Secondly, we present the panel dataset and the empirical framework. Thirdly, we show the results and discuss them. Finally, we draw conclusions and discuss the main policy implications.

2. BACKGROUND

The drivers, barriers and other characteristics that may explain investment by firms in energy efficiency have been widely analysed, as recent reviews of the empirical literature show (Fleiter et al., 2012; Solnordal and Foss, 2018; García-Quevedo and Massa-Camps, 2019).

In particular, Solnordal and Foss (2018) review the drivers used in the empirical literature to examine energy efficiency in manufacturing firms. They develop a categorisation of these drivers, distinguishing between internal and external drivers together with certain controls (firm size and sector). Internal drivers are classified into economic drivers (e.g., technology solutions, energy costs, access to finance and pay-back), and organisational drivers (e.g., awareness of energy efficiency, environmental commitment, motivation of employees, R&D, organisational innovativeness). In the case of external drivers, two categories are considered: market drivers (e.g., competition, customer demands, industrial network, technical support from experts) and policy instruments. These include policy and regulation (legal compliance, subsidies, taxes, agreements and other policy interventions).

The implementation of energy efficiency policies is a current practice in most countries, and the number of such policies has grown substantially since 1990 (Tanaka, 2011). The focus of these policies has also changed and they are now more oriented towards energy efficiency, rather than only concentrating on energy conservation. Moreover, they are very influenced by the increasing importance placed on climate change objectives. Energy efficient technologies may help to reduce the environmental damage associated with energy use and, as Jaffe and Stavins (1994) state, the environmental consequences of energy use is a major market failure, which suggests that energy efficiency may be below the socially desirable level.

Although, as pointed out above, firms may have incentives to invest in energy-saving technologies as a way of reducing costs, investment in energy efficiency may be below the social optimum without the support of public policies because the existence of market failures. In particular, the lack of information on available technologies and the uncertainty of energy investments (Jaffe and Stavins, 1994) provide justification for the use of public policies (Arvanitis et al., 2017). Moreover, the existence of R&D spillovers in the energy-efficiency invention and innovation process can lead to underinvestment in these technologies (Gerarden et al., 2017).

In addition to these market failures that provide justification for government intervention, data for European countries show that energy efficiency has improved slowly since the recession that began in 2008, with limited progress in most industries and no improvement for others such a steel, cement, and machinery (Lapillone, 2016). In contrast to this limited progress, there is huge potential for industry to improve energy efficiency (Tanaka, 2011). In Spain, improvement in energy efficiency in industry is crucial in order to achieve the energy-saving target set by the European Union. According to the 2014-2020 National Energy Efficiency Action Plan (Ministry of Industry, Energy and Tourism of Spain, 2014), 55% of the saving target must be achieved through energy saving and efficiency measures in the industrial sector. This requires the adoption of the best available technologies in terms of equipment and processes, as well as, although to a lesser extent, the implementation of energy management systems. An examination of the potential energy saving for the most energy-intensive industries in Spain shows that there is still room to improve energy efficiency in almost all of them (Club Español de la Energía, 2014). With a more general approach, Román-Collado and Colinet (2018), after carrying out a decomposition analysis to explain the final energy consumption changes in Spain in the period 2000-2013, underline the importance of reinforcing policy measures to improve energy efficiency in different sectors, including industry.

Abadie et al. (2012) point out the potential scope for improving energy efficiency that policies offer, emphasizing that, together with worldwide carbon pricing policies, measures that help to reduce the cost of investment, such as subsidies, cheaper loans and tax deduction, may encourage energy-efficient investments.

Policies for energy efficiency improvements use a broad range of measures and instruments to encourage firms and industries to reduce greenhouse gas emissions and invest in energy-saving technologies. In environmental economics, a common distinction is made between command-and-control (regulations that establish limits and standards) and market-based instruments (subsidies, environmental taxes, tradable emissions permits or tax credits).

Specifically, with respect to policies and measures for energy efficiency in industry, Tanaka (2011) suggests distinguishing between prescriptive, economic, and supportive policies. The first refer to regulations and agreements that target some aspect of industrial energy use such as equipment efficiency levels, not widely used in the industrial sector, or energy management systems that may help firms to improve the use of energy and decide actions and investments to increase energy efficiency.

Economic policies include instruments such as taxes, subsidies and loans, tax credits, and cap and trade schemes. Most of these instruments aim to reduce emissions and can encourage energy efficiency as energy use is related to emissions, but they do not strictly focus on energy efficiency. These instruments influence the cost-effectiveness of energy efficiency investments and may induce innovation in energy-related technologies. In some countries, such as Spain, there are subsidies specifically to foster the adoption of energy efficient technologies. These subsidies reduce the cost of the investment and its payback, therefore encouraging firms to adopt these technologies.

Finally, supportive policies include measures designed to identify tools, provide technical information or encouraging cooperative actions. The main purpose of these measures is to help firms to overcome the market failures related to the lack of information.

Tanaka (2011) proposes different criteria to assess these instruments and provides a qualitative assessment. From a quantitative approach, some papers have included different policy instruments in their analysis of the factors that drive energy efficiency adoption or investments. However, as we show below, these papers use different variables to control for public support, and the results do not coincide.

The analysis of the effects of public instruments on energy efficiency investments have been analysed in some papers that focus on the determinants of eco-innovation, as well as in the literature on drivers and barriers to energy efficiency.

In the former case, various papers have taken into account the effects of public support for the reduction of energy use when examining the factors that drive the introduction of eco-innovation (Horbach et al., 2012) or when specifically assessing the role of different policy instruments on innovations with environmental benefits (Veugelers, 2012). Horbach et al. (2012) include dummy variables for regulations (present and future) and public subsidies to support environmental innovations. The results of the estimates for German firms do not show any positive effects of these variables on the introduction of process innovations in firms with an energy cost-saving objective. Similarly, Costa et al. (2015) do not find a positive relationship between R&D subsidies at different levels of government and energy efficiency innovation.

In contrast, Veugelers (2012) finds a positive effect for public policies on innovations that reduce the use of energy. The definition of the variables that control for public policies reflects whether the firm introduced environmental innovation as a reaction to specific instruments, distinguishing between regulations and environmental taxes, and grants including R&D subsidies and other financial incentives for environmental innovations. Both policy instruments have positive and significant effects in the case of Flemish firms. With a similar definition for policy instruments, Segarra-Blasco and Jové-Llopis (2019) include a variable to control for public support in examining the drivers of energy efficiency and renewable energy in European SMEs. Their results show a positive effect on the adoption of energy-saving actions.

Other papers that specifically address the drivers of and barriers to the adoption of energy efficiency actions or energy-efficient technologies include variables regarding public instruments. Once again, the results are not conclusive. Löschel et al., (2017) include a dummy for subsidized loans in the variables used to examine the decision to invest in energy-saving technologies and do not find a significant effect. Hochman and Timilisina (2012) point out that firms consider a lack of government policies to be an important factor. However, as they highlight, their empirical analysis does not show that the existing rules and regulations act as a barrier to the adoption of energy-efficient technologies. In contrast, Kounetas and Tsekouras (2008) and De Groot et al. (2001) find positive effects for subsidies and taxes, respectively, although, in the case of taxes, the results are heterogeneous between sectors. With respect to the effects of taxes, Davidsdottir and Ruth (2004) report that increases in energy taxes are unlikely to increase investment in energy efficiency permanently. Finally, other studies have analysed specific actions. In particular, the effect of energy audits carried out with public support have been recently evaluated using a large sample of German firms (Schleich and Fleiter, 2019). The results of the evaluation show that energy audits have a positive effect on the adoption of energy efficiency actions in small and medium firms.

3. DATA, VARIABLES AND MODEL

3.1. Database and variables

Empirical analyses of determinants of energy efficiency investments have to overcome limited data availability with respect to the dependent variable, as well as for the independent variables (Solnordal and Foss, 2018; García-Quevedo and Massa-Camps, 2019). In the case of the dependent variable, empirical studies have used different measures, primarily depending on the availability of data. The most common indicators used are the implementation or adoption of energy efficiency measures (mainly with a binary variable), energy consumption (energy cost, energy intensity and total energy expenditure, among others) and investments in energy efficiency, which is the most objective measure (Solnordal and Foss, 2018).

In this paper, we collect information from various surveys carried out annually by the Spanish Institute of Statistics (INE) to construct panel data for manufacturing industries in Spain for the period 2010-2017. The surveys used are the Environmental Protection Activities Survey, the Innovation in Companies Survey, the Industrial Companies Survey, the Air Emissions Account and the Energy Consumption Survey (see Table 1 for descriptive statistics and Table A1 for the definitions of the variables and sources). All these surveys are anonymous and mandatory for the firms and use the same classification of economic activities.

Although using firm-level data provides insight into the dynamics and strategies within industries that is beyond the scope of more aggregate data, the sector approach allows us to exploit the diversity of manufacturing industries, as they differ greatly in several aspects, such as with respect to how they consume or invest in energy, their air emissions and the environmental technological pattern they follow. The use of industry-level data enables us to include a broad range of variables that the literature identifies as potential policy instruments that may drive energy efficiency investments. Furthermore, merging all the databases used in this paper at a firm level enables us to tackle significant barriers due to the use of different samples, particularly for small and medium firms, in the different surveys, as well as overcoming anonymity restrictions. In contrast, the use of industry-level variables with the same classification of economic activities provided annually by INE guarantees its representativeness throughout the merging process.

Using industry-level data allows information to be gathered for a broad range of factors and policy instruments that may be related to energy efficiency investments. In addition, it helps to have information about the specific amounts invested in energy-saving technologies and for policy instruments (subsidies, taxes and tax credits), which is quite uncommon in this field of analysis. We also enjoy the benefits of using panel data, which allows us to control for unobserved characteristics that may influence decisions to invest in energy efficiency.

The Environmental Protection Activities Survey gives us information on the dependent variable (energy efficiency) and some of the independent variables (environmental taxes, subsidies, tax credits and environmental R&D). This survey provides data on spending by firms on environmental protection, distinguishing between current expenditure and investment. The information on investment is split between "end-of-pipe" solutions and integrated cleaner production technologies. For the latter, the survey gives information on the amount invested in nine different categories of environmental area, one of which is the reduction of energy consumption with an environmental purpose that we use as our measure of investment in energy efficiency. Other categories include, for instance, air emissions or wastewater. Although we have a specific measure of investment in energy-efficient equipment and installations, the available information does not enable us to distinguish between the adoption of energy-efficient equipment and innovation in energy-related technologies or examining other potential eco-innovation strategies focusing on the reduction of energy consumption.

In general, Spain experienced a significant reduction in the overall level of cleaner production investments in the manufacturing sector between 2010 and 2017. However, as shown in Figure 1, not all environmental areas (air emissions and energy efficiency) followed the same path, with different technologies being prioritised to boost environmental protection. For instance, the energy efficiency investment trend shows low investment intensity over the period 2010-2017. On average, Spanish manufacturing sectors invested 3.627 million euros in energy efficiency measures, while more than 6 million euros were spent on air-oriented strategies to environmental protection. Although the intensity of overall investment in energy efficiency was mild, reaching its lowest point in 2012 (1.476 million euros), the amount invested in energy-efficient practices experienced a clear gradual increase from 2013 onwards, reaching a peak in 2014 (4.89 million euros). These data also highlight the importance of analysing the amount of the investments and not only whether energy measures have been adopted.

[Insert Figure 1 here]

By sectors, there is considerable variation in the average level of energy efficiency investment. Energy-intensive sectors show greater effort in terms of implementing energy efficiency projects than non-energy intensive sectors (Figure 2). Therefore, it seems appropriate to conduct research focusing on industry-specific determinants.

[Insert Figure 2 here]

The main characteristics of policy instruments in Spain are as follows. Environmental taxes have mainly been implemented in Spain at regional level. Despite the lack of initiative at a central level, a few regional governments decided to introduce a range of environmental taxes. Galicia was the first region to introduce an air pollution tax in 1996. Nowadays, these include taxes on air pollution emissions, waste generation and storage, taxes on water use and sanitation levies, and other environmental taxes mainly imposed on installations and activities that have an environmental impact.

The differences in environmental taxation between regions are substantial, with certain regions having been more active than others (OECD, 2015; Gago, Labandeira, Labeaga, et al., 2019). Although regional governments have progressively introduced environmental taxes, there are still some regions without any environmental taxes. Moreover, there is substantial heterogeneity between the regions in terms of the time of introduction, type of environmental taxes and their rates.

The design of these taxes is considered inappropriate, with weak connections between the tax base and the actual environmental impacts (Gago et al., 2019). Moreover, the relative weight of these taxes is clearly below the European average. Specifically, revenues from environmental taxes amounted to 1.8% of GDP in Spain, compared to a European Union average of 2.4% in 2017 (European Commission, 2019). This limited use of environmental taxes in Spain has been underlined by different authors (Böhringer, Garcia-Muros, and González-Eguino, 2019; Labandeira, Labeaga, and López-Otero, 2019).

Subsidies and tax credits have been provided by the central government. In the period under analysis, within the framework of the Savings and Energy Efficiency Action Plans (Government of Spain, 2017), the central government granted subsidies to manufacturing firms with the specific aim of increasing energy efficiency. One of the main instruments is the aid programme for energy efficiency measures in SMEs and large industrial enterprises, which gives grants to firms to fund investments to improve industrial equipment and process technology and to implement energy management systems. The maximum amount of these grants is 30% of the corresponding eligible investment per application. The aim of this measure is to provide incentives to reduce carbon dioxide emissions by improving energy efficiency and reducing final energy consumption.

Finally, firms could obtain tax credits for their environmental protection investments, including actions to improve energy savings that reduce air emissions. These tax credits were introduced in 1996 at 10% of the firm's level of investment until 2006, when a slow phase-out was announced, with an annual reduction of 2 percentage points every year until 2011. The reason for phasing out this initiative was that the Spanish government considered that the incentive was mostly financing end-of-pipe technologies rather than cleaner production technologies, frequently required by law already. The phase-out continued until the complete elimination of tax credits in January 2011. However, in March of 2011, this tax credit was re-introduced for four more years at the set rate of 8% investment level as a measure to tackle the effect of the financial crisis. Eventually, in 2015, it was removed with a change in the law on corporate taxation (Tchorzewska, 2020).

This heterogeneity in the design and implementation process of policy instruments in Spain is reflected in their level of intensity. Average revenues from environmental taxes in the manufacturing sector during the period 2010-2017 was 1,081,500 euros, while the amount of money received through tax credit was substantially lower, at 695,000 euros on average, but far greater than from the subsidy, indicating that tax credits were significantly more generous (almost three times higher than for subsidies) (Table 1).

In our analysis, we focus on the main measures in the category of economic public policies in line with the taxonomy developed by Tanaka (2011). Although, in Spain, there are also measures in the group of supportive policies, such as providing technical information or encouraging cooperative actions, there is no information available on the amount allocated annually to these supportive policies with a breakdown by industries.

The information from the Environmental Protection Activities Survey has been complemented with data from the Industrial Companies Survey, an annual report that provides information on the main features of sectors (e.g., number of firms in each sector, number of employees, sales and export figures); the Innovation in Companies Survey, which reflects eco-innovation behaviour; the Air Emissions Account, which gives data on the emissions of air pollutants such as carbon dioxide (CO_2); and the Energy Consumption Survey.

[Insert Table 1 here]

3.2. Econometric methodology

To analyse the main drivers of energy efficiency investment, we use a panel estimator to further account for endogeneity, by controlling for some unobserved time-invariant heterogeneity in the model. In particular, a random-effect panel model is used for the following reasons: 1) the Hausman test supports a random-effect model; 2) a fixed-effect estimator may be inappropriate as many crucial determinants of our variables of interest are considerably lower within variations than overall and between variations; 3) estimates computed using fixed-effects models can be biased for panels over short periods.

Specifically, the following equation is estimated:

$$EE_{it} = \beta_0 + \beta_1 CAR_{it} + \beta_2 ENV_{it} + \beta_3 POLICY_{it} + \mu_i + e_{it} \qquad \text{Eq. [1]}$$

Where EE_{it} refers to the total amount invested in reducing energy consumption with an environmental purpose for 19 manufacturing industries (*i*) during the period (*t*) 2010-2017. One of the explanatory variables in Equation [1], CAR_{it} is a vector of explanatory variables containing information about industry characteristics. In the first set of variables, we include the control variables identified in the literature as determinants of energy efficiency investment, as well as being restricted by the variables available to us in our dataset. The size of the sectors in terms of number of workers and the size of the firms in the sector allow us to control for two sector characteristics identified in the literature: the sector's size and the size of the companies it comprises. To minimise any estimation bias due to an omitted variable, as a control variable, we also include the competition in the markets measured in terms of volume of exports. Then, in order to take into account relevant observable energy and environmental characteristics, we introduce a measure of the use of energy products acquired as an indicator of the energy behaviour of sectors and the role of technological and management capabilities measured in terms of effort in environmental R&D. Since industrial sectors differ significantly in terms of the degree of eco-innovativeness, it is important to control specifically for these technology opportunities.

Finally, we introduce a set of variables, $POLICY_{it,}$ to examine the effect of different policy measures on the promotion of energy efficiency investment. As discussed in the previous section, public institutions have access to an extensive group of instruments to encourage energy efficiency projects. In particular, four instruments are analysed in this paper: environmental taxes, tax credits, subsidies and regulation. For the first three instruments, the total amount is reported. As a proxy for regulation, two variables are included. Firstly, the environmental pressures measured in terms of CO_2 air emissions; as an alternative to this variable, a dummy variable could be included for sectors covered by the European Union Emissions Trading Scheme (EU ETS). However, since the correlation between EU ETS and CO_2 emissions is very high (0.73), plus the fact that five sectors covered by this scheme (chemical, petroleum, basic metals, non-metallic minerals and paper) are responsible for around 90% of CO_2 emissions in Spain, we believe that, in line with Constantini and Crespi (2008) and Marin (2014), the amount of CO_2 emissions allows us to differentiate more effectively between sectors and control for regulation in a more general way. The second variable included in this respect is environmental regulation as an innovation objective. $\beta_{0,}$ $\beta_1, \beta_2$and β_3 are unknown parameter vectors to be estimated.

In addition, a set of dummy variables related to the temporal dimension are included in all the regressions to control for cyclical effects. μ_i is a sector-specific effect that captures unobserved time-invariant sector heterogeneity, which may affect the energy efficiency investment, ε_{it} is an idiosyncratic error term. In order to control for potential multicollinearity problems, the correlation matrix and the variance inflation factor (VIF) are calculated (Tables 2 and 3). The individual VIF values are substantially below the recommended cut-off point of 10, indicating that multicollinearity problems do not exist in any of the models.

[Insert Table 2 here]

[Insert Table 3 here]

4. RESULTS

The results of the random effect model to examine the effect of a set of environmental policy instruments to promote energy efficiency investments at a sector level are displayed in Table 4. In the first set of estimations, we only include the industry characteristics. In the second, we expand this specification and include the environmental characteristics. Additional explanatory variables are then included regarding different policy instruments to check for both the individual and overall effects.

[Insert Table 4 here]

Our preferred estimation is the main one that includes all the variables, as it results in a statistically significant improvement in the fit of the model according to the Wald test and the R-squared. The results from this estimation show that, of the policy instruments analysed, only subsidies seem to promote energy efficiency projects. These subsidies, granted at national level and clearly designed to foster the use of energy saving technologies in firms, have a positive and a significant relationship with energy efficiency investments. Comparing this result to other studies that use firm-level data is not straightforward. As mentioned in the background section, most of these studies use dummies to control for public support, while we have been able to use amounts, making it is a more precise measure. Despite these differences and some heterogeneity in the results of firm-level data studies, most of them also find a positive relation between public subsidies and investment in energy efficiency.

In contrast, for the other instruments, there is not enough evidence to claim a positive relationship. Firstly, we have not found a significant relationship between environmental taxes and energy efficiency investment. It is very likely that the size of these taxes is too small to incentivise energy efficiency investments and, as some studies have highlighted, the inappropriate design of these taxes limits their impact and effectiveness (Gago et al., 2019). As discussed in the background section, very few studies have specifically analysed the effect of environmental taxes on energy efficiency investments and their results are not conclusive. With a more general approach, the impact of environmental taxes on environmental investments and innovation have been proven theoretically. However, even in this case, the influence of environmental taxation on the adoption of green technologies is not supported by the empirical literature (Tchorzewska, 2020). Secondly, neither are other instruments such as tax credits statistically significantly. These fiscal incentives were designed to promote environmental investments in general and they do not seem to have fostered energy efficiency investments specifically at an industry level. To the best of our knowledge, only Tchorzewska (2020) gives an empirical assessment of the role of a tax incentive programme on environmental investments, also carried out for Spain. Tchorzewska (2020) uses firm-level data, a different period and specification and tax credits are included as a dummy. Although the comparison with our results is again not straightforward, her analysis also shows that there is not a positive relationship between tax credits and investments specifically intended to improve energy efficiency. Thirdly, the two variables used to capture regulation are not statistically significant in our main estimation. In the period under analysis, due to certain implementation problems, there were some concerns about the EU ETS mechanism providing adequate price signals that incentivised low-carbon investments. In general, the EU ETS system seems to have had a very weak impact on environmental innovation (Borghesi and Montini, 2016). These results may indicate an inappropriate policy mix or that these tools are inadequately designed with respect to the needs of each industry.

Therefore, our results show that policy instruments, with the exception of subsidies, do not have a significant impact on energy efficiency investment. In contrast, other drivers such as operation costs (economic driver) and external competition (market driver) seem to be more important in terms of achieving greater energy efficiency in different sectors. The positive and significant sign for *Exports* suggests that international market competition incentivises energy efficiency practices. Finally, it should be noted that energy consumption is the main factor in the adoption of new technologies related to energy efficiency, which is a plausible and expected result. The positive sign of this variable confirms that energy-intensive firms are more likely to implement energy efficiency measures since the amount of energy products acquired represents a large proportion of the firms' operating costs.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Many countries have implemented policies to increase energy efficiency. Although there are good reasons to justify policy intervention, it is necessary to assess the effectiveness and impact of these policies. The aim of this paper is to shed light on the role of different environmental policy measures affecting investment in energy efficient in the Spanish industrial sector in the period 2010-2017. Previous empirical studies on energy efficiency determinants have often been based at a firm level and focused on the analysis of a particular instrument. Our paper expands this line of research by combining a policy mix (taxes, subsidies, tax credits and regulation) to promote energy efficiency investment, focusing on sectors in view of potential heterogeneous behaviours between them. In addition, using industry-level data collected from several surveys carried out annually by the Spanish Institute of Statistics enables us to obtain information on the specific amounts invested in energy-saving technologies and for different policy instruments, which is quite unusual in this field of analysis.

Through the application of random-effect models, our empirical results suggest that there is a need to evaluate the impact of different policy instruments due to the fact that their effects may differ substantially in terms of their impact on energy efficiency propensity. Our results show that, of all the policy instruments, only subsidies seem to promote energy efficiency investments. While we found a significant and positive parameter for subsides, there is not enough evidence of a positive relationship between environmental taxes, tax credits and regulation and saving energy investments. In contrast, the paper has confirmed the relevance of operation costs and external competition in explaining overall investment behaviour in energy efficiency technologies across sectors.

Certain public policy implications stem from this analysis. Firstly, the results of the analysis carried out for Spain suggest that public policies can work in several directions. Subsidies seem to be effective in triggering energy efficiency investments, while, in contrast, regulation, taxes and tax credits have no impact. The potential validity of these results for other countries should be taken with caution. The analysis has been carried out only for a single country, Spain, and, although we have examined policy instruments that are very frequently used in many countries, the design of these instruments (taxes, subsidies, tax credits and regulations) may be quite different. In addition, as explained previously, the design of these instruments underwent substantial changes during the period of analysis. In spite of these limitations, our results regarding the positive effects of subsidies on energy efficiency investments are similar to other studies based on firm-level data. In addition, at least for Spain, the lack of effectiveness of certain instruments suggests the need for a change in the current regulatory framework, particularly regarding environmental taxes, for which there is some consensus that they are not working properly. Secondly, while policymakers at the European Union have been implementing programmes to meet the energy efficiency objective set for 2020 and 2030, the efforts made by the different Member States are still insufficient and the adoption of new policies and additional measures to those in place today will be needed

(European Environmental Agency, 2019). Therefore, the challenge is to design a policy framework that is well defined, ongoing, and based on consistent economic and environmental conditions. These policies should be properly assessed to examine their impact. Our research and particularly the review of the literature carried out show that our knowledge of the effects of many policy instruments designed to foster energy efficiency in firms is still insufficient.

It is also important to highlight certain limitations of the paper that could be the object of future research and policy initiatives. Firstly, the definition of energy efficiency was limited to the investment proxy, an objective measure. However, not all projects had the same impact or equal success in this respect. It would be convenient to use the different dependent variables as data becomes available. Secondly, our empirical analysis has some shortcomings. In particular, there are significant endogeneity concerns. Correcting this issue would require the use of instrumental variables that are quite difficult to implement in the context of our analysis. Therefore, our results should be considered mainly as relationships and not strictly causal effects. In addition, the empirical analysis is based on a sample of 19 industries over a period of 8 years in the Spanish context. Consequently, the results of this contribution should be taken with caution. Its extension to other geographical area would help provide more general empirical evidence and might lead to a broader understanding of success drivers in terms of socioeconomic and institutional factors, since Member States set their own national non-binding targets for energy efficiency. Thirdly, there are differences between industries regarding energy efficiency investment factors that may require different incentives and policy instruments. Examining this aspect would be very useful for designing policy measures, but this analysis faces significant data availability constraints. Finally, it may also be useful for future research to analyse the effect of possible interactions between different policy instruments.

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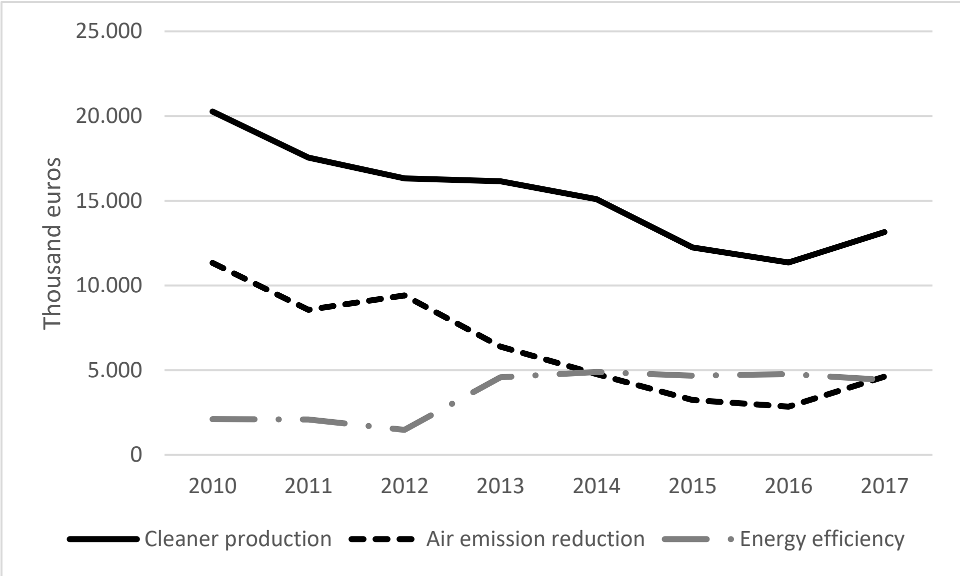
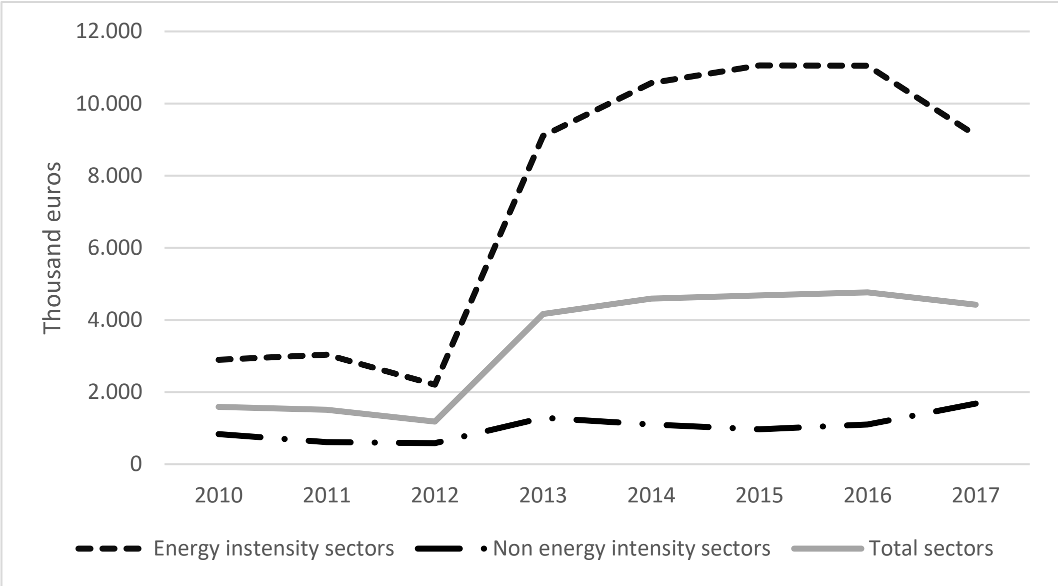
Tables and figures

Figure 1
Trend on cleaner production investment (mean)



Source: Own elaboration based on data provided by the Spanish Institute of Statistics (INE).

Figure 2
Trend on energy efficiency investment by sectors (mean)



Note: Energy intensity sectors includes the following sectors: chemical and petroleum, basic metals, non-metallic minerals, paper and print and, food and tobacco. Non energy intensity sectors include the following sectors: textiles, wearing apparel, leather and related products, wood and products of wood and cork, printing and reproduction of recorded media, basic pharmaceutical products and pharmaceutical preparations, rubber and plastic products, computer, electronic, and optical products, electrical equipment, machinery and equipment n.e.c, motor vehicles, trailers and semi-trailers, other transport equipment, furniture, Repair and installation of machinery and equipment.
Source: Own elaboration based on data provided by the Spanish Institute of Statistics (INE).

Table 1
Descriptive statistics

Variable	Unit	Obs.	Mean	Std. Dev.	Min	Max
Dependent variable						
Investment in energy efficiency	(in logs)	152	5.909	5.481	-25.328	10.774
	(thousand €)	152	3627.4	7499.5	1.00e-11	47765.9
Independent variables						
Industry characteristics						
Workers	(in logs)	152	4.007	0.761	1.952	5.679
	(thousand)	152	72.16	58.08	7.043	292.85
Firm size	(in logs)	152	2.657	1.336	0.649	6.075
	(workers per firm)	152	41.07	88.73	1.914	435.16
Exports	(in logs)	152	15.349	2.023	0.001	17.662
	(thousand €)	152	1.02e+07	9492971	12100	4.68e+07
Environmental characteristics						
Energy consumption	(in logs)	152	12.683	1.191	10.046	14.731
	(thousand €)	152	613594.1	667099.2	23079	2498487
Environmental R&D	(in logs)	152	4.768	2.073	-3.639	8.881
	(thousand €)	152	493.97	935.33	0.000	6766.40
Policy instruments						
Taxes (environmental)	(in logs)	152	6.064	1.524	0.878	8.752
	(thousand €)	152	1081.5	1398.8	2.407	6328.5
Tax credits (environmental)	(in logs)	152	3.680	3.012	-0.650	9.723
	(thousand €)	152	695.61	2021.1	0.000	16709.3
Subsidies (environmental)	(in logs)	152	2.559	2.670	-4.816	8.668
	(thousand €)	152	237.5	777.5	0.000	5817.4
Regulation: CO_2 emissions	(in logs)	152	6.648	1.978	2.990	10.447
	(thousand tonnes)	152	4006.6	7406.4	19.90	34442.8
Regulation: innovation strategy	(%)	152	28.236	9.317	7.550	75.000

Source: Own elaboration based on data provided by the Spanish Institute of Statistics (INE).

Table 2
Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11
1. Investment in energy efficiency	1.0000										
2. Workers	0.1654*	1.0000									
3. Firm size	0.3511*	-0.3605*	1.0000								
4. Exports	0.4415*	0.2822*	0.5557*	1.0000							
5. Energy consumption	0.3377*	0.3689*	0.1745*	0.4113*	1.0000						
6. Environmental R&D	0.4595*	0.0933	0.4981*	0.5817*	0.4110*	1.0000					
7. Taxes	0.2756*	0.1679*	0.2105*	0.3137*	0.6231*	0.2670*	1.0000				
8. Tax credits	0.3132*	0.1320	0.2590*	0.2346*	0.7037*	0.3987*	0.4546*	1.0000			
9. Subsidies	0.2793*	0.4061*	0.0186	0.2652*	0.5654*	0.3368*	0.2979*	0.4537*	1.0000		
10. Regulation: CO_2 emissions	0.2566*	-0.0262	0.3645*	0.4176*	0.7834*	0.4193*	0.5009*	0.4908*	0.3878*	1.0000	
11. Regulation: innovation strategy	0.1517	-0.4473*	0.5996*	0.2929*	0.1520	0.3510*	0.1778*	0.3273*	0.0285	0.2927*	1.0000

* Significant at 5%. Source: Own elaboration based on data provided by the Spanish Institute of Statistics (INE).

Table 3
Variance inflation factors (VIF) test

Variable	**VIF**	**1/VIF**
Workers	3.80	0.2629
Firm size	2.98	0.3355
Exports	3.07	0.3252
Energy consumption	8.48	0.1178
Environmental R&D	1.96	0.5104
Taxes	2.06	0.4862
Tax credits	2.73	0.3665
Subsidies	1.94	0.5161
Regulation: CO_2 emissions	4.77	0.2094
Regulation: innovation strategy	2.09	0.4793
Mean VIF	2.80	

Source: Own elaboration based on data provided by the Spanish Institute of Statistics (INE).

Table 4
Determinants of investment in energy efficiency (random effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Industry characteristics							
Workers	0.882	0.888	0.850	0.727	0.0213	0.722	-0.434
	(1.046)	(1.070)	(0.971)	(1.042)	(0.891)	(1.031)	(0.908)
Firm size	0.756	0.754	0.613	0.771	0.665	0.811	0.701
	(0.574)	(0.563)	(0.540)	(0.590)	(0.479)	(0.686)	(0.575)
Exports	0.375	0.371	0.531	0.383	0.577	0.396	0.751**
	(0.437)	(0.449)	(0.430)	(0.445)	(0.365)	(0.427)	(0.373)
Environmental characteristics							
Energy consumption	0.657	0.658	0.114	0.467	1.712***	0.701*	1.133**
	(0.415)	(0.680)	(0.295)	(0.448)	(0.582)	(0.370)	(0.551)
Environmental R&D	0.600	0.605	0.510	0.556	0.603	0.616	0.507
	(0.442)	(0.458)	(0.446)	(0.429)	(0.444)	(0.470)	(0.476)
Policy instruments							
Taxes		0.00641					-0.107
		(0.390)					(0.354)
Tax credits			0.305**				0.255
			(0.147)				(0.158)
Subsidies				0.214**			0.203*
				(0.106)			(0.123)
Regulation: CO_2 emissions					-0.734**		-0.657
					(0.369)		(0.406)
Regulation: innovation strategy						-0.0294	-0.0631
						(0.123)	(0.117)
Constant	-16.02***	-16.06***	-11.85***	-13.75***	-23.75***	-15.64***	-16.81***
	(4.124)	(5.839)	(3.765)	(4.465)	(4.153)	(4.874)	(5.098)
Observations				152			
Wald Chi^2	604.34	657.00	951.18	1089.49	693.70	799.19	2195.29
Prob > Chi^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2:							
within	0.1386	0.1388	0.1342	0.1476	0.1505	0.1389	0.1595
between	0.7670	0.7665	0.8089	0.7656	0.7905	0.7700	0.8210
overall	0.3373	0.3373	0.3491	0.3427	0.3528	0.3387	0.3694
Mean VIF	1.93	2.05	2.09	2.00	2.48	1.99	2.80

Asterisks indicate significance levels of *1, **5 and ***10%. Estimations control for time dummies. Robust standard errors in brackets clustered at sectoral level. Source: Own elaboration based on data provided by the Spanish Institute of Statistics (INE).

Appendix

Table A.1
Definition of Variables

Dependent variables	**Variable definitions**	**Source**
Investment in energy efficiency	Log of the total amount invested in reducing energy consumption with an environmental purpose	The Environmental Protection Activities Survey
Independent variables		
Industry characteristics		
Workers	Log of the total number of employees	Industrial Companies Survey
Firm size	Average size of the firms in the sector in logs (number of workers per firm)	Industrial Companies Survey
Exports	Log of the total amount of exports	Industrial Companies Survey
Environmental characteristics		
Energy consumption	Log of the total amount of energy products acquired	Energy Consumption Survey
Environmental R&D	Log of the total environmental R&D expenditure in energy	The Environmental Protection Activities Survey
Policy instruments		
Taxes	Log of the total amount of environmental taxes paid	The Environmental Protection Activities Survey
Tax credits	Log of the total amount of tax credits received for environmental protection	The Environmental Protection Activities Survey
Subsidies	Log of the total amount subsidies and grants received for environmental protection	The Environmental Protection Activities Survey
Regulation: CO_2 emissions	Log of the total amount of CO_2 emissions	The Air Emissions Account
Regulation: innovation strategy	Objective of innovation: fulfil environmental, health or safety regulatory requirements (% of firms that consider this to be of high importance)	Innovation in Companies Survey