End-of-pipe and cleaner production technologies. Do policy instruments and organizational capabilities matter? Evidence from Spanish firms.

J. Garcia-Quevedo [*], E. Martinez-Ros [†], K.B. Tchorzewska [‡]

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Abstract

This paper focuses on the drivers of green technology adoption. We distinguish between end-of-pipe and cleaner production technologies aimed at either pollution mitigation or energy efficiency, respectively. We provide empirical evidence of the relations between existing policy instruments, organizational capabilities of firms and the adoption of different types of green technologies. We use a unique firm level panel dataset of 2,562 Spanish manufacturing firms from 2008 to 2014 to carry out the empirical analysis. Our results show, first, that policy instruments drive adoption of green innovation more than organizational capabilities. Second, environmental taxation seems to be ineffective at stimulating the adoption of eco-innovation. Third, both investment subsidies and tax credits do imply higher levels of investments in green technologies. Tax incentives seem to mostly foster cleaner production technologies, while subsidies are used to finance all types of eco–innovations. Fourth, human resources as green employees are positively related with environmental investments. Finally, dynamic capabilities as the introduction of environmental management systems are correlated particularly with cleaner production investments oriented to reduce energy consumption.

Keywords: Eco-innovation; Environmental Taxation; Tax credits; Subsidies; Organisational Capabilities.

JEL Codes: O31; O38; Q55; Q58.

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[*] Chair of Energy Sustainability and Barcelona Institute of Economics (IEB), University of Barcelona, Av/Diagonal 690, 08034 Barcelona, Spain, e-mail: jgarciaq@ub.edu

[†] Carlos III University of Madrid, Calle Madrid, 126, 28903 Getafe, Madrid, Spain, e-mail: emros@emp.uc3m.es

[‡] Chair of Energy Sustainability and Barcelona Institute of Economics (IEB), University of Barcelona, carrer de John Maynard Keynes, 1, 11, 08034 Barcelona, Spain, Present Address: ZEW Leibniz Centre for European Economic Research, L7 1, 68161 Mannheim, Germany, e-mail: kinga.tchorzewska@zew.de

1 Introduction

While arguments in favour of environmental innovation (eco-innovation) are well-rehearsed, given their nature of reducing pollution and using resources more efficiently (EIO, 2012), scholars still try to uncover the black box of firms' decision making on the adoption of green technologies. Firms, while making such decisions are faced with several factors. Firstly, there might exist consumer requirement for green products on the demand side (Kammerer, 2009), or firms might also be more naturally inclined to invest in green innovations given their own organizational capabilities, path dependence, size or sector (Jove-Llopis and Segarra-Blasco, 2018; Demirel and Kesidou, 2011; Triguero, Moreno-Mondéjar, and Davia, 2013). Literature also presents evidence for several external constraints such as capital market failure. Finally, researchers admit that policy stringency may be a very important (if not the most important) incentive to invest in eco-innovations (Porter, 1991; Porter and Van der Linde, 1995). Since both economists and policy makers agree that eco-innovations are crucial in transitioning to sustainable societies (Machiba, 2011) we need to make sure we understand correctly public sector intervention and which specific capabilities and resources of the firms may drive transition to cleaner production technologies.

For the purpose of analyzing the drivers of production process eco-innovation, it is important to distinguish between pollution abating technologies (end-of-pipe) and integrated cleaner production technologies (Frondel, Horbach, and Rennings, 2007; Horbach, 2008; Rennings, 2000). End-of-pipe (EP) technologies are aimed at addressing the environmental objective alone, bear no other benefits and are, in fact, the most incremental of all eco-innovations. What is more, firms consider them as costly investments that might trigger loss in competitiveness (however still significantly cheaper than CP)(Porter and Van der Linde, 1995). In contrast to cleaner production technologies, they do not reduce the amount of pollution created, but simply emitted at the end of the production line - through for example passive filters or scrubbers that remove sulphur particulates from the emissions of coal plants. Consequently, abatement technologies are "net cost for firms and would not be adopted without environmental regulation" and to environmental concerns that affects reputation among the consumers (Carraro et al., 2010). On the other hand, cleaner production technologies aim at both environmental objectives and sustained growth of the company. They use resources more efficiently and through that change in the production process, they lead to decreases in emission as well as long run cuts in operating costs (Demirel and Kesidou, 2011). As example of such investments we could count in installations for reducing the use of water, reuse of waste gas in manufacturing or internal recycling. In particular, the investment in cleaner production technologies with the objectives of reducing air pollution and decreasing energy consumption may have significant effects both on environmental objectives and competitiveness of the firms. In this sense, cleaner production technologies due to their apparent positive effectiveness on competitiveness are considered superior to the end-of-pipe technologies (Frondel, Horbach, and Rennings, 2007).

The aim of our paper is to contribute to the existing literature with new insights on the drivers of different green innovation in the industrial sectors and is most closely related to the work by Demirel and Kesidou (2011). Specifically, we analyse the relations between existing policy instruments, resources and organisational capabilities of firms and the adoption of different types of green technologies. Regarding policy instruments we consider taxes, subsidies and tax incentives, while for the resources and capabilities of the firms we examine the role of human resources and the use of environmental management systems. In the analyses we distinguish between end-of-pipe and cleaner production technologies aimed at either pollution mitigation or improving energy efficiency. In the analysis we use data from National Institute of Statistics of Spain (INE) using "*The Survey on Industry Expenditure on Environmental Protection*" (SIEEP), which allows us to create a panel data set for 2,562 companies between 2008 and 2014 across 30 manufacturing sectors. The survey contains detailed information on the amount invested annually in green innovation by each firm with the distinction between EP and CP technologies as well for some specific purposes - air pollution and energy consumption - of these investments. The survey provides also information on policy instruments, resources and organizational capabilities and some other characteristics of the firms. The dataset provides us with a set of variables containing precise information on the amount of public financing given through subsidies and tax credits as well as amounts paid on air-pollution, waste and other environmental taxes. Unlike the previous papers in the literature on eco-innovations, we use a panel data set at the firm level and so we can control for, among other things, unobserved time invariant and firm heterogeneity.

The rest of the paper is organized as follows. Section 2 analyses the relevant literature and aims at finding gaps. Section 3 presents data, descriptive statistics, explains the way the main variables were measured and describes the empirical analysis used. Section 4 discusses the empirical findings and presents numerous robustness checks. We conclude and present policy implications in Section 5.

2 Literature Review

Scholars have been increasingly interested in the drivers of the adoption of green technologies for over 20 years now (for an extensive revision see Lilliestam, Patt, and Bersalli (2021), del Río, Peñasco, and Romero-Jordán (2016), Horbach, Rammer, and Rennings (2012), Requate (2005), Kerr and Newell (2003), Jaffe, Newell, and Stavins (2002), and Jaffe and Palmer (1997), among others). The justification of such analysis is crucial for policy makers to implement instruments to foster green innovation to help companies gain competitive advantage. Horbach (2008) established the main drivers of eco-innovations to be technological capabilities and market characteristics on the supply side; market demand and social awareness on the demand side; and environmental policy as well as institutional structure on the public-policy side. He was also the first one to carry out a panel data empirical analysis rather than a cross-sectional analysis based on survey questions. Additionally, the literature has recently acknowledged that since eco-innovations have different characteristics they can, in fact, have many different drivers (Triguero, Moreno-Mondéjar, and Davia, 2013; Haller and Murphy, 2012; Horbach, Rammer, and Rennings, 2012; De Marchi, 2012). Scholars commonly divide the drivers into the external (regulation, community or media) and internal categories (organizational resources as skill employees or capabilities such as efficiency, corporate image, investing in environmental certifications). They admit that regulatory push tends to be a strong driver for any eco-innovation. In the following section, we carry out a literature review on policy instruments, resources and organizational capabilities, within the context of eco-innovation.

2.1 Policy-Instruments: environmental taxation, investment tax credits and investment subsidies

Public policy is considered crucial in incentivising firms to perform environmental investments. Already in the 90s Porter and Van der Linde (1995) pointed out that regulators should drive the adoption of green-innovation, since those very technologies produce benefits to the society. However, not much consensus emerges on the use of green policy instruments. The literature on adoption of green innovations typically uses qualitative firm surveys, which do not have the access to detailed information on policy instruments, especially across several years. For example, Triguero, Moreno-Mondéjar, and Davia (2013) uses three dummy variables: existing regulation such as standards, future regulations - future standards as well as access to subsidies and fiscal incentives, which, however, is limited by the fact that questionnaires are filled subjectively by managers based on whether they "consider specific drivers of eco-innovation to be important" (similarly used by Cleff and Rennings (2000), Green, McMeekin, and Irwin (1994), and del Río González (2009)). Otherwise, papers typically either use environmental regulation with the abatement costs (US PACE Survey), the number of inspections concerned with pollution levels (Brunnermeier and Cohen, 2003) or creating a proxy for a firm being under the EU ETS based on the sector it belongs to (Siedschlag and Yan, 2021; Borghesi, Cainelli, and Mazzanti, 2015; Dechezleprêtre et al., 2011). Demirel and Kesidou (2011) proxy the environmental regulation with abatement costs, though taking into account both capital and operating expenditure. Doran and Ryan (2016) showed that surveys point to regulation and customer pressure as the reasons through which firms decide to engage in eco-innovation.

With regards to effectiveness of specific environmental policies, the instruments examined the most are: emission taxes, investment subsidies with almost no research done on tax incentives - particularly investment tax credits. Tax policy is perceived as less distorting than direct regulation, through the use of private information firms use the utility maximizing solutions (Tresch, 2014). That being said, Lilliestam, Patt, and Bersalli (2021) reviews literature and concludes there exist no empirical evidence for carbon pricing triggering either innovation or zero-carbon investment, and so the statement in favour of carbon taxation remains a theoretical one. On the other hand, subsidies and investment tax credits reduce the costs of undertaking innovation and decrease the barrier to innovate by providing a monetary incentive. One fear, however, is that the eligibility for the subsidies and tax deductions are usually limited to known technologies and hence they decrease the use of private information that e.g. emission taxes take advantage of. Additionally, many fear that subsidies crowd-out investment (rather than crowd-in) (Mao and Wang, 2016). It is also important to distinguish between subsidies and investment tax credits. While their goal is similar - they both address the capital market failure, the implementation differs substantially. As pointed out by Sánchez (2007) tax incentives translate into less administrative costs both for firms and public administration. Tax incentives possibly allow firms to exercise more flexibility, when it comes to the technology chosen. In the eyes of that, it might be the case that they drive the investment in green technologies differently.

Lastly, a new literature on policy-mix is gradually emerging, with only a few papers having been written on the topic. There have been some empirical evidence on complementarities between environmental regulations and taxes, as well as environmental regulation and innovation subsidies (Greco et al., 2020; Veugelers, 2012; Costantini, Crespi, and Palma, 2017). Recently also Tchorzewska (2020) investigated the policy mix of environmental taxes and investment subsidies on adoption of green technologies. However, there is still too little evidence and consensus on conclusions.

Consequently, in the context of policy instruments we have decided to focus on the following research questions. Firstly, does environmental taxation drive adoption of green technologies? Secondly, are investment incentives such as subsidies and tax credits decisive drivers for green technologies, are they incentivising different types of technologies? Thirdly, can we observe higher levels of investment when firms are under more than one policy regime, thus investigating a so called policy-mix.

2.2 Organisational capabilities and resources

Kemp and Goodchild (1992) were probably one of the first to point out that investment of firm is dependent on their type, and that firms that engage in environmental practices such as recycling or green product design, have higher probability of investing in green technologies. Additionally, two types of organizational factors were brought forward such as organisational resources and performance monitoring systems, which allegedly play an important role in the process. Kiefer, Del Río González, and Carrillo-Hermosilla (2018) claimed the necessity to increment evidence on the evaluation of internal factors such as resources competences and dynamic characteristics. Taking from Resource-based view theory (Nelson and Winter, 1982), resources refer to tangible (physical capital or financial sources) and intangible (reputation, organization culture, human resources) assets. Capabilities are firms' resources that in the repeated use lead to routines or processes. Once those capabilities are extended and modified following the environment business changes, then they transform into dynamic capabilities (Teece, Pisano, and Shuen, 1997). In our context, this distinction is important, because we mainly consider as organizational resources: the employees occupied in environmental protecting tasks and as organizational capabilities: the investment in some type of environmental certifications. del Río, Peñasco, and Romero-Jordán (2016) states that organisation capabilities are largely unrepresented in the literature, again mostly due to poor data availibility.

Scholars agree that decision processes are determined by the managerial capabilities and that those eventually tend to enhance environmental process innovation. del Río González (2009) pointed out that the internal factors proxy the existing preconditions for facilitating company's involvement in technical change. For example the involvement in environmental procedures, certifications, environmental management systems (EMS) and having green employees dedicated to environmental protection represent important capabilities to eco-innovate. In fact, Horbach (2008) has shown a positive impact that their implementation has on eco-innovation. Simultaneously, hesitation still remains, whether firms simply use them to signal their "green type" rather than implement the green technology directly (Boiral, 2007).

Another factor that scholars have only recently started to investigate is how having green employees affects your innovation. In the literature there exist two major types of green management practices. One related to environmental management used to protect the natural environment and resources, while the second one is concerned with operational effectiveness in resource and energy consumption. The work of Shu et al. (2016) though focusing on product innovation rather than process innovation, finds a positive effect between green management and innovation. The authors emphasize that firms with green management are more likely to introduce radical rather than incremental product innovations.

Consequently, our research questions in relation to resources and organisation capabilities are as follows. Does having having green employees dedicated to environmental protection activities drive the adoption of green technologies? Does involvement in specific environmental procedures incentivise the adoption of green technologies or does it work as a mere signalling strategy towards the customers?

3 Empirical Analysis

3.1 Data

Eco-innovation data used in the following empirical analysis was collected by INE for the annually carried out SIEEP. The objective of the survey is to gather firm level data on environmental protection expenditures, across 30 manufacturing sectors for all regions in Spain, which results in a representative dataset for the entire Spanish industry. The primary activity of the company, and so the sector it belongs to, is defined as the one which gives the greatest added value across all autonomous regions. SIEEP provides also information on the size (includes all establishments hiring 10 and more remunerated employees) and a number of capital environmental expenditure, investment and research data. The firm level data is available between 2008 and 2014, providing an unbalanced panel data set for 2,562 companies, where each company has at least 4 observations across 7 years. Out of all 26 variables available, we chose the most suited for our investigation, which are briefly described below. INE ensures the quality of the data, once survey is created, errors are detected and corrected. Unclear answers are double checked through a phone interview.

We have started with data cleaning. First, we ensured that each firm belongs to a single sector across all years. For firms that have been switching industries between 2008-2014, we have defined its main sector as the one they have belonged to in 2014. We find that less than 10 percent of companies have been switching their primary activities. Second, we have imputed dummy variables for investment tax credits and investment subsidies for 2009. Due to the change in the survey in that year, the authorities failed to gather exact data for those two variables. Consequently, we have decided to create dummy variables for tax credit and subsidy equal to 1 in 2009, if for all other years a given firm has also received the subsidy or has used the tax credit for investment purposes.

3.2 Descriptive Statistics

Table 1 provides a list of variables and their descriptive analysis, while Table 2 presents the correlation matrix, as we can see, there is no problem of correlation, which makes us confident our analysis does not suffer from multicollinearity. We use investment in EP and CP as our dependent variables. Between 2008 and 2014, 30% of companies decided to invest in CP, while 23% in EP. Both those variables measure the total amount of money spent on adoption of a given technology. Surveys commonly ask whether a given company has invested in a green technology, however, the amount of such investment is usually not specified (Horbach, 2008). Consequently, in this analysis we do not only capture the decision to eco-innovate at the extensive margin but also, we pay attention to the decision and the amount at the intensive margin. Additionally, in the analysis we perform a more extensive analysis. Moreover, not only can we capture green technologies in general, but we can also distinguish between a few types of environmentally friendly technologies within each subdivision such as: EP technology reducing air pollution alone (EPair), CP technologies reducing air pollution alone (CPair) and CP technology decreasing energy consumption (CPenc). We do not know of any previous paper having such rich information on the eco-innovative variables.

SIEEP provides also rich information on specific policy-instruments including the amount on the environmental taxes paid each year such as: air pollution taxation, waste taxation and other pollution taxation. We have decided to aggregate those taxes at the firm level into one variable called " environmental taxation". Since some of the taxes are only introduced in certain regions of Spain (Autonomous Communities), the overall percentage of companies that are affected by obligatory environmental taxes (any type) over 7 years is 22%. In the analysis, however, we only use the information on whether a given company was or was not forced to pay environmental taxes as to avoid problems with endogeneity. Since, we do not know the specific tax rates that result in the amount of environmental taxation paid at the firm level - we cannot control for the reason for the increased amount.

Hence, we only use a dummy variable for whether environmental taxes were paid.

Additionally, we also have the aggregated amounts of all subsidies, grants and aids that each firm has been provided with for the purpose of investing in environmental protection technologies. Only 3% of companies report to have received a subsidy for investments in environmental protection technologies. We use investment subsidies as a dummy variable equal to one if the company has received an investment subsidy. Once again, due to endogeneity reasons and difficulty to control for input additionality and crowding out with a rich set of firm characteristics, we have decided once again to use a dummy variable for whether a given firm has received public financing in the form of subsidies or not. It will also help us to compare among all the policy instruments. Dummies are commonly used in environmental policy literature for example in the papers of e.g. González and Pazó (2008), Marino et al. (2016), and Guerzoni and Raiteri (2015), which deal with R&D subsidies.

Similarly to subsidies, only 3% of companies benefited from the tax incentive in place, however, the amount of money received through tax credit is far greater than from the subsidy being equal to EUR 9,018 on average (three times higher than for subsidies), showing that tax credits were much more generous. In fact, tax credit devoted to environmental protection investments consisting of installations used to avoid air pollution, prevent pollution of the surface, water and reduce the industrial waste (art. 39.1, Royal Legislative Decree 4/2004) had a varying rate of 2% to 8% between 2008 and 2014, which might have been incentivising higher expenditure. In this case, for comparison reasons with the two previous policy instruments we also use a dummy variable for receiving an investment tax incentive.

With regards to resources and organizational capabilities, we use the following two measures: the first is a dummy variable indicating whether a given firm has paid for environmental certifications (denv_cert), the second one indicates whether a firm has hired employees dedicated to environmental protection activities (dgreen_employees) as analyzed in the literature review . 33% and 29% of companies have paid for environmental certifications and hired green employees, respectively.

Lastly, to control for observed heterogeneity among firms we use a series of variables. We use a series of size dummies (10-20, 20-50, 50-100, 100-200, >200 employees) to in an attempt to control for non-linear profile, lagged values of investments in green technologies to control for previous innovative activities in either CP or EP and lastly we use the information on the industry (30 sectors) the company belongs to. Quite naturally, given the limitations of the database, there exist concerns for endogeneity issues. That being said, this paper aims at investigating correlations, rather than direct causality, and we believe that, with all the firm and sector fixed effects, as well as by providing several robustness checks, those new and unique findings are grounded enough.

Consequently, we separated the relevant drivers into three distinct categories: policy instruments (taxation, subsidies and tax incentives), which we believe to be driving the adoption level differently; organizational characteristics - both related to environmental regulations or aimed at customer signalling such as environmental procedures/certifications and green employees and lastly firm characteristics such as size, sector or having innovated before. Especially, the last one, also known as path dependency, is crucial following the previous literature on the importance to control for persistence (Siedschlag and Yan, 2021; Jove-Llopis and Segarra-Blasco, 2018).

[Tables 1 and 2 around here]

3.3 Methodology

Our literature review provided important insights on different factors that determine investments in green innovations - both EP and CP technologies. The next step is to test the previously mentioned hypotheses empirically. We propose the following model specification:

$$\begin{aligned} lnECOIN_{i,t} = \beta_0 + \beta_1 lnECOIN_{i,t-1} + \beta_3 dTaxes_{i,t} \\ +\beta_4 dSubsidies_{i,t} + \beta_5 dTaxCredits_{i,t} + \beta_6 dGreenEmp_{i,t} + \beta_7 dEnvCert_{i,t} \\ +\beta_8 size_{i,t} + f_i + f_s + f_t + \epsilon_{i,t} \end{aligned}$$

The dependent variable $lnECOIN_{i,t}$ is measured taking natural logarithm of investment in cleaner production or end-of-pipe technology, lnCP or lnEP respectively. For estimation purposes we use OLS using fixed effects estimator and firm clustered standard errors. We have decided to use this estimation strategy, as it arrives at the most conservative results compared to non-linear models and dynamic linear models used in the robustness check. In the main part of the results we will use fixed effects regression model. We have carried out the Hausman test, which pointed us to the use of fixed effects, instead of random effects. Moreover, we include firm fixed effects, f_i, to control for any unobserved time invariant firm characteristics, time effects, f_t, to account for macroeconomic shocks common to all firms, sectoral effects, f_s, and lastly idiosyncratic error term $\epsilon_{i,t}$.

4 Results

4.1 Main Results

In this section we present estimates of the coefficients in specification from regressing the continuous outcome variables: investment in EP and CP technologies (lnEP, lnCP) on the set of regressors. All the tables report OLS coefficients. The standard errors are clustered at the firm level in all regressions. Table 3 summarizes the estimates obtained for our outcome variables: columns 1-5 show estimations for CP technology (CP, CPair and CPenc), while columns 6-9 for EP technology (EP and EPair). We estimate both the single drivers and the policy mix, columns 5 and 9 for CP and EP, respectively. Most of the results are robust to firm, time and sector fixed effects.

[Table 3 around here]

Firstly, our results support the hypothesis that environmental taxation might not always be effective at stimulating adoption of green technology, as shown by statistically insignificant coefficients for all but one specific type of technology. Admittedly, only a few autonomous communities in Spain have introduced environmental taxes (and at rather low rates), hence the effectiveness of environmental taxation might be challenging. Our results seem to confirm that hypothesis. The coefficients on general CP and EP technologies are non-significant and stable to the inclusion of sector fixed effects. When we extend our analysis to a wider range of technologies, we find that environmental taxes do not appear to drive pollution abating technologies: EPair, CPair. That being said, we find a positive and statistically significant coefficient on CPenc (Table 3, column 4). Waste taxes are among the most popular environmental taxes in Spain, collecting significant revenues, hence it is of no surprise that they incentivize firms to cut their waste production. Cleaner production technologies typically entail more conservative use of natural resources, leading also to reduced output. Since CPenc reduce energy consumption, they also reduce waste output, leading to smaller fines.

With regards to public financing, both receiving subsidies and tax credits for investment purposes is relevant and rather important. However, we observe heterogeneity in responsiveness to those two types of financing. More specifically, it seems that while subsidies are used rather uniformly across all types of green technologies (with a single exception of CPair), tax credits mostly finance CP technologies. Upon a closer analysis, we observe positive and statistically significant coefficients of investment tax credit on CP and CPair, but not CPenc, suggesting that while firms use tax deductions to invest in efficient technologies - they are not necessarily related to reduction of energy consumption specifically.

Additionally, we have also investigated the estimates on the interaction of the policy instruments. Subsidies consistently drive investment in both green technologies, even upon the inclusion of the policy-mix. Tax credits, on the other hand, just as in previous estimations drive only CP technologies, rather than EP technologies (Table 3, columns 5 and 9). With regards to interaction dummies specifically, there exists evidence that the combination of an environmental tax with an investment subsidy drives investment in CP technology, though its coefficient is statistically significant only at the 10% level. Interestingly also, there is a strong negative correlation between all three policy-instruments, possibly suggesting a crowding-out effect. When it comes to investments in EP technologies, only the coefficient on subsidies is positive and statistically significant, showing once more that firms use subsidies to finance investments in pollution abating technologies. Those results, however, should be taken with caution due to limited number of observations for the policy

Having green employees is equally important for the adoption of both technologies as shown by the statistically significant coefficient. It is of similar magnitude to the one on subsidies. It might mean that green employees push the company to invest in adoption of eco-innovations. That being said, once a firm hires employees dedicated to environmental protection activities they seem to be mostly encouraging adoption of technologies that are neither related to air-pollution nor to energy consumption - as indicated by the smaller coefficients for models using those technologies as dependent variables in comparison to the general eco-innovations. At the same time, coefficients on CPenc are higher and stronger than on CPair, which could suggest that once employed they still prefer to stir firms' capital into energy efficient, cost saving technologies rather than solely air emission reducing.

Lastly, while the coefficients on environmental certification are non-significant for EP technologies, they are positive and significant at the 95% level for the CP technologies, suggesting, that while certifications might drive more expensive production altering technologies, they do not, in fact, explain the implementation of filters and scrubbers at the end-of-pipe. As dynamic capabilites literature claims, routines and accumulated knowledge in form of environmental systems favour the adoption of a more radical eco-innovation technologies. After separating CP technologies into those CPair and CPenc, we can observe how environmental certifications are correlated with the latter. As noted in the literature review, firms usually invest in environmental certifications either as a "green signalling" or they are genuinely interested in eco-innovating, which results in investments in energy efficient technologies. In the past environmental certifications were usually assessed as a signal of the green behaviour, which in practice did not provoke further investments and adoptions of eco-innovations. Given also non-statistically significant results for EP technologies, our conclusions seem to be mostly in line with the current state of literature. We do see some green investment, but it is not comparable to other effects and not uniformly correlated with all types of technologies. As a final note, we have included in our analysis lagged dependent variables. While the coefficients are statistically significant and negative, the coefficients are very low, suggesting no economic value.

4.2 Extensions and Robustness Checks

We have carried out several robustness checks to validate whether the coefficients remain significant and of similar magnitude no matter the model specification, methodology or time period used. More specifically, Tables 4-7 show that the baseline results are robust to estimation using balanced panel data set, different time period, different dependent variable (lnRD), censored model, non-linear models and dynamic linear model. We will analyze each in turn.

Balanced Panel Data Set and Different Time Frame (2010-2014): We have used the perfectly balanced panel dataset, which accumulated all establishments with 7 years of observations. The results are presented in Table 4, columns 1 and 2., while the results for a different time period (2010-2014) are in columns 3 and 4. We have decided to use 2010-2014 to avoid the imputed data from 2009 and the financial crisis starting at the time. The replicated results mostly support our main findings.

Different dependent variable: Environmental R&D. In the main results, we have been working on two types of process eco-innovations that firms can adopt without developing it themselves necessarily. Environmental private R&D is a variable very closely related to environmental innovation endeavors the firm is carrying out - without automatically adopting new technologies straight away. That is why, we would expect the investment subsidies and tax-credits not to be effective at encouraging firm's R&D. This is precisely, what we find in Table 4, columns 5 and 6. The coefficients on subsidies, tax incentives and on environmental taxes are all statistically insignificant. This set of results suggest that policy instruments affecting the adoption of the specific technologies in the main results is not a matter of coincidence.

Censoring the non-investing firms: Random effects Tobit model allows to censor the firms at the zero level of investment - to censor those firms that do not decide to invest in eco-innovative technology. However, fixed effects cannot be used and additionally standard errors cannot be clustered at the firm level, and so the standard errors are quite small resulting in large and statistically significant coefficients for all of our variables. That being said, the differences between the coefficients sizes of our variables of interest fit the previous estimations as can be seen in Table 5, columns 1 and 2. Tax credits seem to be the most successful financing CP technologies, subsidies also work though its coefficients are much smaller. Once we censor the firms not having invested in green technology, the coefficient on taxation becomes positive and statistically significant, showing the importance to cluster the standard errors at the firm level. Similar results appear for EP technologies .

Non-linear model estimates with fixed effects. In Table 5, columns 3 and 4, we replicate the main results using a non-linear probability model (logit) instead of a linear one. We have decided to use it, as logit models allow for using fixed effects, which we believe are crucial in our estimations. They also suffer from losing some of its precision by using a binary dependent variable and once again the standard errors are not clustered at the firm level. That being said, the results of the following estimations follow the general pattern; for lnCP it is the tax credit and subsidies that make a difference, while for lnEP it is mostly the subsidy alone.

Dynamic Linear Model. Lastly, in order to control for the endogeneity in the model caused by the lag of the investment in green technologies, we have also utilized the Arellano-Bond Dynamic Panel Estimation model - please see the results in Table 6. After controlling for the endogeneity arising from the persistence of green investment (also known as path dependency), the coefficients on the subsidy turns much less statistically significant. For the cleaner production technologies the results hold, while for end-of-pipe none of the coefficients are statistically significant. The specification tests for both models are shown in Table 7, which confirm that at order 2 there is no serial correlation. In this model, which admittedly is the most appropriate for assessing lagged dependent variable, the coefficients are positive and statistically significant.

As can be seen from the above robustness check review, our results are generally stable to time frame, type of a dataset, type of a model used.

[Tables 4 - 6 around here]

5 Conclusions

Our analysis provides a set of results for identifying crucial regulatory factors and firms' resources and organizational capabilities for encouraging enterprises to invest in green technologies. More specifically, we observe differences between the drivers of investment in cleaner production and end-of-pipe technologies. In addition, we distinguish between investments with the purpose to reduce air pollution and energy consumption.

The results of our estimations are aligned with the results from the previous literature on environmental investment. Firstly, environmental taxation in Spain seems to be rather ineffective at stimulating investment in greener technologies, both for EP and CP technologies. This result is in line with a recent review of the literature (Lilliestam, Patt, and Bersalli, 2021) that concludes that there is not enough empirical evidence to claim a positive effect of environmental taxation. We argue, similarly to Labandeira, Labeaga, and López-Otero (2019), that in the Spanish context this might be caused by relatively low rates of environmental taxation and the fact that under the ETS, environmental taxes might not be doing their tasks effectively. At the same time, firms react positively to investment subsidies and investment tax incentives. Tax credits seems to be especially successful at financing cleaner production technologies while subsidies are positively related to both EP and CP investments. The empirical analyses regarding the role of subsidies have shown that they have positive effects on eco-innovation activities related with the reduction of air emissions (Horbach, Rammer, and Rennings, 2012) and also fostering energy efficiency investments in the case of Spain (García-Quevedo and Jové-Llopis, 2021). The positive effect of tax credits was also pointed out by (Sánchez, 2007) although without carrying out an empirical analysis. The implication derived from these findings reveals that direct policies such as subsidies help firms to convert into greener companies, while tax credits lead to reductions in production costs for firms, that pursue a substantial transformation of their production process.

The results of the estimations distinguishing between investment in technologies with air pollution and energy consumption aims are similar to the previous results but show also some differences. Tax incentives are oriented towards financing CP technologies reducing air pollution, while subsidies are related to CP investments with the purpose of reducing energy consumption. Again, here we confirm that EP technologies are easier to implement with subsidies. Subsidies aid in the deep transformation of firms, acting on the core of production process to become green.

The brief investigation of the policy-mix leaves us with an impression that the existing policy mixes are inefficient at encouraging higher levels of investment in green technology in tandem. In fact, while the policies work relatively well separately, as a policy-mix they are rather irrelevant. The only policy-mix that seems to be related with investment in cleaner production technologies alone is a combination of environmental taxation and subsidies. Following the previous literature, that might be caused by the lack of specific policies implemented that would complement each other at specific industry levels. This remains to be a platform for further investigation.

Additionally, we can conclude that organizational resources matter for investment in green technologies. Admittedly, hiring green employees is a strong factor pushing each firm towards green investment, while the relationship between investing in green procedures and certifications is not clear. As del Río González (2009) showed internal factors act as antecedents to facilitate firms' involvement in the transformation of technical change, so hiring green employees could be a requirement in favor of accelerating that change. Our ambiguous finding on green certifications leads us to think that sometimes companies trat them as "symbolic signals" to the market of their green awareness rather than transformation itself (Boiral, 2007).

The analysis has some limitations. Firstly, confidentiality rules of the Spanish Institute of Statistics (INE) prevents us from merging our data set with any other data set that could provide relevant information on further firms' characteristics such as revenues, energy consumption, yearly pollution amount. Secondly, INE has also ruled out access to data on the autonomous communities each firm belongs to, which prevents us from developing the analysis controlling for regional differences. All of the former, is raising doubts related to endogeneity issues in our paper. However, given our aim of observing the correlations rather than causality combined with the fact the general robustness of the results hold, make us confident in saying that firms use different strategies to adopt different green technologies.

Results are interesting both for policy makers and managers of companies committed to investment in environmental technologies. Results provide evidence that public incentives produce better stimulus than taxation; so policy makers are faced with a great opportunity to design appropriate incentive programs as to further aid firms in making the transition to a more environmentally friendly production process. For managers, findings strongly support the use of voluntary policy in creating a greener workforce since it leads to gains due to transformation to a more environmental involvement of companies. A corporate culture that embeds human resource policy empowers employees to care for environment, and ultimately we believe will drive improvements in the greening of firms' performance.

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Table 1: Variables and descriptive statistics

Variable	**Definition**	**Mean**	**Std**	**Min**	**Max**
size	number of employees	274	548	10	22500
CP	Cleaner Production technologies (euros)	172,579	1,363,846	0	5.24e+07
lnCP	natural logarithm of CP+0.001	-3.22	9.36	-9.21	17.77
dCP	=1 if the firm invested in CP in a given year	0.30		0	1
CPair	air pollution reducing CP technologies (euros)	94,263	1,115,950	0	5.24e+07
lnCPair	natural logarithm of CPair+0.001	-6.77	6.65	-9.21	17.77
dCPair	=1 if the firm invested in CPair	0.12		0	1
CPenc	energy consumption reducing CPenc technologies (euros)	22,927	281,354	0	1.45e+07
lnCPenc	natural logarithm of CPenc+0.001	-7.13	6.10	-9.21	16.49
dCPenc	= 1 if the firm invested in CPenc	0.10		0	1
EP	End-of-Pipe technologies (euros)	116,973	1,074,002	0	5.80e+07
lnEP	natural logarithm of EP+0.001	-4.57	8.51	-9.21	17.86
dEP	= 1 if the firm invested in EP	0.23		0	1
EPair	air pollution reducing EP technologies (euros)	41,432	741,608	0	5.68e+07
lnEPair	natural logarithm of EPair+0.001	-7.62	5.46	-9.21	17.86
dEPair	= 1 if the firm invested in EPair	0.08		0	1
RD	private environmental Research and Development (euros)	4,668	70,434	0	4942003
lnRD	natural logarithm of RD+0.001	-8.16	4.30	-9.21	15.41
dRD	= 1 if the firm invested in RD	0.06		0	1
env_cert	implementation of the environmental certifications (euros)	1,297	10,810	0	507,195
denv_cert	= 1 if the firm paid for environmental certifications	0.21		0	1
green_empl	annual salaries spent on employees dedicated to environmental protection (euros)	72,687	197,800	0	4,905,524
dgreen_empl	= 1 if the firm has employees dedicated solely to environmental protection	0.29		0	1
lagCP	lagged amount of investment in CP (euros)	172,434	1,363,780	0	5.24e+07
llagCP	natural logarithm of lagCP+0.001	-3.22	9.33	-9.21	17.77
lagEP	lagged amount of investment in EP (euros)	116,943	1,074,032	0	5.80e+07
llagEP	natural logarithm of lagEP+0.001	-4.57	8.51	-9.21	17.87
taxes	sum of environmental taxes (euros)	70,788	1,925,554	0	1.32e+08
dtax	= 1 if the firm paid environmental taxes	0.05		0	1
subsidies	subsidies and grants received for adoption of eco-innovations (euros)	3194	81,489	0	6,855,127
dsub	= 1 if the firm received subsidies	0.03		0	1
tax_credits	tax credits received for adoption of eco-innovations (euros)	9,018	261,007	0	2.53e+07
dtcred	= 1 if the firm received tax credits	0.03		0	1

Note: The mean of a dummy variable represents the proportion or percentage of cases that have a value of 1 for that variable. All firms have at least 10 renumerated employees. Based on an unbalanced panel of 2563 individual firms across 7 years (half of the firms have data from 6 out of 7 years); 14723 observations in total.

Table 2: Correlation matrix

	dtax	dtcred	dsub	denv_cert	dgreen_empl	lnCP	lnEP	lnRD	lnCPenc	lnEPair	lnCPair
dtax	1.0000										
dtcred	0.0766	1.0000									
dsub	0.0067	0.1674	1.0000								
denv_cert	0.0643	0.0533	0.0439	1.0000							
dgreen_empl	0.0834	0.0389	0.0319	0.1491	1.0000						
lnCP	0.1110	0.2095	0.0942	0.1522	0.1532	1.0000					
lnEP	0.1197	0.1514	0.0786	0.1314	0.1195	0.3356	1.0000				
lnRD	0.0502	0.0394	0.0368	0.0775	0.0609	0.1135	0.1241	1.0000			
lnCPenc	0.0684	0.1062	0.0803	0.1076	0.1018	0.5402	0.1852	0.0628	1.0000		
lnEPair	0.1201	0.1465	0.0707	0.0860	0.0732	0.2216	0.5656	0.1112	0.1208	1.0000	
lnCPair	0.0963	0.1992	0.0683	0.1007	0.0896	0.6030	0.2400	0.0820	0.2291	0.2403	1.0000

Table 3: Main Results: Fixed effects regression estimations for log investment in CP, CPair, CPenc, EP, EPair

	lnCP (1)	lnCP (2)	lnCPair (3)	lnCPenc (4)	lnCP (5)	lnEP (6)	lnEP (7)	lnEPair (8)	lnEP (9)
L.1	-0.04***	-0.03***	-0.01	0.01	-0.04***	-0.05***	-0.05***	-0.02***	-0.05***
	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
dtax	0.27	0.27	-0.24	0.43**	0.28	0.12	0.12	0.14	0.06
	(0.28)	(0.28)	(0.21)	(0.21)	(0.29)	(0.28)	(0.28)	(0.18)	(0.28)
dsub	1.55***	1.52***	0.62*	1.05***	1.35**	1.25***	1.25***	0.77**	1.18**
	(0.46)	(0.46)	(0.36)	(0.36)	(0.55)	(0.41)	(0.41)	(0.33)	(0.48)
dtcred	3.67***	3.66***	2.19***	0.27	4.22***	0.87	0.86	1.08**	0.14
	(0.57)	(0.57)	(0.54)	(0.51)	(0.74)	(0.54)	(0.54)	(0.48)	(0.69)
dtax # dtcred					-1.07				1.60
					(1.13)				(1.08)
dtax # dsub					2.16*				-0.70
					(1.12)				(1.10)
dtcred # dsub					0.01				0.80
					(1.28)				(1.37)
dtax # dsub # dtcred					-5.10***				2.16
					(2.28)				(2.67)
dgreen_empl	1.04***	1.02***	0.56**	0.68***	1.04***	1.35***	1.39***	0.74***	1.36***
	(0.36)	(0.36)	(0.29)	(0.18)	(0.36)	(0.36)	(0.35)	(0.21)	(0.35)
denv_cert	0.62**	0.62*	0.07	0.45*	0.63**	0.01	-0.02	0.01	0.00
	(0.32)	(0.32)	(0.24)	(0.24)	(0.32)	(0.29)	(0.29)	(0.18)	(0.29)
size dummies	x	x	x	x	x	x	x	x	x
time FE	x	x	x	x	x	x	x	x	x
firm FE	x	x	x	x	x	x	x	x	x
sector FE		x	x	x			x	x	
N	14,528	14,528	14,528	14,528	14,528	14,528	14,528	14,528	14,528
F stat	11.44				9.65	26.61			21.92
Prob >F	0.00				0.00	0.00			0.00

Note: All standard errors are clustered at the firm level. ***, **, * denote significance at the 99% level, 95% level and 90% level, respectively. Mean Variance Inflation Factor (VIF) is equal to 8.18. All the models include time, firm and sector fixed effects, except for models 1, 5, 6 and 9 which do not include sector fixed effects.

Table 4: Extensions and Robustness Checks: Balanced Panel Dataset and Different Time Frame (2010-2014) and Different Dependent Variable

	Balanced Panel Data		2010-2014		Different Dependent Variable	
	lnCP	lnEP	lnCP	lnEP	lnRD	lnRD
	(1)	(2)	(3)	(4)	(5)	(6)
L.1	0.00	0.01	-0.06***	-0.08***	-0.08***	-0.08***
	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)
dtax	0.55	-0.36	0.43	0.08	0.06	0.06
	(0.41)	(0.41)	(0.37)	(0.34)	(0.16)	(0.16)
dsub	1.19**	1.23**	2.71***	1.67***	-0.05	-0.04
	(0.59)	(0.57)	(0.66)	(0.62)	(0.26)	(0.26)
dtcred	3.29***	1.27*	4.34***	1.97**	-0.22	-0.22
	(0.73)	(0.67)	(0.79)	(0.78)	(0.31)	(0.32)
dgreen_empl	0.14	2.11***	0.68	0.70	0.33	0.37*
	(0.66)	(0.68)	(0.54)	(0.48)	(0.21)	(0.21)
denv_cert	1.21**	-0.16	0.48	0.41	0.10	0.10
	(0.52)	(0.48)	(0.42)	(0.36)	(0.16)	(0.16)
size dummies	x	x	x	x	x	x
time FE	x	x	x	x	x	x
firm FE	x	x	x	x	x	x
sector FE						x
N	6,958	6,958	9,125	9,125	14,528	14,528
F stat	6.25	15.53	8.67	8.44	14.88	
Prob >F	0.00	0.00	0.00	0.00	0.00	

Note: All standard errors are clustered at the firm level. ***, **, * denote significance at the 99% level, 95% level and 90% level, respectively. All the models include time and firm fixed effects, except for model 6 which also includes sector fixed effects.

Table 5: Extensions and Robustness Checks: Random effects Tobit model and Fixed effects logit model

	Random Effects Tobit Model		Fixed Effects Logit Model	
	lnCP	lnEP	dCP	dEP
	(1)	(2)	(3)	(4)
L.1	0.34***	0.37***	-0.01***	-0.02***
	(0.03)	(0.03)	(0.00)	(0.00)
dtax	1.77***	2.86***	0.14	0.13
	(0.56)	(0.64)	(0.09)	(0.10)
dsub	4.30***	4.49***	0.47***	0.47***
	(0.93)	(1.07)	(0.14)	(0.15)
dtcred	9.23***	4.48***	1.04***	0.26
	(0.96)	(1.10)	(0.17)	(0.17)
dgreen_empl	11.35***	11.29***	0.45**	0.72***
	(1.05)	(1.20)	(0.18)	(0.21)
denv_cert	0.87	-0.03	0.28**	-0.02
	(0.57)	(0.64)	(0.11)	(0.12)
size dummies	x	x	x	x
time FE	x	x	x	x
firm FE	x	x	x	x
sector FE	x	x		
N	14,528	14,528	7,931	7,280
$Wald\ chi^2$ / $LE\ chi^2$	1260.04	1441.90	215.50	577.69
$Prob > chi^2$	0.00	0.00	0.00	0.00

Note: All standard errors for fixed effects logit model are clustered at the firm level, for the tobit model they are reported through asymptotic theory (oim). ***, **, * denote significance at the 99% level, 95% level and 90% level, respectively. Models 1 ans 2 include time, firm and sector fixed effects, while models 3 and 4 include firm and time fixed effects.

Table 6: Extensions and Robustness Checks: Arellano-Bond model controlling for persistence of investment of cleaner production technologies (lnCP) and end-of-pipe technologies (lnEP)

	lnCP (1)	lnEP (2)
L.1	0.16*** (0.02)	0.14*** (0.02)
dtax	-0.48 (0.43)	0.11 (0.41)
dsub	1.21* (0.71)	1.02 (0.67)
dtcred	3.01*** (0.91)	1.06 (0.93)
dgreen_empl	1.84** (0.73)	0.58 (0.65)
denv_cert	0.62*** (0.35)	0.83*** (0.33)
size	x	x
N	7,940	7,940
$Wald\ chi^2$	100.31	57.95
$Prob > chi^2$	0.000	0.000

Note: All standard errors are clustered at the firm level. ***, **, * denote significance at the 99% level, 95% level and 90% level, respectively.

Table 7: Extensions and Robustness Checks: Arellano-Bond model specification test.

Order	z	Prob >z
lnCP		
1	-20.925	0.000
2	0.330	0.741
lnEP		
1	-19.238	0.000
2	1.510	0.131