UNIVERSITAT DE BARCELONA

Essays on Environmental Policy and Green Investment

Kinga Barbara Tchórzewska

PhD in Economics

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Contents

1 Introduction

We can increasingly observe societies around the world adopting the anti-pollution mentality. Citizens have become concerned with their health outcomes resulting from high pollution levels as well as fires and droughts resulting from the climate change, quite often protesting publicly [1] but admittedly there is still significant resistance within the industry. In the following doctoral thesis, I investigate the role of the public policy at inducing adoption of green technologies and indirectly affecting employment outcomes results using quasi-experimental methods and a game theoretical model. This type of combination presents us with both normative and positive types of analyses.

Scholars have underlined the crucial role that the governments need to take to transition to green economy (Nordhaus, 2010; Golosov et al., 2014; Acemoglu, Aghion, et al., 2012; Acemoglu, Akcigit, et al., 2016) and although the importance of environmental policy is present in academic and public debates for years, especially since the well-known Kyoto agreement, governments made rather unsatisfactory progress in implementing strong, successful and coordinated environmental policies.

The effectiveness of environmental policy instruments has been discussed for years. The economic literature related to public policy and green innovation is rather well established. There exists a consensus that market-based policies are much more efficient than command and control and do increase green innovation levels (Jaffe, Newell, and Stavins, 2002; Popp, 2006; Popp, Newell, and Jaffe, 2010; Acemoglu, Aghion, et al., 2012; Aghion et al., 2016; Acemoglu, Akcigit, et al., 2016). However,

[1] "Climate crisis: 6 million people join latest wave of global protests", 27.09.2019, https://www.theguardian.com/environment/2019/sep/27/climate-crisis-6-million-people-join-latest-wave-of-worldwide-protests, accessed 14.06.2020

equally frequent are the concerns about environmental policy having adverse effects on firm competitiveness (in case of environmental taxes) or whether the subsidies for green technology perhaps suffer from the crowding-out effect.

It might be surprising that among the plethora of empirical research, there is still little causal evidence. In fact, an important absence in this debate has been reliable empirical evidence. Due to the sensitivity of the firm level data, which frequently restricts its availability, as well as identification issues, convincing empirical evidence on environmental policy instruments is still limited. Many scholars underline the need for more quasi-experimental papers entangling the real effects. Admittedly, some recent studies have been starting to fill the gap in the literature (Martin, De Preux, and Wagner, 2014; Marino et al., 2016; Calel and Dechezlepretre, 2016; Yamazaki, 2017; Kube et al., 2019). Understanding how firms respond to environmental policies is crucial when considering the design and implementation of such instruments, hence, evidence-based research is necessary in this context.

The following PhD thesis follows a natural path of the research progress given the unanswered research questions and database at hand. In the second chapter I focus on governmental incentives to encourage different types of green technologies, thus studying social welfare outcomes arriving from different policy scenarios using game theory [2]. In the third chapter, I perform a descriptive analysis of the drivers of investments in green technology using Spanish industrial data, including environmental taxes, subsidies, environmental tax incentives, human resource factors, and dynamic capabilities [3]. In the fourth chapter, I then investigate environmental taxes in more detail, I study its heterogeneous effects on green investment on their own and as a policy-mix with public financing [4]. Finally, in the fifth chapter, using a quasi-experimental design, I examine the effects of environmental investment tax incentives on green technology and green employment outcomes.

[2]This study is co-authored with Ana Espinola-Arredondo
[3]This study is co-authored with Jose Garcia-Quevedo and Ester Martinez-Ros
[4]This study is co-authored with Jose Garcia-Quevedo and Ester Martinez-Ros

The research that I conduct in this thesis aims at improving our understanding of the effects of environmental policies and arising social welfare outcomes. The following PhD thesis contributes to this literature by studying effectiveness of environmental taxation and subsidies/environmental investment tax incentives, separately and as a policy-mix. These responses are analyzed in the fourth and fifth chapters of the thesis, respectively.

Public policy may influence firms decision making with regards to environmental investment thanks to provision of subsidies and tax credits (to alleviate the cost of eco-investment) or/and by introducing stringency regulations through taxes. As Porter and Van der Linde (1995) pointed out, regulation should drive the adoption of green-innovation, since those very technologies produce benefits to society.

However, not much consensus emerges on the use of such instruments. The literature on the adoption of green innovations typically uses qualitative firm surveys, which do not have access to detailed information on policy instruments, especially across several years. For example Triguero, Moreno-Mondéjar, and Davia (2013) use 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)). When papers do not use subjective qualitative surveys, they usually proxy with several techniques. They can either use environmental regulation with the abatement costs (US PACE Survey), the number of inspections concerned with pollution levels (Brunnermeier and Cohen, 2003), and by considering the effects of a specific change in environmental legislations (Popp, 2006). 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 regulation and customer pressure are mechanisms through which companies get involved in eco-innovation. That being said, many papers look at environmental policy instruments, without focusing on specific policy instruments and their mix.

One of the main contributions of the literature on policy instruments was the realization that command and control versus market-based policy instruments provide different incentives to firms to innovate and adopt new technologies. Command and control types of regulations establish emission limits and standards. Environmental taxes and charges and tradable emission permits, on the other hand, are classified as market-based instruments. Those have economic incentives, since they internalize environmental externalities in and between markets, thus triggering static and dynamic efficiency (Costa-Campi, García-Quevedo, and Martínez-Ros, 2017). Market-based instruments are taxes, subsidies and tradable permits, so such instruments that address the negative externality by setting a price on the pollution levels (Carraro et al., 2010).

In the context of those specific policy instruments and eco-innovations there is only handful of papers. One of the more known examples of such research is the paper by Fischer, Parry, and Pizer (2003), where the authors show that choosing objectively the best policy instrument might be an impossible task. The paper by Johnstone, Haščič, and Popp (2010), on the other hand, comments on policy instruments using patent count data and shows how investment incentives seem to play a crucial role in the adoption of renewable technologies at the early phases of technological development. As technologies mature quantity-based instruments become increasingly effective. Very often, the effect of policy instruments is magnified or reduced by firm heterogeneity [5] or other heterogeneous nature of the market it exists in - such as degree of liberalization of the energy market (Nesta, Vona, and Nicolli, 2014). The literature is even more abundant with regards to the eco-innovation determinants focused on differentiated environmental impact. Horbach, Rammer, and Rennings, 2012 underline how current and expected regulation is important for encouraging abatement technologies, while taxes might be more

[5] Larger, exporting and energy-intensive firms are more likely to invest in eco-innovations (Haller and Murphy, 2012).

relevant for motivation related to cost savings and hence more energy efficient technologies.

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. Admittedly, tax policy is perceived as less distorting than direct regulation and through the use of private information the individuals and firms use the utility maximizing solutions (Tresch, 2014). It is, therefore, a common public policy to use taxation such as pigovian taxes. However, countries may also provide tax incentives to encourage firms to invest in specific types of technologies. Environmental protection investment tax credits, in theory, lower the after-tax cost of innovation both from capital and labour perspective by providing a tax deduction for all eligible environmental protection investments. It, thereby, reduces the costs of undertaking innovation and decreases the barrier to innovate by providing an incentive. One fear, however, is that the eligibility for the tax deduction is usually limited to known technologies and hence it decreases the use of private information that e.g. emission taxes take advantage of. Additionally, as tax deductions are not uniformly applied, they are usually sought by companies that would be interested in innovating anyway, and since they are funded from the public capital, tax deductions are criticized for being wasted on companies that do not need additional incentives to innovate (Mao and Wang, 2016). Lastly, environmental protection tax credits do not per se provide incentives to invent new technology, rather they incentivise companies to comply with environmental legislation. Consequently, OECD (2010) states that they are expected to mostly drive pollution abating technologies rather than efficient technologies.

Subsidies, while no longer allow firms to use their private information, address capital market failure, which can be especially difficult to overcome for smaller firms. The higher the subsidy, the easier it is for the firm to decide to invest in green technology. However, given different costs of technologies, as well as the fact that some of them affect the production process and some do not, they might be more or less difficult to implement. Importantly, the importance of savings resulting from the investment in green technologies, for instance, the amount saved in emission tax through the pollution abating technology and the amount saved in production costs through the energy efficient technology. It must be said, however, that the potential savings must be high enough for firms to be willing to engage in a costly investment of green technology.

del Río González (2005) identified regulatory pressure and corporate image as the main drivers of adopting cleaner technology. It was also observed, that stringency of environmental policies pushes firms to adopt end-of-pipe technologies (Aragón-Correa and Sharma, 2003; Frondel, Horbach, and Rennings, 2007; Hart, 1995). With regards to the effect of technologies on firm outcomes, Rennings, Ziegler, and Zwick (2004) show that the effect on employment is negative. Porter and Van der Linde (1995), provided a contrary argument, claiming that environmental regulations provide firms with increased opportunities, making them more efficient, which are accompanied expansion and should ultimately increase employment. Likewise, Costa-Campi, Duch-Brown, and Garcia-Quevedo (2014) show evidence that norms and regulations governing the environment and matters of health and safety foster investment in R&D.

Another relevant factor in this debate, is the distinction between the decisions that firms might have as a result of environmental policy in place when choosing between green technologies. In all of the papers of this thesis, I make a distinction between two main types: pollution abating technologies (commonly known as end-of-pipe) and integrated cleaner production technologies (Frondel, Horbach, and Rennings, 2007; Horbach, 2008; Rennings, 2000). This distinction is important as both of those have different characteristics. End-of-pipe technologies are aimed at addressing the environmental objectives 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 cleaner production (CP) technologies. In contrast to CP, end-of-pipe technologies (EP) do not reduce the amount of pollution created but simply emitted at the end of the production line – through for example passive filters of scrubbers that remove sulphur particulates from the emissions of coal plants. As a result of that, abatement technologies are “net cost for the firms and would not be adopted without environmental regulation” and to environmental concerns that affect reputation among the consumers (Carraro et al., 2010). On the other hand, cleaner production technologies aim both at environmental objectives and cost-efficiency. They use natural resources more efficiently, and thus through that change in the production process, the reduce the emissions and long-run 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 the 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.

To study the effectiveness of environmental policy instruments in the chapters three, four and five I use the same dataset provided by the Spanish Institute of Statistics of Spain (INE). The data is available over the span of 7 years between 2008 and 2014 thanks to the Survey on Industry Expenditure on Environmental Protection (SIEEP). The main purpose of the annual survey is the assessment of current expenditures and investments of the Spanish industry, done with the effect of reducing negative environmental effects. SIEEP, therefore, provides a wide range of information at the firm level e.g. firm size (establishments hiring 10 or more remunerated employees), number of employees dedicated to environmental protection, several capital environmental expenditures such as green investments, and even private environmental R&D. The firm level data is currently available at request and from a special room with restricted access, creating an unbalanced panel dataset for 2,562 firms, where each firm is observed at least 4 times across a 7 year survey span. INE ensures the quality of data by employing CCU (centralised collection unit), which is dedicated to obtaining all the information from the questionnaire. The underlying data is collected for administrative purposes and firms are obliged to fill out the survey forms truthfully by law. All manufacturing firms in the sample with more than 10 employees have to report on an annual basis. Each firm receives a firm identifier, which allows to track the same company from year to year. In case any doubts arise, the INE employees make phone interviews to clarify any questions related to the answers, errors are detected and corrected. For the chapter two I do not use any data as I develop a game-theoretical model there.

The following thesis contributes to several strands of the environmental literature: the governmental incentives for environmental policy design, the drivers of eco-innovation, the effectiveness of a single policy instrument and the effectiveness of a policy-mix. The following paragraphs review the contributions and content of each of the chapters more extensively.

The second chapter contributes to the literature on social welfare outcomes arising from different environmental policy instruments implementation. To our knowledge, this paper is the first one to provide a theoretical model that would compare (1) different incentive-based policy instruments and their effects on the behaviour of firms, when those can choose pollution abating and energy efficient technologies (2) as well as analyse the resulting social welfare outcomes. More specifically, we have decided to compare two policy instruments: emission taxes and proportional investment subsidies and allow firms to have a more realistic set of options, that is allow them to choose between (1) not investing in any type of technology, (2) investing in cheaper solely emission reducing technology such as end-of-pipe and (3) investing in more expensive energy efficient technology that also reduces the amount of emissions created - the so-called cleaner production technologies. Consequently, we examine the incentives of polluting firms in the energy sector to invest in clean technologies, who are subject to one of the two policy instruments such as emission taxation and proportional investment subsidy (also understood as investment tax credits). Additionally, we investigate how social welfare changes under different scenarios for the environmental damage and firms investment decisions. Firms compete a la Cournot producing a homogeneous good and emissions as a by-product. This can be due to the use of a polluting input such as coal or due to a polluting production process itself.

Regarding the investment decision, we consider that firms can choose between keeping their current (dirty) technology, or invest in one of two clean technologies available on the market: (i) cleaner production technology or (ii) end-of-pipe technology, assuming that both decrease emissions' intensity of output, while only cleaner production technology also decreases production costs (Frondel, Horbach, and Rennings, 2007).

We model the game as follows. In the first stage, the regulator decides to either introduce an emission tax on the amount of pollution created or an available investment subsidy (or tax deduction), which is equivalent with an expenditure for the regulator. In the second stage, given the policy instrument in place the firms choose whether or not to invest in one type of green technology and output production.

Our paper arrives at following conclusions. Firstly, we show that it is better for the society to encourage adoption of clean technology even if it involves fully subsidizing the investment costs for the firms. Additionally, as the environmental damage increases it will become more and more important for the efficiency of the clean technologies to improve and so the government should keep investing in environmental R&D. Lastly, in the current state of technology, firms are discouraged from investing in CP due to high investment costs and relatively low efficiency of pollution reduction, as the technology improves their sentiments would change.

The third chapter contributes to the literature on eco-innovation. That paper aims 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). More specifically, we look at adoption of general end-of-pipe technologies and cleaner production technologies as well as EP and CP technologies with air pollution and energy consumption aims, which is a unique contribution. We do not know of any previous paper having such rich information on the eco-innovative variables. In the past, previous literature has either emphasized drivers of pollution abating and energy efficient technologies separately, or has investigated between the two types of technologies using data from cross-sectional surveys. Not only does our paper manage to distinguish between two main types of eco-innovations but it also analyses a wide range of sub-divisions of eco-innovations. What is more, in this investigation, we compare relation of policy instruments and organizational capabilities with environmental investment. Lastly, since there is still little research and agreement on how different policy-mixes drive specific types of eco-innovation, we also address that gap.

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 end-of-pipe as well as for cleaner production technologies. We argue that in the Spanish context this might be caused by relatively low rates of environmental taxation. 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 end-of-pipe and cleaner production investments. 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 fourth chapter contributes to the large literature on the impact of environmental policy on firms behaviour [6]. Among this plethora of papers, there is surprisingly little evidence showing causal inference on market-based instruments such as environmental taxes on manufacturing firms. And while the role of environmental taxes - carbon tax especially - on innovative activity is proven theoretically, the role that environmental taxes might have on the adoption of green technologies is not supported

[6] For a review of the current state literature on the impact of environmental regulation on competitiveness please see Dechezleprêtre and Sato (2017).

by the empirical literature. Martin, De Preux, and Wagner (2014) were the first ones to study the causal inference of a carbon tax on a manufacturing sector in the UK, finding evidence in favour of implementing carbon tax. Even more scarce is the evidence on the effectiveness of a policy-mix between environmental policy instruments, though in recent years it started to develop dynamically. Most of the scholars have focused on complementarities of policy-mixes (Mohnen and Röller, 2005) or on increased effectiveness of their interaction (Marino et al., 2016; Reichardt and Rogge, 2016; Guerzoni and Raiteri, 2015; Cunningham et al., 2013; Popp, 2006; Hascic et al., 2009; Fischer, Parry, and Pizer, 2003). This paper aims to fill the gap in the environmental economics literature by focusing on instrument choice on the adoption of new technologies. While, the effectiveness of environmental taxes in inducing innovation and adoption of technologies has been addressed before, it is still far from reaching conclusion on the appropriate level of such tax, which is crucial from the policy-making side. Additionally, we are, to the best of our knowledge, the first to empirically analyse the impact of a policy-mix between environmental taxes and different types of public financing on firms' decision in green investment.

This paper thus exploits the regional heterogeneity of environmental tax implementation. First, we investigate how different levels of environmental taxes (air pollution, waste and others) affect investment in green technologies. To that aim, we divide firms into four categories: those that did not have paid any environmental taxes and three groups paying *low*, *medium* and *high* levels. Further, we perform categorical treatment matching of firms to study the heterogeneous effects of different levels of taxation. We match firms on observable characteristics such as size, sector, previous green investment and organizational capabilities and perform categorical treatment matching to compare the effects of not only between paying low, medium or high environmental taxes or not, but also between low and medium, low and high and medium and high levels of environmental taxation. Consequently, we assume that once we match firms on observables most of differences between taxation levels come from regional differences in tax implementation. Second, this paper uses also propensity score matching technique to investigate the effects of a policy-mix between environmental taxes and public financing in the form of subsidies and fiscal incentives.

Our main estimates indicate that, on average, low levels of environmental taxation do not induce adoption of green technologies. However, as the level of environmental taxation increases, the effect becomes statistically significant and rises. Additionally, we find that even at low levels environmental taxation can be effective if combined with public financing. In that case the effect is stronger than from providing public financing alone. However, the synergical effect disappears at the high level of environmental taxation. For high levels, the taxation alone is sufficient to encourage adoption of green technologies among firms.

The fifth paper of this thesis investigates in turn the effect of one particular environmental investment fiscal incentive – Spanish Environmental Investment (EI) tax credit – and determines its impact on both firm green investment and employment. To understand the influence on employment in detail, I distinguish between firms' general employment and employees dedicated to environmental protection activities within the firm alone. The analysis is done using comprehensive firm level data, allowing us to control for firm fixed effects. The central outcome of interest for a policy such as EI tax incentives are the resulting investments in green technologies.

I study a large-scale national tax incentive program in Spain, which started in 1996 and finished in 2015. Due to data availability I focus on the 2008-2014 time window. For identification, I use two strategies. Firstly, I exploit the policy change that happened in March of 2011, when after a planned phase-out of the Environmental Investment (EI) tax credit in January of 2011, the government decided to suddenly bring it back to benefit the private sector for a few more years. However, it changed the conditions through which the tax incentive was incentivising investments in technologies that are energy efficient rather than solely pollution abating. I implement, therefore, a difference-in-difference design comparing firms that did receive the tax credit before and after the policy change. Secondly, I have used an Instrumental Variable (IV) approach to take advantage of the fact that I have a continuous treatment variable available. The IV used is the amount of tax credit received by the firms in 2008 in combination with the difference-in-difference approach. And so in the first stage I study the effect of the policy change in the combination with receiving a certain amount of tax credit in 2008 on the amount received in the post-policy change period. In the second stage, I study the effect of the tax credit on green investment and employment.

I find that an increase in the EI tax credit did increase both green investment and employment. The effect is particularly high on the level of employees dedicated to environmental protection activities. The policy change, aimed at switching financing to energy efficient technologies, is assessed as semi-effective. While it is true that it has decreased investment in pollution abating technologies, especially aimed at reducing air pollution, there is no evidence to support the claim that the investment in energy consumption reducing technologies has increased. The policy change helped to increase cleaner production investments for small firms (below 50 employees) but reduced it for large firms (above 200). Also, the results from the heterogeneous analysis make it clear that the policy change induced higher investment levels in cleaner production technologies aimed at air pollution and energy consumption reduction for firms polluting NO2. The results from the IV estimations of the EI tax credit point to the fact that this particular tax incentive was successful at inducing green investment, although favouring air pollution over energy consumption reducing technologies. Additionally, the local average treatment effects show that the tax credit had a positive indirect effect on the number of green employees, and even private environmental R&D.

Finally, the last chapter summarises the main results, discusses the policy implications and offers proposals meant to overcome some of the issues concerned with implementation of environmental policy instruments identified throughout this thesis.

2 Social welfare, public policy and clean technology

2.1 Introduction

There exists a substantial amount of literature both recognizing the effects of human activity on climate change (Stott, Stone, and Allen, 2004; Emanuel, 2005; Landsea, 2005) as well as the negative economic consequences from the destructive weather conditions (Mendelsohn, Nordhaus, and Shaw, 1994). Scholars have identified the crucial role governments need to play in smooth transitioning from dirty to clean technologies that would guarantee, to a certain extent, a control over the scope of the climate change (Nordhaus, 2010; Golosov et al., 2014). The topic is even more relevant, in the eyes of recent Paris Agreement, and cooperative efforts to limit the increase in temperatures, which simultaneously motivate countries to significantly reduce the emission levels.

Recent theoretical economic literature seems to majorly favour market-based instruments for regulating negative externalities of energy production (environmental pollution) since they ensure decrease in environmental pollution with no major cost to the society. However, they are often criticized for making companies less competitive and while a number of countries have implemented either carbon taxes or energy taxes levied on carbon content OECD (2016),[1] there is still much resistance to the idea within the industry [2] and little consensus on the right amount of

[1] Carbon taxes are used in 14 countries in Europe. Scandinavian countries have introduced carbon taxation over 25 years ago, while others only recently. accessed: 23.04.2018 https://www.vermontlaw.edu/sites/default/files/Assets/etpi/Carbon20Taxation 20in20Europe20Andersen202016.pdf

[2] An appropriate carbon tax would wipe out billions from polluters' profits. accessed:

tax rate (Kettner-Marx, Kletzan-Slamanig, et al., 2018). At the same time, regulators have the option of utilizing tax incentives in the form of tax credits/deductions and investment subsidies, which, however, translate into a significant burden for the social welfare at a smaller cost for the company. Policymakers in the United States,[3] Spain [4] and other countries [5] quite frequently provide firms with an investment tax credit for investments in environmentally friendly technologies, and develop renewable energy projects. Nevertheless, there is little consensus on how to design an efficient investment subsidy, such that it provides a good incentive to adopt a green technology, without an excessive burden on the policymaker side (Meyer, Prakken, and Varvares, 1993).

In Europe private R&D is expected to grow by 4.7 percent in the next two years, having grown this year by 1.4 percent.[6] On aggregate level, in 2015 private companies have spent on Research & Development in the United States (US$463 billion), China (US$377 billion) and the European Union (US$346 billion).[7] Firms are in pursuit of increasing their profits, through introduction of more efficient technologies, and pollution decreasing technologies, that would cut costs of eminent carbon taxation. By introducing cleaner technologies, firms can reduce costs on two levels, first, they can start producing more efficiently (with smaller amount of natural resources needed)[8] and, second, reduce the amount of pollution

23.04.18, https://www.theguardian.com/environment/2017/sep/04/emissions-carbon-tax-profits-polluters-paris-targets

[3]Solar Investment Tax Credit is one of the most important federal policy for encouraging adoption of solar power (30% tax credit), accessed: 23.04.18, https://www.seia.org/initiatives/solar-investment-tax-credit-itc

[4]Until 2011 Spain had an investment tax credit for environmentally friendly technological innovation, which was equal to 10% of the final investment costs. accessed: 23.04.18, OECD (2010), "Annex E. R&D and Environmental Investments Tax Credits in Spain", in Taxation, Innovation and the Environment, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264087637-13-en.

[5]China has introduced an investment tax credit and the productivity grew by 3.7 percent, accessed: 23.04.18 https://itif.org/publications/2017/09/05/after-china-implemented-investment-tax-credit-productivity-grew-37-percent

[6]accessed: 23.04.18, http://iri.jrc.ec.europa.eu/survey17.html

[7]accessed: 23.04.18, http://www.visualcapitalist.com/global-leaders-r-d-spending/

[8]For instance, the case of environmental innovation in the Oil Industry. For more details see: https://www.linkedin.com/pulse/energy-startups-bringing-efficiency-innovation-oil-gas-hank-torbert/

emitted to the air/water that is more and more often taxed[9] During and in the aftermath of the Covid-19 pandemy, countries even more so, need to make an emphasis on the green technologies that would ultimately be also reducing production costs, making the firms increasingly efficient.

Consequently, we examine the incentives of polluting firms in the energy sector to invest in clean technologies, who are subject to one of the two policy instruments such as emission taxation and proportional investment subsidy (also understood as investment tax credits). Additionally, we investigate how social welfare changes under different scenarios for the environmental damage and firms investment decisions. Firms compete a la Cournot producing a homogeneous good and emissions as a by-product. This can be due to the use of a polluting input such as coal or due to a polluting production process itself.

Regarding the investment decision, we consider that firms can choose between keeping their current (dirty) technology, or invest in one of two clean technologies available on the market: (i) cleaner production technology or (ii) end-of-pipe technology, assuming that both decrease emissions' intensity of output, while only cleaner production technology also decreases production costs (Frondel, Horbach, and Rennings, 2007). End-of-pipe technologies, typically include a wide range of currently available pollution abating technologies, such as filters, installations for steam collection and recovery, air compressors and others. As a result of emissions standards put upon the EU countries, Poland, whose biggest energy supply comes from coal is expected to spend over 10 billion PLN (2.5 billion euros) on appropriate filters [10]. With regards to cleaner production technologies we consider waste and emission prevention technologies at the source, those avoiding potentially toxic processes and materials and those that make a more energy efficient use of the fuel (Chang et al., 2016), for example, a new Power Plant in Wyoming uti-

[9] Some examples can be found in the Renewable Power Plant providing opportunity for cutting their power bill, accessed: https://www.telegraph.co.uk/business/energy-efficiency/how-to-reduce-business-energy-costs/

[10] accessed: 03.05.18, https://energianews.rp.pl/smog/co2/8001-miliardy-pojda-na-nowe-filtry-do-elektrowni-i-cieplowni

lizing technology to convert untreated coal into a cleaner burning and more efficient fuel, which is to be built in the next few years. [11]

We model the game as follows. In the first stage, the regulator decides to either introduce an emission tax on the amount of pollution created or an available investment subsidy (or tax deduction), which is equivalent with an expenditure for the regulator. In the second stage, given the policy instrument in place the firms choose whether or not to invest in one type of green technology and output production.

Our paper arrives at the following conclusions. Firstly, we show that society should encourage the adoption of clean technology even if it involves fully subsidizing the investment costs for the firms. Additionally, as the environmental damage increases, it will become more and more important for the efficiency of the clean technologies to improve and so the government should keep investing in environmental R&D. Lastly, in the current state of technology, firms are discouraged from investing in green technologies due to high investment costs and low cost efficiency, as the technology improves their sentiments would change.

The remainder of the paper is organized as follows. Section 2 discusses the literature review. Section 3 derives the theoretical model and Section 4 discusses equilibrium results at each stage of the game. Lastly, in Section 5 we conclude with several policy implications.

2.2 Literature Review

Since the seminal work of Pigou (1920) in the early 20th century, over the last 50 years, the research on various economic environmental policy instruments for the purpose of limiting environmental pollution has been developing, starting with the work of Magat (1979). He presented probably the first theoretical model, which compared the effects of several environmental instruments (taxes, subsidies, permits, effluent standards

[11] accessed: 03.05.18, http://www.coalage.com/news/latest/5630-clean-coal-technologies-signs-agreement-for-pristine-m-plant-in-wyoming.html.Wusb2ohuY2w

and technology standards) concluding that they provide similar incentives to reduce emissions through induction of innovation. Popp, Newell, and Jaffe (2010) provided further insights into the literature of public policy, by analyzing empirically whether market-based instruments are more effective at inducing green innovation than command and control instruments.[12] Taxes are a good example of such an incentive based instrument (Downing and White, 1986; Newell, Jaffe, and Stavins, 1999), given its ability to equalize marginal abatement costs across firms and consequently arrive at efficient outcomes (Baumol and Oates, 1988). It is especially the case of energy industry, since energy is an essential good and its demand is rather inelastic, consequently the resulting carbon taxes or energy taxes are especially effective. As an example, Aghion et al. (2016) find evidence for a significant and positive impact of carbon prices on energy saving innovations while using data from the automobile industry. Acemoglu, Aghion, et al. (2012) and Acemoglu, Akcigit, et al. (2016) also agree that carbon taxes should be successful at directing technologies change towards greener technologies, however, only if combined with research subsidies.[13]

When it comes to tax incentives and investment subsidies in the context of environmentally friendly innovation, the research is much scarcer. Admittedly, Christiansen and Smith (2015) agree that firms can arrive at a much more efficient outcome if the regulator combines emission tax with an investment subsidy or some other type of environmental regulation. In a world with much uncertainty about the future, the emission taxes are not flexible enough, and so the firms need further encouragement to adopt environmentally friendly technologies. There exist, additionally, several works on tax incentives and subsidies alone. Murray

[12] In contrast to command and control instruments, market-based instruments use market forces (above all prices) to reduce emissions in a cost-effective way, encouraging firms to apply their private information on the best technology available to them, at the same time providing revenues for the government.

[13] These authors consider that if dirty technologies are rather well developed, it might be too challenging for cleaner technologies to compete with them since they have to catch up with advancing the effectiveness. Therefore, they claim that relying on carbon taxes and delaying intervention can result in significant welfare costs for the society.

et al. (2014) analyze empirically the case for the USA electricity market, where the companies have the option of choosing between receiving production tax credit or an investment tax credit (but not both), which lowers the cost of electricity generated from renewable resources, which thereby significantly reduces the production from fossil fuels. Metcalf (2010) on the other hand, shows how the production tax credit has been playing an important role in driving investment in wind energy. Similar study has been done in the Chinese context. Mao and Wang (2016) take advantage of the introduction of ITC (investment tax credit) for firms who decide to engage in investment which either reduces environmental pollution or is considered energy efficient. They find out that while the tax credit was widely unpopular, it did help to reduce coal consumption for a specific group of firms that are affiliated with the central government. They consequently underline the importance of properly advertising the tax incentives available, as well as the close cooperation of firms with the regulator.

This paper aims to fill a gap in the environmental economics literature by focusing on instrument choice on the adoption of new technologies. While the effectiveness of policy instruments in inducing adoption has been addressed before, it always did it with a single: either pollution abating or energy efficient technology in mind (Milliman and Prince, 1989; Malueg, 1989; Requate, 1995). More specifically, even quite recently scholars have been focused on examining the incentive to adopt pollution abatement technologies (Amacher and Malik, 2002) for a single firm under emission tax or on comparing the effects of several policy instruments to adopt an energy efficient technology (Van Soest, 2005). At the same time, scholars modeled the competition between clean and dirty technologies in production and innovation, asking what would be optimal policy from social welfare point of view: encouraging carbon taxes or research subsidies (Acemoglu, Akcigit, et al., 2016).

Our model builds on the literature of strategic effects of regulation and investment. Within this literature significant effort has been directed to study the effects of emission fees under complete and incomplete information on the firm's R&D investments, as well as considering the role of environmental regulation in deterring entry (Espínola-Arredondo and Munoz-Garcia, 2013; Espinola-Arredondo, Munoz-Garcia, and Bayham, 2014; Espinola-Arredondo, Munoz-Garcia, and Liu, 2019). But perhaps, the most related paper to what we plan to achieve in our work is the one by Strandholm, Espinola-Arredondo, and Munoz-Garcia (2017), where the authors analyse a three-stage game with spillover effects. The regulator has the option of introducing either a uniform or type-dependent emission fee. Ultimately, they find that social welfare is higher under the type-dependent regime. This paper is a specific case of the model, since we consider specific green technologies that the firms can decide to adopt, and add another layer of analysing two types of environmental policy instrument instead of one.

To our knowledge, this paper is the first one to provide a theoretical model that would compare (1) different incentive-based policy instruments and their effects on the behaviour of firms, when those can choose between pollution abating and energy efficient technologies (2) as well as would analyse the resulting social welfare outcomes. More specifically, we have decided to compare two policy instruments: emission taxes and proportional investment subsidies and let firms to have a more realistic set of options, that allows them to choose between (1) not investing in any type of technology, (2) investing in cheaper solely emission reducing technology such as end-of-pipe and (3) investing in more expensive energy efficient technology that also reduces the amount of emissions created - the so-called cleaner production technologies.

2.3 Model

Two homogeneous producers of energy (i = 1,2) compete a la Cournot, which generates pollution e_i. Firms face linear inverse demand function p(Q)= a - Q, where p is price, $Q = q_1 + q_2$ is the aggregate output level. Both firms have the same marginal cost of production c, where a > c> 0. Additionally, we denote total emission level as $E = e_1 + e_2$ and the environmental damage as $ED = dE$, where $d > \frac{1}{4}$. The regulator can either set a tax on emissions t or provides a subsidy s to firm i that is proportional to the amount of investment, where $s \in (0, 1)$.

Each firm i can either produce using its current dirty technology generating profit Π_i^{BU}, which denotes business as usual. Firms can also decide to adopt green technology - either cleaner production or end-of-pipe - to reduce emissions. If firm i decides to invest in cleaner production technology, its level of emissions is reduced by the factor of θ and the costs of production are reduced by α , where

$\alpha, \theta \in (0, 1)$. If firm i decides to invest in end-of-pipe its level of emissions is reduced by the factor of β, where $\beta \in (0, 1)$, end-of-pipe technology does not affect production.

If

$\theta > \alpha$ the impact on reducing emissions is lower than the production cost reduction. However, if $\alpha > \theta$, it implies that the clean technology reduces the cost production less than the reduction in emission. If

$\beta > \theta$, the end-of-pipe technology is less effective reducing emissions than the clean production, otherwise $\beta < \theta$.

Consider the cost of investment in cleaner production technology, $\hat{F}_i$ being higher than the cost of investment in end-of-pipe technology, F_i (Frondel, Horbach, and Rennings, 2007). [14]

The structure of the game is the following. In the first stage the regulator either sets an emission tax, t, or provides an investment subsidy, s. While in the second stage each firm simultaneously decides whether to invest in one of the two green technologies (either cleaner production or end-of-pipe) and they compete in output. We will analyse both symmetric and asymmetric situations.

[14] End-of-pipe technologies are installed at the end of the production line, in contrast to radical changes introduced to the whole production process by the cleaner production technologies.

2.3.1 Equilibrium Analysis

Second Stage

Solving by backward induction, we analyze the optimal output under both policy regimes. We consider three different profits of firms: $\Pi_i^{BU,P}$, $\Pi_i^{CP,P}$ and $\Pi_i^{EP,P}$ for scenarios business as usual, investing in cleaner production and investing in end-of-pipe, respectively. P denotes policy regime under analysis, either taxation or subsidy, where $P = t, s$.

Symmetric Cases. We first focus on the case in which firms choose the same strategy (symmetric case), that is, both firms keep their technology, or they choose the same clean technology and then study the asymmetric case in which firms choose different types of investment. Therefore, in the symmetric case under emission fee, each firm solves:

$$\Pi_i^{BU,t} = (a - q_i - q_j)q_i - cq_i - t(q_i) \tag{2.1}$$
$$\Pi_i^{CP,t} = (a - q_i - q_j)q_i - \alpha cq_i - \hat{F}_i - t(\theta q_i) \tag{2.2}$$
$$\Pi_i^{EP,t} = (a - q_i - q_j)q_i - cq_i - F_i - t(\beta q_i) \tag{2.3}$$

where profits include the reduction in emissions when firms invest in cleaner production (θ) or in end-of-pipe (β), α represents the reduction in costs when firm i invests in CP. $\hat{F}_i$ and F_i are firm i's fixed cost of investing in cleaner production and end-of-pipe, respectively. Under the subsidy/tax credit regime each firm solves the following profit maximizing functions:

$$\Pi_i^{BU,s} = (a - q_i - q_j)q_i - cq_i \tag{2.4}$$
$$\Pi_i^{CP,s} = (a - q_i - q_j)q_i - \alpha cq_i - \hat{F}_i(1 - s) \tag{2.5}$$
$$\Pi_i^{EP,s} = (a - q_i - q_j)q_i - cq_i - F_i(1 - s) \tag{2.6}$$

where $s \in (0, 1)$ and represents the proportion of tax credit/subsidy, while all other variables remain the same.

Lemma 1: *In the symmetric case, output level under an emission* *fee becomes* $q_i^{BU,t} = \frac{1}{3}(a - c - t)$, $q_i^{CP,t} = \frac{1}{3}(a - \alpha c - \theta t))$ *and* $q_i^{EP,t} = \frac{1}{3}(a - c - t\beta)$. *However, under subsidy, those are:* $q_i^{BU,s} = q_i^{EP,s} = \frac{1}{3}(a - c)$ *and* $q_i^{CP,s} = \frac{1}{3}(a - \alpha c)$ *for BU, EP, and CP, respectively.*

Hence, when both firms choose the same technology, the emission tax reduces their output level but the investment in the green technology ameliorates the negative effect of an emission fee, if the reduction in pollution, θ, and/or reduction in costs, α, are positive. Interestingly, under the subsidy scenario the output result for end-of-pipe technology is identical to the business as usual situation. However, since cleaner production technology produces the good more efficiently (less costly) the output level increases.

Corollary 1: *In the symmetric case and tax regime, it holds that profits under cleaner production technology and end-of-pipe technology are higher than business as usual if both* $\hat{F}_i$ *and* F_i *are sufficiently low. In addition, profits under CP are higher than EP, if the difference in investment costs are sufficiently low and* $\theta < \beta$. *Otherwise this is satisfied if tax is sufficiently low. In the symmetric case and subsidy, it holds that profits under CP are higher than BU if* $\hat{F}_i$ *is sufficiently low. Additionally, profits from BU are higher than those of EP for all parameter values, except for* $s = 1$ *for which both profits coincide. Lastly, profits under CP are higher than EP when the difference between* $\hat{F}_i - F_i$ *is sufficiently low.*

The condition that supports a higher profit under CP than BU is less demanding than that for the profits under EP if $\beta > \theta$. Intuitively, the firm has more incentives to adopt CP, rather than keeping its dirty technology, when the reduction in emissions is more significant with this type of technology. Otherwise, the incentives or acquiring CP will depend on the emission fee. In the case of a subsidy, firms do not have incentives to invest in EP since the additional cost from an emission is not present. However, if the technology is fully subsidised then both profits coincide. Finally, profits from CP are higher than those from EP if the difference from the fixed investment cost is minimal. Otherwise, the firm will prefer to invest in EP.

Asymmetric Cases. In this context, firms choose different types of technology. Specifically, we identify three cases: (1) firm i follows business as usual, while firm j invests in cleaner production; (2) i follows business as usual, while firm j invests in end-of-pipe, and (3) firm i invests in cleaner production, while firm j invests in end-of-pipe. We next discuss the output level for each context.

Lemma 2: *In the asymmetric case and under emission fees, firms' outputs in Scenario (1) are:* $q_i^{*,BU,t}(q_j) = \frac{a-c(2-\alpha)-t(2-\theta)}{3}$ *and* $q_j^{*,CP,t}(q_i) = q_j^{CP,t} = \frac{a-c(2\alpha-1)-t(2\theta-1)}{3}$. *In Scenario (2)* $q_i^{*,BU,t}(q_j) = \frac{a-c-t(2-\beta)}{3}$ *and* $q_j^{*,EP,t}(q_i) = q_j^{EP,t} = \frac{a-c-t(2\beta-1)}{3}$ *and in Scenario (3):*
$q_i^{*,CP,t}(q_j) = \frac{a-c(2\alpha-1)-t(2\theta-\beta)}{3}$ *and* $q_j^{*,EP,t}(q_i) = \frac{a-c(2-\alpha)-t(2\beta-\theta)}{3}$.

Consequently, we can see that under scenarios (1) and (2), when one firm keeps its dirty technology, while the other invests in green technology, the output of the former is always lower than the latter. This is a direct result of either both reduction in pollution and production costs for scenario 1 and solely reduction in pollution for scenario 2. In other words, as one competitor becomes more efficient, the other is always forced to reduce its output level, given that it has decided not to invest. Both results hold for all parameter values. The scenario (3), however, is more complex and it depends on the relation between β and θ. In this case, output from cleaner production technology is always greater than that from end-of-pipe conditional on $\beta > \theta$. Otherwise, when $\beta < \theta$, taxation must be sufficiently low $t < \frac{c(1-\alpha)}{\theta-\beta}$ to guarantee a similar result. This is because, the relations here are twofold. On one hand, we are faced with a free riding effect - one firms reduction in emission, benefits the other by lowering emission fees. On the other hand, however, once the cleaner production competitor reduces its marginal cost it hurts EP's efficiency and final output at the same time.

Lemma 3: *In the asymmetric case and under the subsidy, firms' outputs in Scenario (1) are:* $q_i^{*,BU,s} = \frac{a-c(2-\alpha)}{3}$ *and* $q_i^{*,CP,s} = \frac{a-c(2\alpha-1)}{3}$. *In Scenario (2) are:* $q_i^{*,BU,s} = q_i^{*,EP,s} = \frac{a-c}{3}$ *and in Scenario (3):* $q_i^{*,CP,s} = \frac{a-c(2\alpha-1)}{3}$ *and* $q_i^{*,EP,s} = \frac{a-c(2-\alpha)}{3}$.

Under subsidy, firms' outputs are defined solely by the efficiency in production. Therefore, under scenarios (1) and (3) efficiency in production costs always makes the cleaner production firm to produce more than its competitor. However, if the reduction in production cost is not significant, the firm keeping its dirty technology will be able to produce more. Under scenario (2) since both firms technologies do not affect their cost reduction, they end up producing the same amount of output.

Corollary 2: *In the asymmetric case and tax regime, when one firm choses to keep its dirty technology, the profits from adopting CP and EP are always higher if the investment cost is sufficiently lower. In addition, profits from adopting CP are always higher than from EP if the cost difference between investing in CP and EP is sufficiently low. Otherwise, the firm investing in EP technology obtains higher profits.*

In the case in which one firm keeps its dirty technology and the other decides to adopt CP technology, profits are always higher for the latter than the former if the cost of investing is sufficiently low. Similarily, if one firm adopts EP technology while the other keeps its dirty technology, profits are higher from acquiring that technology if the investment cost is low. However, if the cost is differential is minimal, the firm investing in CP obtains higher profits than acquiring EP. This is always the case if $\beta > \theta$, that is, the reduction in emissions is more reducing for CP than EP. Meaning that a firm has incentives to acquire a CP technology, when its competitor adopts EP, when the benfits from reducing emissions are substantially higher with this type of technology. Otherwise, the firm will only acquire CP if the emission fee is sufficiently low.

Corollary 3: *In the asymmetric case and subsidy, it holds that the profits for business as usual are lower than the profits for CP if* $\hat{F}_i$ *is sufficiently low. In addition, profit from EP is also lower than for business as usual, unless the cost of investment is fully subsidised, for which case the profits become equal. Finally, the profit under EP are lower than under CP, when the difference between costs in investment is sufficiently low.*

Similarily to Corollary 1, Corollary 3 also shows that profits from cleaner production technology are higher than from using dirty technology when the cost of investment is sufficiently low. In addition, similar to the symmetric case, profits from not investing in green technology are higher than those from investing in end-of-pipe technology. It is connected to the fact that EP does not offer reduction in production costs, so the investment in the technology, unless fully subsidised, results in decrease in profits. Lastly, firms earn higher profits from cleaner production rather than end-of-pipe when the difference in investment costs are sufficiently low.

First Stage

Let us now examine optimal fees under uniform regulation in the first stage of the game. In this case, the regulator aims to choose a fee that maximizes social welfare, which is defined as follows

$$Social\ Welfare = CS + PS - ED + tE,$$

where CS is the consumer surplus, PS is the producer surplus and can be written down as a sum of both firms' profits, ED is the environmental damage function defined as $ED = d(q_i + q_j)$, given the assumption that the amount of pollution produced is the amount of pollution emitted, and tE is the government revenue received due to emission fee. In case of introducing an investment subsidy, the regulator solves the following social welfare function:

$$Social\ Welfare = CS + PS - ED - s(F_i + F_j),$$

where $i, j = CP, EP$. The regulator has to also include additional expenditure related to the subsidy offered to the firms.

Proposition 1: *Under the symmetric case, the regulator can set an optimal emission fee, or a "non-optimal" investment subsidy of*

$t^{*,BU} = \frac{(a-c)(4d-1)}{2+4d}$ *when both firms keep their dirty technology,*

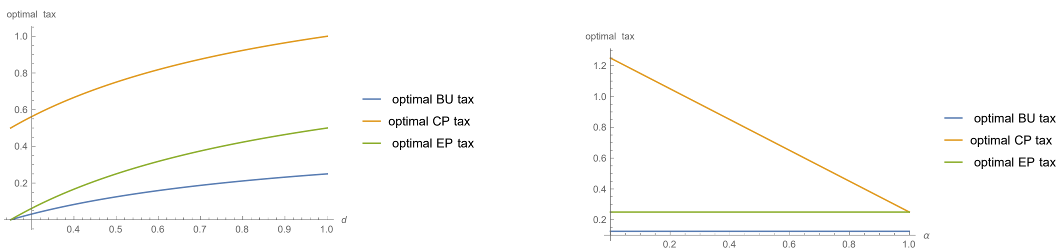
$t^{*,CP} = \frac{a(4d-1)-c(3-2\alpha-4d\alpha)}{2\theta(1+2d)}$ *if both firms invest in CP;*

$t^{*,EP} = \frac{(a-c)(4d-1)}{2\beta(1+2d)}$ *if both firms invest in EP, or*

$s^{*,CP} = \frac{(1-\alpha)(c^2-2ac)+9\hat{F}}{9\hat{F}}$, *or*

$s^{EP} = 1$ *(fully subsidizing the end-of-pipe technology)*

Note that in case of the proportional subsidy in place, the government is unable to introduce an optimal subsidy, since the subsidy itself does not affect the production levels. Having this in mind and assuming that the regulator believes it is worth subsidising green technologies, we have found an alternative way to calculate a subsidy that would encourage the firms to invest in environmentally friendly technologies. More precisely, for EP we decide to fully subsidise the technology ($s = 1$) and for CP we construct such a subsidy that also takes into the account the technology's cost efficiency (α). Given such construction of subsidies, the subsidy for EP will be equal or higher than the subsidy for CP.



(a) Depending on the value of environmental damage, d

(b) Depending on cost efficiency, α

Figure 2.1: Symmetric Case: ranking of optimal taxes.

Under symmetric scenarios, we can observe the ranking of optimal taxes in the Figure 2.1. As we can see in both (a) and (b), the ranking is quite stable no matter the values of the environmental damage (d) or cost efficiency (α). Namely, the highest taxes exist for firms when the both invest in CP technologies, they are significantly lower when both firms invest in EP technologies, while they are the smallest (and quite minimal) when both firms produce in the business as usual scenario.

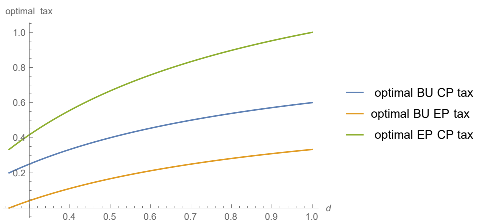
Proposition 2: *In the first stage of the asymmetric cases, the regulator can set an optimal emission fee,*

$$t^{*,BU-CP} = \frac{a(4d-1)-c(\alpha+2d(1+\alpha)-2)}{(1+2d)(1+\theta)}$$

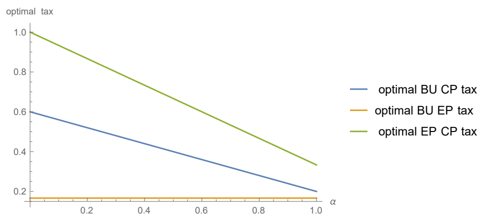
$$t^{*,BU-EP} = \frac{(a-c)(4d-1)}{(1+2d)(1+\beta)}$$

$$t^{*,EP-CP} = \frac{a(4d-1)-c(\alpha+2d(1+\alpha)-2)}{(1+2d)(\beta+\theta)}$$

In case when firms make asymmetric decisions, the ranking of optimal taxes for each scenario is presented in Figure 2.2. It appears the firms are taxed the most when both of them invest in green technologies, we need to remember this might result in punishing the less efficient firm. The second highest optimal tax in the ranking is implemented in the case that one firm keeps producing with its current dirty technology, while the other one invests in CP. The lowest optimal tax is introduced in the case that one firm keeps producing with the dirty technology, and the other invests in EP. The ranking holds no matter the environmental damage function nor the cost efficiency of the CP technology.



(a) Depending on the value of environmental damage, d



(b) Depending on cost efficiency, α

Figure 2.2: Asymmetric Case: ranking of optimal taxes.

2.4 Discussion

In this section we provide profit and social welfare comparisons under different scenarios. We shall begin by comparing profits for firms under the tax regime and later on under the proportional investment subsidy available to later on move to social welfare comparisons under the optimal emission tax and non-optimal investment subsidy.

Ranking of Profits. While comparing the profits of the firms arising from implementation of the optimal taxes, we start with the symmetric cases, which are presented in Figure 2.3. Firms reach higher profits under the tax regime if they decide not to invest in any green technology. This is not surprising, should they both wish to make decision to invest in green technologies, their taxes would be immediately adjusted to a higher level, and so the resulting profit for the firm decreases. The profits themselves also decrease as the environmental damage increases. In case both firms decide to invest in EP technologies, their profits decrease substantially compared to BU case, while if they both invest in CP their profit decreases even further, though it is only slightly smaller than the symmetric EP scenario.

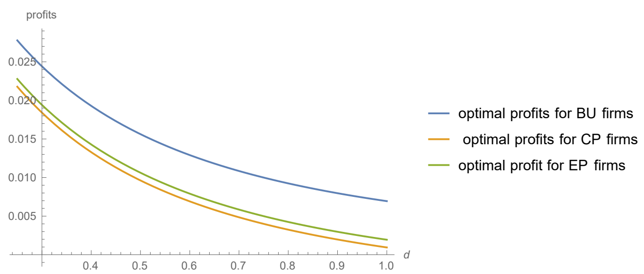
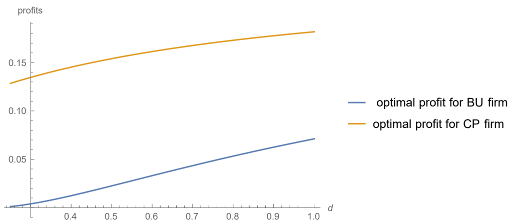
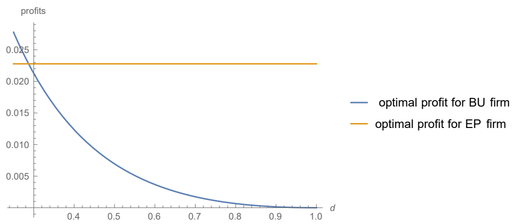


Figure 2.3: Symmetric Case: ranking of optimal profits under tax regime.

Figure 2.4a compares profits when one firm invests in CP, while the other produces BU. The profit of CP firm is much higher than that of the BU firm, since the optimal tax is adjusted only to one firm investing and becoming more efficient. Both firms' profits increase as environmental damage increases. In Figure 2.4b we compare a similar situation, this time, however, the investing firm adopts EP. Under this scenario, once again the profit of the green adopter is higher than of a dirty polluter. Notably, the trends of the profit functions differ. While the profit function of the green adopter remains stable no matter the damage function, the profit function of the business as usual firm keeps decreasing as the damage function increases.



(a) One firm not investing, one investing in CP.



(b) One firm not investing, one investing in EP.

Figure 2.4: Asymmetric Case: ranking of optimal profits under tax regime - one firm investing and one firm not investing.

Lastly, Figure 2.5 compares profits should each firm decide to invest in a different type of green technology. In this case, the optimal tax is implemented in such a way that it hurts competitiveness of the firms by eliminating firms profits and make them run at a small loss. Those results suggest that firms would prefer to either not invest at all, or should they decide to adopt green technology, collude and agree on the preferred type.

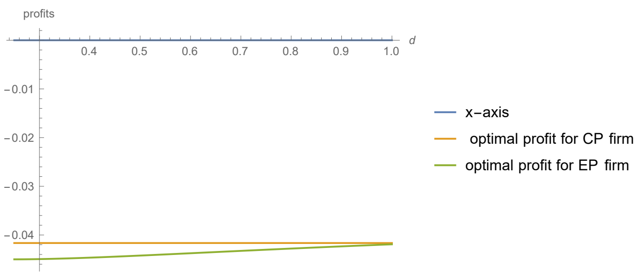


Figure 2.5: Asymmetric case: ranking of optimal profits under tax regime. One firms investing in CP, one in EP.

Under the proportional investment subsidy and symmetry of firms' choices, the situation looks quite different. Admittedly, we know that the subsidy cannot be optimal, in the sense that it does not affect the production levels, it merely provides more capital to the firm for the purchase of the technology. Additionally, since the end-of-pipe technologies do not affect the production costs, investing in it is strictly worse from the firm perspective to competing in the business as usual scenario, unless the technology is fully subsidised, in which case they are indifferent.

However, when firms are faced with a choice between investing in CP and EP, the profits that they accrue from EP technologies are slightly higher than the profits accrued by producing with CP technology as can be seen in Figure 2.6. This is because the subsidy is much higher for EP than for CP technology, so only at very low and/or very high cost efficiency of CP technology the profits for both green technologies equalise. This leaves us with a question of whether the policy instrument in place should be accompanied by a specific regulation requiring switching into green technologies, giving firms freedom to choose the technology that they find better suited. That being said, since the investment subsidy for EP is non-optimal and is equal to the full amount of money necessary for the purchase of the technology, this might have serious consequences on the social welfare function. We will analyse it in more detail later on.

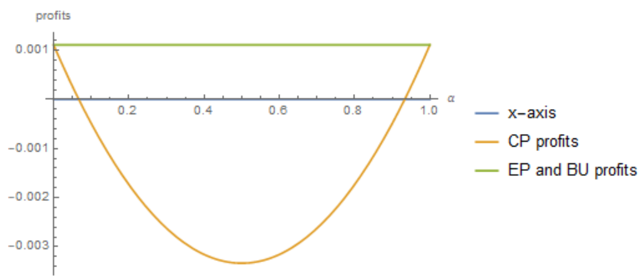


Figure 2.6: Symmetric Case: ranking of optimal profits under subsidy.

Under the proportional investment subsidy and asymmetry of firms' choices we arrive at two specific cases. One for when one firm invests in EP and the other decides to produce in the business as usual scenario. Given the full subsidy in place for EP technologies, their profits equalise and remain positive as can be seen in Figure 2.7. Figure 2.8 provides a visualisation for profit functions under "non-optimal" subsidies for the case when one firm invests in CP and the other either decides to invest in EP or keeps producing using the current dirty technology (BU). Under this scenario, their profits are positive yet decreasing as the CP technology becomes more cost efficient. As we can see, the profits of the CP adopter are always significantly higher than that of the other less efficient competitor. This suggests there exists an incentive in being the first company to adopt CP technology, when your competitor does not.

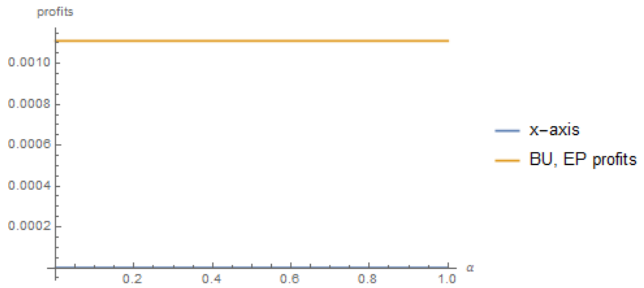


Figure 2.7: Asymmetric Case: ranking of optimal profits under subsidy. The case for BU and EP.

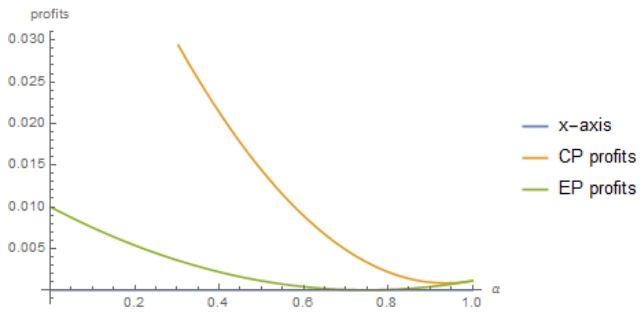
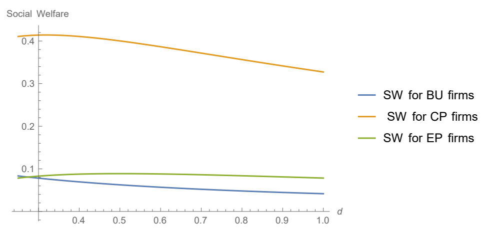


Figure 2.8: Asymmetric Case: ranking of optimal profits under subsidy. The case for CP and EP.

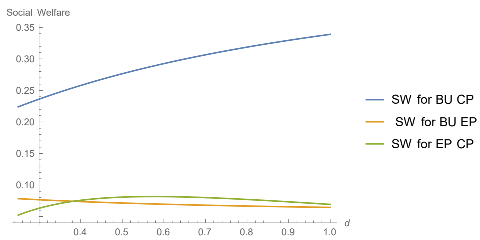
Ranking of Social Welfares under tax: Once we know the exiting incentives for firms, we can take a step back and observe the regulator's incentives. We will be interested in what kind of firms' choices will be increasing the social welfare. The complexity of the equilibrium social welfare does not make comparisons tractable or intuitive, for this reason, we provide graphical analysis of the social welfare considering parameter values consistent with the rest of the analysis. The graphical rankings of the social welfare functions under the tax regime and subsidy in place are pictured below.

Let us first investigate the incentives of the regulator under the symmetric scenario. Given the efficiency of the CP technology with respect to costs and pollution abatement, the social welfare is significantly higher when both firms invest in CP solutions (Figure 2.9a), though admittedly it decreases slightly as the environmental damage increases. The social welfare from both firms either investing in EP technologies, or both producing BU is much lower and closer in magnitude, though quite clearly social welfare under both firms investing in end-of-pipe technologies is higher, the difference between social welfare under EP and BU increases as d also increases.

In the asymmetric situations (Figure 2.9b), the social welfare is maximised when one of firms invests in CP, while the other continues producing using the current dirty technology. The SW value is much lower for the two other asymmetric cases. Given the fact that both firms produce at a loss when they both invest in green technologies, initially this scenario produces the lowest SW value, while at a certain value of environmental damage, the pollution abatement is high enough to make it preferable to the case when one firm invests in EP, and the other is a dirty polluter. As we move on to higher levels of environmental damage, the asymmetric scenario of EP and BU becomes inferior.



(a) Symmetric Case.



(b) Asymmetric Case.

Figure 2.9: Tax regime. Ranking of optimal social welfare. Simulation Values: $a = 0.5, c = 0.4, \alpha = 0.5, \beta = 0.5, \gamma = 0.5, F = 0.001, \hat{F} = 0.001$

One might also consider the fixed costs of investment in green technologies. Do they affect the preference of the regulator? The differences in social welfare with respect to investment costs are presented in Figures 2.10 and 2.11. Figure 2.10a shows that the social welfare is higher from both firms investing in CP rather than BU, as long as the fixed cost of CP is lower than 0.2. Similarly, in Figure 2.10b the regulator would prefer both firms investing in CP rather than EP as long as the difference in investment costs between the two technologies is small enough. From a policy standpoint, given the pollution reduction abilities of CP technology, as well as its cost efficiency the regulator favours investment in that specific one but only under the condition that the CP technology is not substantially more expensive, which suggests that significant effort into investment in environmental R&D should also be recommended.

(a) Difference in social welfare between firms investing in CP and BU wrt. $\hat{F}_i$

(b) Difference in social welfare between firms investing in CP and EP wrt. $\hat{F}_i - F_i$

Figure 2.10: Tax regime. Differences in Social Welfare wrt. investment costs. Simulation Values: $a = 0.5, c = 0.4, \alpha = 0.5, \beta = 0.5, \gamma = 0.5, F = 0.001, \hat{F} = 0.001$

Lastly in Figure 2.11, given the nature of the EP solution, which does not increase firm efficiency, the social welfare from both firms investing in EP will be always lower than the SW from business as usual, no matter the cost of the EP solution. We need to underline here, however, all other parameters are ceteris paribus, environmental damage included.

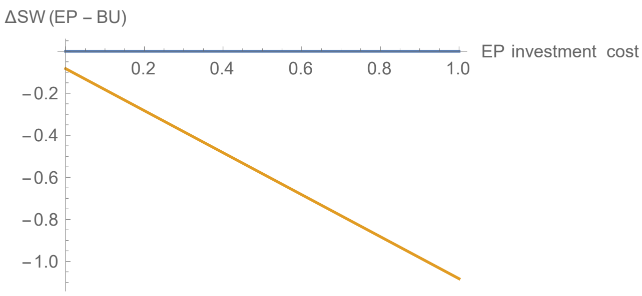


Figure 2.11: Tax regime. Differences in social welfare between firms investing in EP and BU wrt. F_i investment costs. Simulation Values: $a = 0.5, c = 0.4, \alpha = 0.5, \beta = 0.5, \gamma = 0.5, F = 0.001, \hat{F} = 0.001$

Ranking of social welfares under subsidy. Lastly, in case of "non-optimal" proportional investment subsidy in place and under symmetry of firms choices (Figure 2.12), once again the society is strictly worse off when firms produce with the current dirty technology rather than invest in green technologies. What is more, the social welfare is negative for majority of the environmental damage values and keeps decreasing as d increases further. Surprisingly, the social welfare is also mostly negative when both firms invest in EP technologies, this is due to the fact that the technology in place does not increase firm efficiency and the technology is still too expensive to fully subsidise it by the regulator without consequences for the social welfare. Lastly, the social welfare for both firms investing in CP technology is positive only until the value of 0.4, when it turns negative and it keeps decreasing itself.

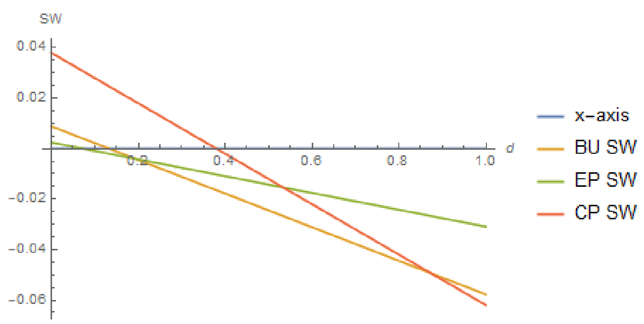


Figure 2.12: Subsidy. Symmetric Case. Ranking of optimal social welfare. Simulation Values: $a = 0.5, c = 0.4, \alpha = 0.5, \beta = 0.5, \gamma = 0.5, F = 0.001, \hat{F} = 0.001$

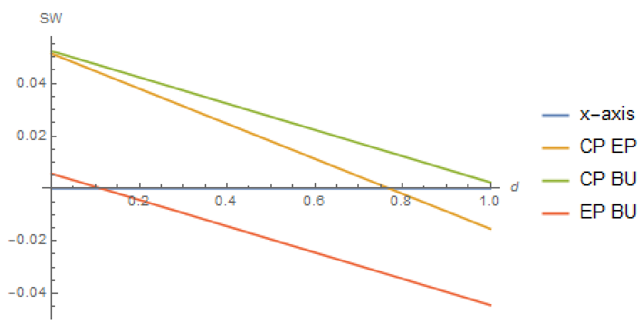


Figure 2.13: Subsidy. Asymmetric Case. Ranking of optimal social welfare. Simulation Values: $a = 0.5, c = 0.4, \alpha = 0.5, \beta = 0.5, \gamma = 0.5, F = 0.001, \hat{F} = 0.001$

Additionally, when we consider the asymmetric cases in Figure 2.13, we can once again observe that the regulator would prefer the most a scenario in which one firm invests in CP while the other chooses business as usual. The second best is the scenario where one firm invests in CP while the other invests in EP (both are positive until very high levels of d). Not surprisingly also, the scenario where one firm continues in the BU case and the other invests in EP is the least preferred, arriving at negative values for the social welfare function.

Summarising, this section identifies under which conditions the regulator and the firms' incentives will be aligned. In case of the symmetric cases, we are dealing with asymmetry of choices, while the regulator would maximise the social welfare under investment in clean technologies, the firms would prefer both not to invest. However, in case of the asymmetric scenarios, it is never the case that both the regulator and the firms prefer not to invest. In fact, under the tax regime the firms are most attracted by the asymmetric scenario where one firm invests in CP and the other does not invest. This outcome also results in high social welfare outcome than even the symmetric case for both firms producing using dirty technology. As firms cannot coordinate their efforts, however, it is very likely that they end up in the prisoners dilemma situation, where ultimately they both decide to invest in CP. This results in very high social welfare outcomes. Of course, understandably, this decreases their final profit, due to the high resulting optimal tax. For this reason, from the policy standpoint it is important to incentivise also environmental R&D to further decrease the investment costs for cleaner production technologies and increase their cost-efficiency, as to make firms more competitive and effective given the investment costs they need to accrue.

Under the subsidy scenario the regulator would prefer asymmetric scenarios where one firm invests in CP, the other investing in EP or producing with their current dirty technology. In the symmetric cases, investment of both firms in CP is also preferred, however, for high values of environmental damage even this firm choice results in negative social welfare values. With regards to firm preferences, they do also prefer to invest in different technologies, as investment of both of them in CP may result in negative profits for some of the cost efficiency parameter values, that being said, firms are incentivise to be the first adopter of CP when the competitor keeps producing its dirty technology, as this case results in the highest profits.

2.5 Conclusions

We analyse how firms react to two different environmental policy instruments with respect to investment decisions and ultimately, how their choices affect social welfare outcomes. Our results show that in case of the tax regime, we are faced with a prisoners dilemma in the sense that firms would be much better off if they were not investing in the green technology at all, since any green investment immediately raises their optimal environmental taxes. Firms, however, are incentivised to invest, hoping that the competitor would not be a green adopter, to reap the benefits of an unequal asymmetric tax and have an increased resulting profit. Ultimately, however, they would also much better off if they coordinated on the type of green technology to adopt, in contrast to when they do not coordinate. Under subsidy, firms face a similar conflict, they can either face a stable profit from non-adopting or investing in EP - which is fully subsidised - or try to be the first CP adopter to reap the benefits from the cost efficiency within the market. If both of the firms decide to invest in CP at the same time, this may result in negative profits for both of them.

Tax vs. Subsidy. Since emission fee is easier to implement, our findings imply that the regulator can rely on this policy tool to achieve high social welfare outcomes. Concerning proportional investment subsidy, the implementation is a bit more difficult, as it requires high amounts of capital to finance those technologies. Once implemented, however, it does help firms to change their production behaviour, ultimately increasing social welfare. Such proportional subsidies can be also more easily implemented through tax incentive scheme, where all green types of investments are applicable at the end of the financial year. Sánchez (2007) claims that tax incentives typically entail less administrative costs than subsidies for both public administration and firms themselves. However, it has to be kept in mind that at the current level of costs of investment, it seems only CP technologies should be encouraged and not to all interested firms.

Asymmetry of Choices. In the above model, what becomes apparent is that, we are faced with asymmetry of decision making. While the regulator clearly favours investment in cleaner production technologies, which reduces total pollution level and raises cost efficiency of firms, firms prefer to keep producing using their dirty technology in symmetric scenarios. The question that arises, therefore, is how an equilibrium of aligned preferences can be induced? It might be the case that with more money being directed at R&D, technologies would become more efficient with respect to production costs and substantially cheaper, making it more desirable for firms. From the policy perspective, investment in private environment R&D is highly encouraged.

Further research. Our model could be extended along different dimensions. First, it would be interesting to investigate the social welfare outcomes if firms could be faced simultaneously with uniform emission fee and investment subsidy. It is curious if in that case, firms would be incentivised to invest in green technology even if the emission fee would not be taxed at the optimal level. Also, another interesting extension would be to analyse companies within the market competing over heterogeneous goods e.g. in the manufacturing sectors, where similar green investments are made by the firms.

2.A Appendix

2.A.1 Proof of Lemma 1:

Business as usual. In the second stage of the game each firm i maximizes its profit.

$$\max_{q_i} \Pi_i^{BU,t} = (a - q_i - q_j)q_i - cq_i - tq_i \tag{2.7}$$

$$\frac{\delta \Pi_i^{BU,t}}{\delta q_i} = a - 2q_i - q_j - c - t = 0 \tag{2.8}$$

and the best response for each firm is

$$q_i^{BU,t}(q_j) = \frac{a - c - t - q_j}{2} \tag{2.9}$$

By symmetry, we obtain the optimal output level, $q_i^{BU,t} = q_j^{BU,t} = \frac{a-c-t}{3}$.

Consequently, substituting back the optimal quantities we obtain profits:

$$\Pi^{BU,t*} = \frac{1}{9}(a - c - t)^2$$

Under a subsidy, s, firm i's maximization problem does not change since the firm does not invest in clean technology. However, the emission fee is absent, thus, output level becomes $q_i^{BU,s} = q_j^{BU,s} = \frac{a-c}{3}$.

Cleaner production. Under emission fee, in the second stage of the game each firm i maximizes its profit as follows

$$\max_{q_i} \Pi_i^{CP,t} = (a - q_i - q_j)q_i - \alpha c q_i - \widehat{F_i} - t\theta q_i \tag{2.10}$$

$$\frac{\delta \Pi_i^{CP,t}}{\delta q_i} = a - 2q_i - q_j - \alpha c - t\theta = 0 \tag{2.11}$$

Therefore, firm i's best response function and, by symmetry, optimal output level are

$$q_i^{CP,t}(q_j) = \frac{a - \alpha c - t\theta - q_j}{2} \tag{2.12}$$

$$q_i^{CP,t} = q_j^{CP,t} = \frac{a - \alpha c - t\theta}{3} \tag{2.13}$$

Finally, firm i's profit is

$$\Pi_i^{CP,t*} = \frac{1}{9}((a - c\alpha - t\theta)^2 - 9\widehat{F}_i)$$

Under a subsidy, s, firm i's maximization problem becomes

$$\Pi_i^{CP,s} = (a - q_i - q_j)q_i - \alpha c q_i - \widehat{F}_i(1 - s) \tag{2.14}$$

Hence, output level is now $q_i^{CP,s} = q_j^{CP,s} = \frac{a-\alpha c}{3}$, and firm i's profit is

$$\Pi_i^{CP,s*} = \frac{1}{9}(a - \alpha c)^2 - \widehat{F}_i(1 - s)$$

End-of-pipe Technology. Under emission fee in the second stage of the game each firm i maximizes its profit as follows

$$\Pi_i^{EP,t} = (a - q_i - q_j)q_i - cq_i - F_i - t\beta q_i \tag{2.15}$$

$$\frac{\delta \Pi_i^{EP,t}}{\delta q_i} = a - 2q_i - q_j - c - t\beta = 0 \tag{2.16}$$

Therefore, firm i's best response function and, by symmetry, optimal output level are

$$q_i^{EP,t}(q_j) = \frac{a - c - t\beta - q_j}{2} \tag{2.17}$$

$$q_i^{EP,t} = q_j^{EP,t} = \frac{a - c - t\beta}{3} \tag{2.18}$$

Consequently, substituting back the optimal quantities we obtain profits,

$$\Pi_i^{EP,t*} = \frac{1}{9}((a - c - \beta t)^2 - 9F_i)$$

Under a subsidy, s, firm i's maximization problem becomes

$$\Pi_i^{EP,s} = (a - q_i - q_j)q_i - cq_i - F_i(1 - s) \tag{2.19}$$

Hence, output level is now $q_i^{CP,s} = q_j^{CP,s} = \frac{a-c}{3}$, which coincides with the case in which firms keep dirty technology, and firm i's profit is

$$\Pi_i^{EP,s*} = \frac{1}{9}(a - c)^2 - F_i(1 - s)$$

2.A.2 Proof of Corollary 1:

Under Symmetry and Taxation

$\Pi_i^{BU,t} \leq \Pi_i^{CP,t}$ iff:

$$\frac{1}{9}(a - c - t)^2 \leq \frac{1}{9}((a - c\alpha - t\theta)^2 - 9\widehat{F_i}) \tag{2.20}$$

$$\hat{F}_i \leq \frac{(a - \alpha c - \theta t)^2 - (a - c - t)^2}{9} \tag{2.21}$$

where $\frac{(a-\alpha c-\theta t)^2-(a-c-t)^2}{9} \geq 0$ iff

$$(a - \alpha c - \theta t) \geq (a - c - t) \tag{2.22}$$

Note that this is always true since θ, α belong to $(0, 1)$. Hence, the condition on the investment cost is satisfied - it is always positive .

$\Pi_i^{BU,t} \leq \Pi_i^{EP,t}$ iff:

$$\frac{1}{9}(a - c - t)^2 \leq \frac{1}{9}((a - c - t\beta)^2 - 9F_i) \tag{2.23}$$

$$F_i \leq \frac{(a - c - \beta t)^2 - (a - c - t)^2}{9} \tag{2.24}$$

where $\frac{(a-c-\beta t)^2-(a-c-t)^2}{9} \geq 0$ iff

$$(a - c - \beta t) \geq (a - c - t) \tag{2.25}$$

Note that this is always true since β belongs to $(0, 1)$. Hence, the condition on the investment cost is satisfied - it is always positive .

$\underline{\Pi_i^{EP,t} \leq \Pi_i^{CP,t}}$ iff:

$$\frac{1}{9}(a - c - t\beta)^2 F_i \leq \frac{1}{9}((a - c\alpha - t\theta)^2 - 9\hat{F}_i) \tag{2.26}$$

$$\hat{F}_i - F_i \leq \frac{(a - \alpha c - \theta t)^2 - (a - c - t\beta)^2}{9} \tag{2.27}$$

where $\frac{(a-\alpha c-\theta t)^2-(a-c-\beta t)^2}{9} \geq 0$ iff

$$(a - \alpha c - \theta t) \geq (a - c - \beta t)c(1 - \alpha) \geq t(\theta - \beta) \tag{2.28}$$

Note that the cost differential is positive when $\theta \leq \beta$. If $\theta \geq \beta$, then emission fee, t, needs to be sufficiently low.

Under Symmetry and Subsidy:

$\underline{\Pi_i^{BU,s} \leq \Pi_i^{CP,s}}$ iff:

$$\frac{1}{9}(a - c)^2 \leq \frac{1}{9}((a - c\alpha)^2 - \widehat{F_i}(1 - s) \tag{2.29}$$

$$\hat{F}_i \leq \frac{(a - \alpha c)^2 - (a - c)^2}{9(1 - s)} \tag{2.30}$$

where $\frac{(a-\alpha c)^2-(a-c)^2}{9(1-s)} \geq 0$ iff

$$(a - \alpha c) \geq (a - c) \tag{2.31}$$

and

$$1 - s \geq 0 \tag{2.32}$$

Note that this is always true since α, s belong to $(0,1)$. Hence, the condition on the investment cost is satisfied - it is always positive. Note that, the numerator is always positive since α belongs to $(0,1)$.

$\underline{\Pi_i^{BU,s} \leq \Pi_i^{EP,s}}$ iff:

$$\frac{1}{9}(a-c)^2 \leq \frac{1}{9}(a-c)^2 - F_i(1-s) \tag{2.33}$$

$$F_i \leq 0 \tag{2.34}$$

Note that, the firm will never voluntarily invest in EP.

$\underline{\Pi_i^{EP,s} \leq \Pi_i^{CP,s}}$ iff:

$$\frac{1}{9}(a-c)^2 - F_i(1-s) \leq \frac{1}{9}(a-c\alpha)^2 - \widehat{F_i}(1-s) \tag{2.35}$$

$$\hat{F}_i - F_i \leq \frac{(a-\alpha c)^2 - (a-c)^2}{9(1-s)} \tag{2.36}$$

where $\frac{(a-\alpha c)^2-(a-c)^2}{9(1-s)} \geq 0$ iff

$$(a - \alpha c) \geq (a - c) \tag{2.37}$$

and

$$1 - s \geq 0 \tag{2.38}$$

Note that this is always true since α, s belong to $(0,1)$. Hence, the condition on the investment cost is satisfied - it is always positive. Note that, the numerator is always positive since α belongs to $(0,1)$. This is the same condition we had for the BU and CP profits. This, however, here is less stringent in comparison to the latter.

2.A.3 Proof of Lemma 2

Under Asymmetry and Taxation

Asymmetric scenario 1: $Firm_i$ produces with current dirty technology, $Firm_j$ invests in CP. In the second stage of the game each firm maximizes its profit.

$$\max_{q_i} \Pi_i^{BU,t} = (a - q_i - q_j)q_i - cq_i - -tq_i \tag{2.39}$$
$$\max_{q_j} \Pi_j^{CP,t} = (a - q_j - q_i)q_j - c\alpha q_j - t\theta q_j \tag{2.40}$$

and, substituting q_i into q_j, we arrive at optimal output levels

$$q_i^{*,BU,t}(q_j) = \frac{a - c(2-\alpha) - t(2-\theta)}{3} \tag{2.41}$$
$$q_j^{*,CP,t}(q_i) = q_j^{CP,t} = \frac{a - c(2\alpha - 1) - t(2\theta - 1)}{3} \tag{2.42}$$

Finally, firm i's and j's profits are

$$\Pi_i^{*,BU,t} = \frac{1}{9}(a - c(2-\alpha) - t(2-\theta))^2$$
$$\Pi_j^{*,CP,t} = \frac{1}{9}(a - c(2\alpha - 1) - t(2\theta - 1)^2 - \widehat{F}_j$$

Asymmetric scenario 2: $Firm_i$ produces with current dirty technology, $Firm_j$ invests in EP. In the second stage of the game each firm maximizes its profit.

$$\max_{q_i} \Pi_i^{BU,t} = (a - q_i - q_j)q_i - cq_i - -tq_i \tag{2.43}$$
$$\max_{q_j} \Pi_j^{EP,t} = (a - q_j - q_i)q_j - cq_j - t\beta q_j \tag{2.44}$$

and, by maximizing the profit functions and substituting q_i into q_j (and vice-versa), we arrive at optimal output levels

$$q_i^{*,BU,t}(q_j) = \frac{a-c-t(2-\beta)}{3} \tag{2.45}$$

$$q_j^{*,EP,t}(q_i) = q_j^{EP,t} = \frac{a-c-t(2\beta-1)}{3} \tag{2.46}$$

Finally, firm i's and j's profits are

$$\Pi_i^{*,BU,t} = \frac{1}{9}(a-c-2t+t\beta)^2$$

$$\Pi_j^{*,EP,t} = \frac{1}{9}(a-c+t-2t\beta) - F_j$$

Asymmetric scenario 3: $Firm_i$ invests in CP, $Firm_j$ invests in EP. In the second stage of the game each firm i maximizes its profit.

$$\max_{q_i} \Pi_i^{CP,t} = (a-q_i-q_j)q_i - \alpha c q_i - \widehat{F_i} - t\theta q_i \tag{2.47}$$

$$\frac{\delta \Pi_i^{CP,t}}{\delta q_i} = a - 2q_i - q_j - \alpha c - t\theta = 0 \tag{2.48}$$

$$\Pi_{ij}^{EP,t} = (a-q_j-q_i)q_j - cq_j - F_j - t\beta q_j \tag{2.49}$$

$$\frac{\delta \Pi_j^{EP,t}}{\delta q_j} = a - 2q_j - q_i - c - t\beta = 0 \tag{2.50}$$

Therefore, firm i's and j's best response functions are:

$$q_i^{CP,t}(q_j) = \frac{a-\alpha c - t\theta - q_j}{2} \tag{2.51}$$

$$q_j^{EP,t}(q_i) = q_i^{EP,t} = \frac{a-c-t\beta-q_i}{2} \tag{2.52}$$

and, substituting q_i into q_j, we arrive at optimal output levels

$$q_i^{CP,t}(q_j) = \frac{a-c(2\alpha-1)-t(2\theta-\beta)}{3} \tag{2.53}$$

$$q_j^{EP,t}(q_i) = q_j^{EP,t} = \frac{a-c(2-\alpha)-t(2\beta-\theta)}{3} \tag{2.54}$$

Finally, firm i's and j's profits are

$$\Pi_i^{*,CP,t} = \frac{1}{9}((a + c - 2c\alpha + t\beta - 2t\theta)^2 - 9\widehat{F}_i)$$
$$\Pi_j^{*,EP,t} = \frac{1}{9}((a - 2c + 2c\alpha - 2t\beta + t\theta)^2 - 9F_j)$$

2.A.4 Proof of Lemma 3

Under Asymmetry and Subsidy

Asymmetric scenario 1: $Firm_i$ produces with current dirty technology, $Firm_j$ invests in CP. In the second stage of the game each firm maximizes its profit.

Under a subsidy, s, firms i's and j's maximization problems become

$$\Pi_i^{BU,s} = (a - q_i - q_j)q_i - cq_i \tag{2.55}$$

$$\Pi_j^{CP,s} = (a - q_j - q_j)q_i - \alpha c q_j - \widehat{F}_j(1 - s) \tag{2.56}$$

Hence, output levels are now

$$q_i^{BU,s} = q_j^{BU,s} = \frac{a - c(2 - \alpha)}{3} \tag{2.57}$$
$$q_j^{CP,s} = q_i^{CP,s} = \frac{a - c(2\alpha - 1)}{3} \tag{2.58}$$

and firm i's and j's profits are

$$\Pi_i^{BU,s*} = \frac{1}{9}(a - 2c + \alpha)^2$$
$$\Pi_j^{CP,s*} = \frac{1}{9}(9\widehat{F}_j(s - 1) + (a + c - 2c\alpha)^2)$$

Asymmetric scenario 2: $Firm_i$ produces with current dirty technology, $Firm_j$ invests in EP. In the second stage of the game each firm maximizes its profit.

Under a subsidy, s, firms i's and j's maximization problems become

$$\Pi_i^{BU,s} = (a - q_i - q_j)q_i - cq_i \tag{2.59}$$

$$\Pi_j^{EP,s} = (a - q_j - q_j)q_i - cq_j - \widehat{F}_j(1-s) \tag{2.60}$$

Hence, output levels are now identical

$$q_i^{BU,s} = q_j^{EP,s} == \frac{a-c}{3} \tag{2.61}$$

and firm i's and j's profits are

$$\Pi_i^{BU,s} = \frac{1}{9}(a - 2c + \alpha)^2$$

$$\Pi_j^{EP,s} = \frac{1}{9}(9F_j(s-1) + (a-c)^2)$$

Asymmetric scenario 3: $Firm_i$ invests in CP, $Firm_j$ invests in EP. In the second stage of the game each firm i maximizes its profit.

Under a subsidy, s, firm i's maximization problems become

$$\Pi_i^{CP,s} = (a - q_i - q_j)q_i - \alpha c q_i - \widehat{F}_i(1-s) \tag{2.62}$$

$$\Pi_j^{EP,s} = (a - q_j - q_j)q_i - \alpha c q_j - \widehat{F}_j(1-s) \tag{2.63}$$

Hence, output levels are now

$$q_i^{CP,s} = q_j^{EP,s} = \frac{a + c - 2\alpha c}{3} \tag{2.64}$$

$$q_j^{EP,s} = q_i^{CP,s} = \frac{a - 2c + \alpha c}{3} \tag{2.65}$$

and firm i's and j's profits are

$$\Pi_i^{CP,s*} = \frac{1}{9}(9\widehat{F}(s-1) + (a + c - 2\alpha c)^2)$$

$$\Pi_j^{EP,s*} = \frac{1}{9}(9F(s-1) + (a - 2c + 2\alpha c)^2)$$

2.A.5 Corollary 2: Under Asymmetry and Taxation

$\Pi_i^{BU,t} \leq \Pi_j^{CP,t}$ iff:

$$\frac{1}{9}(a - c(2-\alpha) - t(2-\theta))^2 \leq \frac{1}{9}(a - c(2\alpha - 1) - t(2\theta - 1))^2 - \widehat{F_j} \tag{2.66}$$

$$\hat{F}_i \leq \frac{1}{9}(a - c(2\alpha - 1) - t(2\theta - 1))^2 - (a - c(2-\alpha) - t(2-\theta))^2 \tag{2.67}$$

And so $\hat{F}_j$ needs to be sufficiently low. It also needs to be strictly positive. Note that this is the case when:

$$(a - c(2-\alpha) - t(2-\theta))^2 \leq \frac{1}{9}(a - c(2\alpha - 1) - t(2\theta - 1))^2 \tag{2.68}$$

$$3c\alpha + 3t\theta < 3c + 3t \tag{2.69}$$

$$c\alpha + t\theta < c + t \tag{2.70}$$

which is always true since both $\alpha, \theta \in (0, 1)$.

$\Pi_i^{BU,t} \leq \Pi_j^{EP,t}$ iff:

$$(a - c - t(2-\beta))^2 \leq (a - c - t(2\beta - 1))^2 - 9\widehat{F_j} \tag{2.71}$$

$$\hat{F}_i \leq \frac{(a - c - t(2\beta - 1))^2 - (a - c - t(2-\beta))^2}{9} \tag{2.72}$$

Again, $\hat{F}_j$ needs to be sufficiently low. Note that, the numerator is always positive since

$$a - c - t(2\beta - 1) > a - c - t(2-\beta) 2\beta - 1 < 2 - \beta 3\beta < 3 \tag{2.73}$$

which is always true given that β belongs to $(0, 1)$.

$\Pi_i^{EP,t} \leq \Pi_j^{CP,t}$ iff:

$$\frac{1}{9}(a - c(2-\alpha) - t(2\beta - \theta))^2 - F_i \leq \frac{1}{9}(a - c(2\alpha - 1) - t(2\theta - \beta))^2 - \widehat{F_j} \tag{2.74}$$

$$\hat{F}_i - F_i \leq \frac{(a - c(2\alpha - 1) - t(2\theta - \beta))^2 - (a - c(2-\alpha) - t(2\beta - \theta))^2}{9} \tag{2.75}$$

The difference between the fixed costs of investment, $\hat{F}_i - F_i$ needs to be sufficiently low. Additionally, the numerator is positive if

$$(a - c(2\alpha - 1) - t(2\theta - \beta)) > (a - c(2-\alpha) - t(2\beta - \theta)) \tag{2.76}$$

$$-c2\alpha + c - 2t\theta + t\beta > -2c + c\alpha - 2t\beta + t\theta \tag{2.77}$$

$$3c + 3t\beta > 3c\alpha + 3t\theta \tag{2.78}$$

$$t\beta - t\theta > c\alpha - c \tag{2.79}$$

$$t(\beta - \theta) > c(\alpha - 1) \tag{2.80}$$

$$t(\beta - \theta) < c(1 - \alpha) \tag{2.81}$$

$t < \frac{c(1-\alpha)}{\beta - \theta/)}$, which on the other hand is positive if $\theta \leq \beta$.

2.A.6 Corollary 3: Under Asymmetry and Subsidy

$\Pi_i^{BU,s} \leq \Pi_j^{CP,s}$ iff:

$$\frac{1}{9}(a - c(2-\alpha))^2 \leq \frac{1}{9}(a - c(2\alpha - 1))^2 - \widehat{F_j}(1-s) \tag{2.82}$$

$$\hat{F}_i \leq \frac{(a - c(2\alpha - 1))^2 - (a - c(2-\alpha))^2}{9(1-s)} \tag{2.83}$$

$\hat{F}_j$ needs to be sufficiently low. Note that, the numerator is always positive if s is different from 1 and because α belongs to $(0, 1)$.

$\Pi_i^{BU,s} \leq \Pi_j^{EP,s}$ iff:

$$(a-c)^2 \leq (a-c)^2 - 9F_j(1-s) \tag{2.84}$$
$$0 \leq -9F_j(1-s) \tag{2.85}$$

In the above scenario, for the firm to have profit from end-of-pipe technology equal to business as usual, the investment needs to be fully subsidized. There does not exist a situation where the profit from EP would be higher than BU.

$\underline{\Pi_i^{EP,s} \leq \Pi_j^{CP,s}}$ iff:

$$\frac{1}{9}(a-c(2+2\alpha))^2 - 9F_i(1-s) \leq \frac{1}{9}(a-c(2\alpha-1))^2 - 9\widehat{F_j}(1-s) \tag{2.86}$$
$$\hat{F}_j - F_i \leq \frac{(a-c(2\alpha-1)) - (a-c(2+2\alpha))^2}{9(1-s)} \tag{2.87}$$

The difference between the fixed costs of investment, $\hat{F}_j - F_i$ needs to be sufficiently low. Additionally, the numerator is always positive given that $s \in (0,1)$.

2.A.7 Proposition 1

Under Taxation

Optimal BU taxation for symmetric situations

Finally, in the first stage of the game the government sets the optimal emission tax

$$maxSW(t)_{BU,t} = CS(t) + PS(t) - Env(t) + TaxQ(t) \tag{2.88}$$
$$\tag{2.89}$$

therefore the social welfare if firms invest in end-of-pipe technology and the emission tax is in place is:

$$maxSW(t)_{BU} = \frac{bQ^2}{2} + 2\Pi_i - dQ + tQ \tag{2.90}$$
$$maxSW(t)_{BU} = 2bq^{*2} + 2\Pi_i - 2dq^* + 2tq^* \tag{2.91}$$

and solving the first order conditions (FOC) with respect to t we obtain the optimal tax,

$$\frac{\delta SW(t)_{BU}}{\delta t} = 0 \tag{2.92}$$

arriving at the socially optimal taxation:

$$t^* = \frac{-a + c + 3d}{2} \tag{2.93}$$

Finally, substituting optimal t into the SW(t), we obtain:

$$SW(t)^*_{BU} = \frac{1}{2}(-a + c + d)^2 \tag{2.94}$$

Optimal EP taxation for symmetric situations

First, note that the emission fee is imposed on both firms. Hence, firms 1's and 2's profits are identical to those in lemma 1. Therefore, both firms solve the following maximization problem.

$$\Pi_i = (a - q_i - q_j)q_i - cq_i - F_i - t\beta q_i \tag{2.95}$$
$$\frac{\delta\Pi_i}{\delta q_i} = 0 \tag{2.96}$$
$$\tag{2.97}$$

Once we derive the profit function we arrive at the best response of each firm.

$$q_i = \frac{a - c - t\beta - q_j}{2} \tag{2.98}$$
$$q_i = q_j = \frac{a - c - t\beta}{3} \tag{2.99}$$

Since firms are identical, they produce identical amount of the good. Consequently, substituting back the optimal quantities we obtain profits:

$$\Pi_i = \frac{1}{9}((-a + c + \beta t)^2 - 9F_i) \tag{2.100}$$

Finally, in the first stage of the game the government sets the optimal emission tax

$$maxSW(t)_{EPt} = CS(t) + PS(t) - Env(t) + TaxQ(t) \tag{2.101}$$
$$\tag{2.102}$$

therefore the social welfare if firms invest in end-of-pipe technology and the emission tax is in place is:

$$maxSW(t)_{EP} = \frac{bQ^2}{2} + 2\Pi_i - dQ + tQ \tag{2.103}$$
$$maxSW(t)_{EP} = 2bq_i^{*2} + 2\Pi_i - 2dq_i^* + 2tq_i* \tag{2.104}$$

and solving the first order conditions (FOC) with respect to t we obtan the optimal tax,

$$\frac{\delta SW(t)_{EP}}{\delta t} = 0 \tag{2.105}$$

arriving at the socially optimal taxation:

$$t^* = \frac{7a - 7c - 3d\beta}{10\beta} \tag{2.106}$$

Finally, substituting optimal t into the SW(t), we obtain:

$$SW(t)^*_{EP} = \frac{1}{10}(-20F - (a - c + d\beta)^2) \tag{2.107}$$

Optimal CP taxation for symmetric situations

First, note that the emission fee is imposed on both firms. Hence, firms 1's and 2's profits are identical to those in lemma 1. Therefore, both firms solve the following maximization problem.

$$max\Pi_i = (a - q_i - q_j)q_i - \alpha c q_i - \widehat{F_i} - t\theta q_i \tag{2.108}$$

$$\frac{\delta \Pi_i}{\delta q_i} = 0 \tag{2.109}$$

$$\tag{2.110}$$

Once we derive the profit function we arrive at the best response of each firm equal to

$$q_i = \frac{a - \alpha c - t\theta - q_j}{2} \tag{2.111}$$

$$q_i = q_j = \frac{a - \alpha c - t\theta}{3} \tag{2.112}$$

Since firms are identical, they produce the same amount of the good. Consequently, substituting back the optimal quantities we obtain profits:

$$\Pi_i = \frac{1}{9}((-a + c\alpha + t\theta)^2 - 9\widehat{F_i}) \tag{2.113}$$

Finally, in the first stage of the game the government sets the optimal emission tax

$$maxSW(t)_{CPt} = CS(t) + PS(t) - Env(t) + TaxQ(t) \tag{2.114}$$
$$\tag{2.115}$$

therefore the social welfare if firms invest in cleaner production technology and the emission tax is in place is:

$$maxSW(t)_{CP} = \frac{bQ^2}{2} + 2\Pi_i - dQ + tQ \tag{2.116}$$
$$maxSW(t)_{CP} = 2bq_i^{*2} + 2\Pi_i - 2dq_i^* + 2tq_i* \tag{2.117}$$

and solving the first order conditions (FOC) with respect to t we obtan the optimal tax,

$$\frac{\delta SW(t)_{CP}}{\delta t} = 0 \tag{2.118}$$

arriving at the socially optimal taxation:

$$t^* = \frac{-a + c\alpha + 3d\theta}{2\theta} \tag{2.119}$$

Finally, substituting optimal t into the SW(t), we obtain:

$$SW(t)^*_{CP} = \frac{1}{2}((-4G + (-a + c\alpha + d\theta)^2) \tag{2.120}$$

Under Subsidy

Optimal BU subsidy for symmetric situations

Subsidy does not exist in the world where both firms produce a la Cournot. And so the subsidy s=0. The firms profits and the social welfare function follow the general case:

$$\Pi_i = (a - q_i - q_j)q_i - cq_i \tag{2.121}$$
$$\frac{\delta \Pi_i}{\delta q_i} = 0 \tag{2.122}$$
$$\tag{2.123}$$

Once we derive the profit function we arrive at the best response of each firm.

$$q_i = \frac{a - c - q_j}{2} \tag{2.124}$$
$$q^* = q_i = q_j = \frac{a - c}{3} \tag{2.125}$$

Since firms are identical, they produce identical amount of the good. Consequently, substituting back the optimal quantities we obtain profits:

$$\Pi^* = \frac{1}{9}(-a + c)^2 \tag{2.126}$$

Finally, in the first stage of the game the government sets the optimal subsidy, which is equal to 0, since non of the firms decide to invest in the green technology.

$$maxSW_{BU} = CS + PS - Env \tag{2.127}$$
$$\tag{2.128}$$

therefore the social welfare if firms keep producing a la Cournot is:

$$maxSW_{BU} = \frac{bQ^2}{2} + 2\Pi_i - dQ \tag{2.129}$$

$$maxSW_{BU} = 2bq^{*2} + 2\Pi^* - 2dq^* \tag{2.130}$$

And so, the social welfare under BU is equal to:

$$SW_{BU} = \frac{2}{9}(a-c)(2a-2c-3d) \tag{2.131}$$

Optimal EP subsidy for symmetric situations

First, let us remember firms 1's and 2's profits are identical to those in lemma 2. Therefore, both firms solve the following maximization problem.

$$\Pi_i = (a - q_i - q_j)q_i - cq_i - F_i(1-s) \tag{2.132}$$

$$\frac{\delta \Pi_i}{\delta q_i} = 0 \tag{2.133}$$

$$\tag{2.134}$$

Once we derive the profit function we arrive at the best response of each firm equal to the general Cournot case.

$$q_i = \frac{a-c-q_j}{2} \tag{2.135}$$

$$q^* = q_i = q_j = \frac{a-c}{3} \tag{2.136}$$

Since firms are identical, they produce identical amount of the good. Consequently, substituting back the optimal quantities we obtain profits:

$$\Pi_i^* = \frac{1}{9}(a-c)^2 + (-1+s)F_i \tag{2.137}$$

Finally, in the first stage of the game the government is supposed to set the optimal amount of subsidy. However, since the level of subsidy does not affect firm's pollution and production decisions. We shall show instead that social welfare under end-of-pipe technology is higher or equal to that under BU assuming that the investment cost (F) is equal to 0. And so, taking the costs aside, it is always beneficial for the society to have firms investing in green technology.

Step 1: Showing that Social Welfare under EP is higher or equal to Social Welfare under BU, assuming that F=0.

$$maxSW(s)_{EP} = CS(s) + PS(s) - Env(s) - 2Subsidy(s) \tag{2.138}$$

$$\tag{2.139}$$

therefore the social welfare if firms invest in end-of-pipe technology and if the subsidy is in place is:

$$maxSW_{EP} = 2q_i^{*2} + 2\Pi_i - 2dq_i^* \tag{2.140}$$

Similarly, the social welfare if firms does not invest in anything is equal to:

$$maxSW_{BU} = 2q_i^{*2} + 2\Pi_i - 2dq_i^* \tag{2.141}$$

We can see the Social Welfare function is exactly the same for both scenarios, making the regulator indifferent between the both cases.

Step 2: Comparing the firms' profits under EP and firms' profits under BU and solving for the "non-optimal" s.

$$\Delta\Pi = \Pi(s)_{EP} - \Pi(s)_{BU} \tag{2.142}$$

$$\Delta\Pi = \frac{1}{9}(a-c)^2 + F(s-1) - \frac{1}{9}(a-c)^2 \tag{2.143}$$

$$\frac{\delta\Pi}{\delta s} = 0 \tag{2.144}$$

$$s* = 1 \tag{2.145}$$

The firms would invest in end-of-pipe technology if it was fully subsidized.

Optimal CP subsidy for symmetric situations

As in the previous case, let us remember firms 1's and 2's profits are identical to those in lemma 2. Therefore, both firms solve the following maximization problem.

$$\Pi_i = (a - q_i - q_j)q_i - \alpha c q_i - \widehat{F_i}(1-s) \tag{2.146}$$

$$\frac{\delta\Pi_i}{\delta q_i} = 0 \tag{2.147}$$

$$\tag{2.148}$$

Once we derive the profit function we arrive at the best response of each firm.

$$q_i = \frac{a - \alpha c - q_j}{2} \tag{2.149}$$

$$q^* = q_i = q_j = \frac{a - \alpha c}{3} \tag{2.150}$$

Since firms are identical, they produce identical amount of the good. Consequently, substituting back the optimal quantities we obtain profits:

$$\Pi_i^* = \frac{1}{9}(a - \alpha c)^2 + (-1+s)\widehat{F_i} \tag{2.151}$$

Finally, in the first stage of the game the government is supposed to set the optimal amount of subsidy. However, since the level of subsidy does not affect firm's pollution and production decisions. We shall show instead that social welfare under cleaner production technology is higher or equal to that under BU assuming that the investment cost (F) is equal to 0. And so, taking the costs aside, it is always beneficial for the society to have firms investing in green technology.

Step 1: Showing that Social Welfare under EP is higher or equal to Social Welfare under BU, assuming that $\widehat{F} = 0$.

$$maxSW(s)_{CP} = CS(s) + PS(s) - Env(s) - 2Subsidy(s) \tag{2.152}$$
$$\tag{2.153}$$

therefore the social welfare if firms invest in cleaner production technology and if the subsidy is in place is:

$$SW_{CP} = 2q_{CP}^{*2} + 2\Pi_{CP} - 2dq_{CP}^{*} \tag{2.154}$$
$$SW_{CP} = \frac{2}{9}(2(a - \alpha c)^2 - 3d(a - c\alpha)\theta) \tag{2.155}$$

Similarly, the social welfare if firms does not invest in anything is equal to:

$$SW_{BU} = 2q_{BU}^{*2} + 2\Pi_{BU} - 2dq_{BU}^{*} \tag{2.156}$$
$$SW_{BU} = \frac{2}{9}(a - c)(2a - 2c - 3d) \tag{2.157}$$

Social Welfare under cleaner production is always greater than Social Welfare under BU.

Step 2: Comparing the firms' profits under CP and firms' profits under BU and solving for the "non-optimal" s.

$$\Delta\Pi = \Pi(s)_{CP} - \Pi(s)_{BU} \tag{2.158}$$

$$\Delta\Pi = \frac{1}{9}(a-\alpha c)^2 + \widehat{F}(s-1) - \frac{1}{9}(a-c)^2 \tag{2.159}$$

$$\frac{\delta\Pi}{\delta s} = 0 \tag{2.160}$$

$$s* = \frac{(1-\alpha)(c^2-2ac)+9\widehat{F}}{9\widehat{F}} \tag{2.161}$$

That is the non-optimal subsidy level that would make the firm indifferent to invest in cleaner production rather than keep producing BU.

Consequently, the "socially optimal" level of social welfare when both firms produce with the non-optimal subsidy is as follows:

$$SW^*_{CP} = \frac{2}{9}(2(a-\alpha c)^2 - 3d(a-c\alpha)\theta) - 2\frac{(1-\alpha)(c^2-2ac)+9\widehat{F}}{9\widehat{F}} \tag{2.162}$$

2.A.8 Proposition 2

In the asymmetric cases, we are faced with three optimal taxes, which result with three optimal social welfares.

Asymmetric Case 1: Optimal tax for one firm investing in CP, the other producing in BU

$$maxSW(t)_{BUCP} = \frac{(q_i+q_j)^2}{2} + \Pi_i + \Pi_j - d(q_i+q_j) + t(q_i+q_j) \tag{2.163}$$

$$t^*_{BUCP} = \frac{a(4d-1) - c(\alpha - 2 + 2d(a+\alpha))}{(1+2d)(1+\theta)} \tag{2.164}$$

Asymmetric Case 2: Optimal tax for one firm investing in EP, the other producing in BU

$$maxSW(t)_{BUEP} = \frac{(q_i + q_j)^2}{2} + \Pi_i + \Pi_j - d(q_i + q_j) + t(q_i + q_j) \tag{2.165}$$

$$t^*_{BUEP} = \frac{(a - c)(4d - 1)}{(1 + 2d)(1 + \beta)} \tag{2.166}$$

The optimal asymmetric tax is then added back into the social welfare function to arrive at the socially optimal level of social welfare, which is analysed in the Discussion section.

Asymmetric Case 3: Optimal tax for one firm investing in CP, the other investing in EP

$$maxSW(t)_{CPEP} = \frac{(q_i + q_j)^2}{2} + \Pi_i + \Pi_j - d(q_i + q_j) + t(q_i + q_j) \tag{2.167}$$

$$t^*_{CPEP} = \frac{(a(4d - 1) - c(\alpha - 2 + 2d(1 + \alpha))}{(1 + 2d)(\beta + \theta)} \tag{2.168}$$

Under Subsidy: the non-optimal subsidies remain the same as in the symmetric case, however, given firms decision choices, they result in three different social welfare outcomes, which will be discussed in the Discussion section more thoroughly.

3 Drivers of eco-innovations

3.1 Introduction

While arguments in favor of environmental innovation (eco-innovation) are well-rehearsed - given their nature of reducing pollution and/or 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 policymakers agree that eco-innovations are crucial in transitioning to sustainable societies (Machiba, 2010) we need to make sure we understand correctly public sector intervention and which specific capabilities and resources of the firms may drive the 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 affect 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 environmental economists consider market-based instruments superior to command-and-control policies in emission reduction. They reduce costs through allowing firms to exercise the flexibility and the use of their private information on the best strategy (Milliman and Prince, 1989). On the other hand, it was also emphasized in the theoretical literature by Porter and Van der Linde (1995) that environmental regulation can have positive impact on firms' performance such as increasing firms' competitiveness, though the empirical evidence thus far is quite mixed (Lanoie et al., 2011; Berman and Bui, 2001; Jaffe, Peterson, et al., 1995; Gollop and Roberts, 1983). Several scholars argue that environmental regulation in combination with environmental R&D is the most profitable to the firm and welfare maximising to the society - through addressing both negative externality and the knowledge market failure (Acemoglu, Aghion, et al., 2012; Popp, 2006; Hart, 2004). Firms, however, to invest in innovation need an establishment of a policy-mix between environmental, energy and technological regulatory measures due to their reluctance to engage in high costs activities with significant risk (Costa-Campi, García-Quevedo, and Martínez-Ros, 2017).

The aim of our paper is to contribute to the existing literature with new insights on the drivers of different green innovation in the manufacturing sector and is most closely related to the work by Demirel and Kesidou (2011). More specifically, we look at adoption of general end-of-pipe technologies (EP) and cleaner production technologies (CP) as well as EP and CP technologies with air pollution and energy consumption aims, which is unique. We do not know of any previous paper having such rich information on the eco-innovative variables. In the past, previous literature has either emphasized drivers of pollution abating and energy efficient technologies separately, or has investigated between the two types of technologies using data from cross-sectional surveys. Not only does our paper manage to distinguish between two main types of eco-innovations but also, additionally, analyses a wide range of subdivisions of eco-innovations. What is more, in this investigation, we compare relation of policy instruments and organizational capabilities with environmental investment. Lastly, since there is still little research and agreement on how different policy-mixes drive specific types of eco-innovation, we would like to address that gap.

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, 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 3.2 analyses the relevant literature and aims at finding gaps. Section 3.3 offers a simple theoretical model of firms' decision making process while adopting green technologies. Section 3.4 presents data, descriptive statistics, explains the way the main variables were measured and describes the empirical analysis used. Section 3.5 discusses the empirical findings and presents numerous robustness checks. We conclude and present policy implications in Section 3.6.

3.2 Literature Review

Quite recently scholars turned their attention towards drivers of the adoption of green technologies (for an extensive revision see del Río, Peñasco, and Romero-Jordán (2016) and Horbach, Rammer, and Rennings (2012), among others). The justification of such analysis is crucial for policy makers to implement instruments to foster green innovation in order to help companies to gain competitive advantage. Admittedly, the literature on green innovation and environmental policy is a recent one and keeps on growing dynamically. 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 of any eco-innovation. In the following section, we carry out a literature review on policy instruments and organizational capabilities, within the context of eco-innovation.

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

Public policy may influence firms decision making with regards to environmental investment thanks to provision of subsidies and tax credits (to alleviate the cost of eco-investment) or/and by introducing stringency regulations through taxes. As Porter and Van der Linde (1995) pointed out, 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 such 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). When papers do not use subjective qualitative surveys, they usually proxy with several techniques. They can either use environmental regulation with the abatement costs (US PACE Survey), the number of inspections concerned with pollution levels (Brunnermeier and Cohen, 2003), and by considering the effects of a specific change in environmental legislations (Popp, 2006). 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 regulation and customer pressure are mechanisms through which companies get involved in eco-innovation. That being said, many papers look at environmental policy instruments, without focusing on specific policy instruments and their mix.

One of the main contributions of the literature on policy instruments was the realization that command and control versus market based policy instruments provide different incentives to firms to innovate and adopt new technologies. Command and control type regulations are instruments that establish emission limits and standards, on the other hand, environmental taxes and tradable emission permits are classified as market-based instruments. Those last ones internalise environmental externalities in and between markets, and so incentivise dynamic efficiency (Costa-Campi, García-Quevedo, and Martínez-Ros, 2017). Market-based instruments are taxes, subsidies and tradable permits, so such instruments that address the negative externality by setting a price on the pollution levels (Carraro et al., 2010). In the context of those specific policy instruments and eco-innovations there is only handful of papers. One of the more known examples of such research is the paper by Fischer, Parry, and Pizer (2003), where the authors show that choosing objectively the best policy instrument might be an impossible task. The paper of Johnstone, Haščič, and Popp (2010), on the other hand, comments on policy instruments using patent count data and shows how investment incentives seem to play a crucial role for the adoption of renewable technologies at the early phases of technological development. As technologies mature quantity based instruments become increasingly effective. Very often, the effect of policy instruments is magnified or reduced by firm heterogeneity [1] or other heterogenous nature of the market it exists in - such as degree of liberalization of the energy market (Nesta, Vona, and Nicolli, 2014). The literature is even more abundant with regards to the eco-innovation determinants focused on differentiated environmental impact. Horbach, Rammer, and Rennings, 2012 underline how current

[1] larger, exporting and energy intensive firms are more likely to invest in eco-innovations (Haller and Murphy, 2012)

and expected regulation is important for encouraging abatement technologies, while taxes might be more relevant for motivation related to cost savings and hence more energy efficient technologies.

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. Admittedly, tax policy is perceived as less distorting than direct regulation and through the use of private information the individuals and firms use the utility maximizing solutions (Tresch, 2014). It is therefore a common public policy to use taxation such as pigovian taxes. However, countries may also provide tax incentives to encourage firms to invest in specific types of technologies. Environmental protection investment tax credits, in theory, lower the after tax cost of innovation both from capital and labour perspective by providing a tax deduction for all eligible environmental protection investments. It, thereby, reduces the costs of undertaking innovation and decreases the barrier to innovate by providing an incentive. One fear, however, is that the eligibility for the tax deduction is usually limited to known technologies and hence it decreases the use of private information that e.g. emission taxes take advantage of. Additionally, as tax deductions are not uniformly applied they are usually sought by companies that would be interested in innovating anyway, and since they are funded from the public capital, tax deductions are criticized for being wasted on companies that do not need additional incentives to innovate (Mao and Wang, 2016). Lastly, environmental protection tax credits do not per se provide incentives to invent new technology, rather they incentivise companies to comply with environmental legislation. Consequently, OECD states that they are expected to mostly drive abatement technologies rather than efficient technologies (OECD, 2010).

Looking at subsidies and the way they address capital market failure, the higher the subsidy the easier it is for the firm to decide to invest in the green technology. However, given different costs of the technologies themselves, as well as the fact that some of them affect the production process and some do not, they might be more or less difficult to implement. The importance of savings resulting from the investment in green technologies cannot be understated, such as the amount saved in emission tax through the pollution abating technology and the amount saved in production costs through the energy efficient technology. It must be said, however, that the potential savings must be high enough for firms to be willing to engage in costly investment of green technology. del Río González (2005) identified regulatory pressure and corporate image as the main drivers of its adoption of cleaner technology.

Consequently, two research questions that might arise in connection to policy instruments is first, whether environmental taxation actually drives adoption of green technologies if it is sufficiently high and second, whether investment incentives such as subsidies and tax credits are decisive drivers for green technologies, but financing different types.

3.2.2 Organisational capabilities and resources

As we have pointed out earlier, firms are influenced by internal and external factors in the decisions to adopt some type of green innovation. 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. They found different effects of resources and capabilities as drivers of environmental innovations but also these differences vary according to the types of environmental innovation considered. 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 polluting tasks and as organizational capabilities: the investment in some types of environmental certifications.

Kemp and Goodchild (1992) were probably one of the first to point out that investments of a firm is dependent on their type, and that firms that do 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. Those two are claimed to be crucial in the process also.

Scholars also agree that the decision process is very much determined by the managerial capabilities and that those 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. As such involvement in environmental procedures, certifications, environmental management systems (EMS) and having green employees dedicated to environmental protection represent important capabilities to continuously generate or adopt new eco-innovations (Wagner, 2007). In fact, Horbach (2008) has shown a positive impact that their implementation has on eco-innovation. At the same time, there have been several concerns, whether firms simply substitute such action and use it 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 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) looks at product innovation rather than process innovation, however, authors find evidence to support a hypothesis of the positive effect between green management and innovation. What is more firms with green management are more likely to lead to radical rather than incremental product innovations.

In fact, firms increasingly integrate environmentally related ideas into their new strategies. Possibly, they might be incentivized to increase green reputation, but also they might be genuinely concerned with environmental issues and so they are focused on increasing productivity through adoption of green technologies. del Río, Peñasco, and Romero-Jordán (2016) point out that organizational capabilities are largely unrepresented in the literature. Authors argue that this is caused by poor data availability, as only good quality data could be successfully used in econometric models. Those variables include: adoption of EMS; ownership of an approved certification, relevant changes in organizational structure, technological capabilities proxied by RD, and employee qualification. We consider that firms might be asking themselves a question on how important are the future payoffs. In that case, how do they picture the future demand of their product? This forward thinking style might affect their organisational capabilities, "green signaling" by adopting environmental certifications or hiring employees dedicated to environmental protection alone.

Consequently, our research questions with relation to organizational capabilities are focused on investigating whether having green employees dedicated to environmental protection activities drives adoption of any green technology, while involvement in specific environmental procedures might be working as a mere signalling strategy towards the customers.

3.3 Theoretical Model

We consider a simple model, which studies incentives for firms to invest in two different green technologies: abatement technology and efficient technology. Let us assume that a government has put in place emission taxation ($t > 0$) in an effort to reduce air-pollution and hence encourage adoption of eco-innovations ($I > 0$). In accordance with classical economic theory, emission taxation encourages firms to use private information that allows them to make the decision on the optimal amount of pollution they are willing to produce and the technology it is best for them to invest in. Additionally, the government also offers subsidies ($s \in (0, 1)$) for investments in environmentally friendly technology, which decreases the problem of credit constraint for all firms, which are aware that such subsidies are available and desire to invest in technologies that are not considered - so called standard technologies.

The identical firms can face profit functions, where Π_1, Π_2 and Π_3 are profits from not investing in anything, investing in green technology without the subsidy, investing in green technology with the subsidy provided, respectively. Profit functions accruing from these decisions would be:

$$\Pi_1 = y - c - t, \tag{3.1}$$

$$\Pi_2 = y - \hat{c} - \hat{t} - I, \tag{3.2}$$

$$\Pi_3 = y - \hat{c} - \hat{t} - I + sI - e, \tag{3.3}$$

where $c > \hat{c}$ are production costs for cleaner production technologies, $c = \hat{c}$ are production costs for end-of-pipe technologies. We also assume that $t > \hat{t}$ for both green technologies as well as that the subsidy $s \in [0, 1]$ is proportionate to the investment and can take any value from 0 to 1 but at the same time applying and receiving a subsidy is connected to exercising some kind of effort $e \geq 0$.

3.3.1 One-Period Model

Firstly, let us analyse the stronger assumption. What are the incentives for firms to decide to invest in eco-innovation at all? To arrive at the conditions, we need to assume that the profits from investing in cleaner technology without the subsidy must be higher than the profits while producing with current dirty technology, and so without the help of the subsidy it is still affordable for the firm to deal with the additional cost given solely the emission taxation in place. Hence,

$$\Pi_2 > \Pi_1, \tag{3.4}$$

$$y - \hat{c} - \hat{t} - I > y - c - t, \tag{3.5}$$

$$I < c - \hat{c} + t - \hat{t} \tag{3.6}$$

The amount required to invest in cleaner technology must be smaller than the savings done due to more efficient technology in place and the reduction of taxation paid due to lower emission levels. However, this requirement is very strong and one might wonder what happens if the government introduces a subsidy.

We can also deal with the weaker assumption, that is to assume that the subsidy addresses the gap necessary to convince the firms to invest in the green technology. Consequently, we need to find out under which conditions the profit from investing in eco-innovation with subsidy is higher than the profit from investing in eco-innovation without it.

$$\Pi_3 > \Pi_2 \tag{3.7}$$
$$y - \hat{c} - \hat{t} - I + sI - e > y - \hat{c} - \hat{t} - I \tag{3.8}$$
$$sI > e \tag{3.9}$$
$$I > \frac{e}{s} \tag{3.10}$$

If the effort function is very high or the subsidy inefficiently low, a firm might consider looking and applying for a subsidy as a burden and decreasing its profits. If the investment level I is higher than e over s, the profits with the subsidy are higher. If that is the case we have a weaker assumption of investing in green technology altogether. And so consequently:

$$\Pi_3 > \Pi_1 \tag{3.11}$$
$$y - \hat{c} - \hat{t} - I + sI - e > y - c - t \tag{3.12}$$
$$I < \frac{(c - \hat{c} + t - \hat{t} - e)}{(1 - s)} \tag{3.13}$$

In this case, the equation is not as restrictive as long as s is sufficiently large and e is sufficiently low. Given that the effort functions differ for particular firms (e.g. depending on their size, experience, number of employees dedicated to those matter or contacts) there exist only a portion of companies μ that will use the subsidy to invest in eco-innovation, out of $1 - \mu$ some will still invest in eco-innovation others will not.

3.3.2 Two-Period Model

In the following section we extend our analysis to two time periods and so we analyse the behaviour and incentives of the company within a two-period model $t = [1, 2]$, where in t=1 a firm decides to invest in green technology or not and in both t=1 and t=2 firm produces with a resulting technology. As a consequence we can exercise two types of assumptions. The stronger assumption checks under which conditions a company would decide to invest in green technology in t=1 and enjoy lower emission taxes in both t=1 and t=2 and also lower production costs if it decided to invest in CP technology.

In the two period model the strong assumption is concerned with finding the conditions for the situation, where investing in green technology without the subsidy but given taxation is strictly better than not investing. And so:

$$\Pi_{21} + \beta\Pi_{22} > \Pi_{11} + \beta\Pi_{12} \tag{3.14}$$

$$y - \hat{c} - \hat{t} - I + \beta(y - \hat{c} - \hat{t}) > y - c - t + \beta(y - c - t) \tag{3.15}$$

$$I < c - \hat{c} + t - \hat{t} + \beta(c - \hat{c} + t - \hat{t}) \tag{3.16}$$

Weak assumption, on the other hand, is concerned with a situation, where investing in green technology with the subsidy and tax in place is strictly better than investing without the subsidy.

$$\Pi_{31} + \beta\Pi_{32} > \Pi_{21} + \beta\Pi_{22} \tag{3.17}$$

$$y - \hat{c} - \hat{t} - I + Is - e + \beta(y - \hat{c} - \hat{t}) > y - \hat{c} - \hat{t} - I + \beta(y - \hat{c} - \hat{t}) \tag{3.18}$$

$$I > \frac{e}{s} \tag{3.19}$$

Then

$$\Pi_{31} + \beta\Pi_{32} > \Pi_{11} + \beta\Pi_{12} \tag{3.20}$$

$$I < \frac{(c - \hat{c} + t - \hat{t} + \beta(c - \hat{c} + t - \hat{t}) - e)}{(1 - s)} \tag{3.21}$$

Consequently, we can conclude that there exist several variables that seem to have a significant impact on the firms' decision making. For one, it is the effort, e - how much effort does it require to find and apply for a subsidy in a particular industry and whether a specific firm can afford it. We make here a special assumption that is, that the larger the company - the easier it becomes to find an appropriate subsidy, apply for it and ultimately obtain the financing. Consequently, in our following empirical model we should control for both sector and size of the firm.

Second variable that appears to be relevant is the s - the actual amount of subsidy provided. We believe that the higher the subsidy the easier it is for the firm to decide to invest in the green technology given the addressed capital market failure (Haas and Kempa, 2018). However, given different costs of the technologies themselves as way as the fact that some of them affect the production process and some do not - they might be more or less difficult to implement.

The next variables, that we find crucial, are related to the importance of the savings resulting from the investment in green technologies, more specifically $t - \hat{t}$ the amount saved in emission tax through the pollution abating technology and $c - \hat{c}$ the amount saved in production costs through the energy efficient technology. We make a note here, however, that the potential savings must be high enough for firms to be willing to engage in costly investment of green technology therefore we might be asking whether environmental taxes successfully drive the adoption of green technologies, given the current taxation level in Spain. And also whether investment incentives such as subsidies and tax credits are decisive drivers of eco-innovations.

Lastly, in the two-period model firms start finding relevant the β discounting factor. Since, they do not only restrict their optimisation to the current time frame, they begin thinking of their future payoffs and how to attract customers in the next period. This forward thinking style might affect their organisational capabilities, "green signaling" by adopting environmental certifications of hiring employees dedicated to environmental protection alone. The question we arrive at then, is whether having employees dedicated to environmental protection activities increase the adoption of green technologies, while environmental certifications might be working as a mere signaling strategy towards the customers.

Consequently, we can separate the relevant variables 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 signaling such as environmental procedures/certifications and green employees and lastly firm characteristics such as size, sector or having innovated before. We consider the last one, also known as path dependency, following the previous literature on the importance to control for persistence (Jove-Llopis and Segarra-Blasco, 2018).

3.4 Empirical Analysis

3.4.1 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.

3.4.2 Descriptive Statistics

Table 3.1 provides a list of variables and their descriptive analysis. 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 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 organizational capabilities, we use 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 and the theoretical model. 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 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.

3.4.3 Methodology

Our theoretical model together with the 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:

$$lnECOIN_{i,t} = \beta_0 + \beta_1 lnECOIN_{i,t-1} + \beta_3 dTaxes_{i,t} + \beta_4 dSubsidies_{i,t} + \beta_5 dTaxCredits_{i,t} + \beta_6 dGreenEmp_{i,t} + \beta_7 dEnvCert_{i,t} + \beta_8 size_{i,t} + \alpha_i + \alpha_s + \alpha_t + \epsilon_{i,t}$$

The dependent variable $lnECOIN_{i,t}$ is measured taking natural logarithm of investment in cleaner production of 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. 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 $\epsilon_{i,t}$.

3.5 Results

3.5.1 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 3.2 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.

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 3.2 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. 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 2, 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.

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 the pipe. After separating CP technologies into those CPair and CPenc, we can observe how environmental certifications are correlated with the latter. Given that they were also not correlated with investment in EP technologies, it is possible that firms that invest in environmental certifications either use it as a "green signaling" or they are genuinely interested in eco-innovating, which results in investments in energy efficient technologies. In the previous literature environmental certifications were usually assessed as a signal of the green behavior but in practice it does not seem to provoke further investments and adoptions of eco-innovations. Our results seem to be mostly in line with that hypothesis for adoption of air-pollution technologies. The only outlier, in that sense, are CP technologies aimed at reducing energy consumption - but even for them the coefficient is significant at a 10% level suggesting that it does play a role in the adoption decision.

3.5.2 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 3.3-3.5 show that the baseline results are robust to estimation using balanced panel data set, different time period, placebo 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 3.3, 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 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 3.3, 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 0 level of investment, and so to censor those that do not decide to invest in eco-innovative technology. That being said, such a model does not allow for fixed effects and standard errors cannot be clustered at the firm level, and so the SE are too small resulting in large and statistically significant coefficients for all of our variables. That being said, the differences between the sizes of the coefficients of our variables of interest fit the previous estimations as can be seen in Table 3.4, 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 3.4, 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 tax credits 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 utililsed the Arellano-Bond Dynamic Panel Estimation model - please see the results in Table 3.5. 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, however, we would like to underline here that the assumption of autocorrelation does not hold for lnCP, which makes the results for end-of-pipe non-interpretable.

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.

3.6 Conclusions and Policy Recommendations

Our analysis provides a set of results for identifying crucial regulatory factors and firms' 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 as well as for CP technologies. We argue that in the Spanish context this might be caused by relatively low rates environmental taxes might not be doing their task 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 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 also show some differences. Tax incentives are oriented towards financing CP technologies directed to reduce air pollution while subsidies are related to CP investments to reduce energy consumption. Again, here we confirm that EP technologies are easier to implement with subsidies. Subsidies help in the deep transformation of firms, acting in 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 organization capabilities matter for investment in green technologies. Admittedly, hiring green employees is a strong factor pushing each firm towards green investments, while the relationship between investing in green procedures and certifications is not clear.

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 policymakers 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.

3.7 Tables

Table 3.1: Variables and descriptive statistics

Variable	Definition	Mean	Std
size	number of employees	274	548
CP	cleaner production technologies (euros)	172,579	1,363,846
lnCP	natural logarithm of CP+0.001	-3.22	9.36
dCP	=1 if the firm invested in CP in a given year	0.30	
CPair	air pollution reducing CP technologies (euros)	94,263	1,115,950
lnCPair	natural logarithm of CPair+0.001	-6.77	6.65
dCPair	=1 if the firm invested in CPair	0.12	
CPenc	energy consumption reducing CPenc technologies (euros)	22,927	281,354
lnCPenc	natural logarithm of CPenc+0.001	-7.13	6.10
dCPenc	= 1 if the firm invested in CPenc	0.10	
EP	end-of-pipe technologies (euros)	116,973	1,074,002
lnEP	natural logarithm of EP+0.001	-4.57	8.51
dEP	= 1 if the firm invested in EP	0.23	
EPair	air pollution reducing EP technologies (euros)	41,432	741,608
lnEPair	natural logarithm of EPair+0.011	-7.62	5.46
dEPair	= 1 if the firm invested in EPair	0.08	
RD	private environmental Research and Development (euros)	4,668	70,434
lnRD	natural logarithm of RD+0.001	-8.16	4.30
dRD	= 1 if the firm invested in RD	0.06	
env_cert	implementation of the environmental certifications (euros)	74,025	412,334
denv_cert	= 1 if the firm paid for environmental certifications	0.33	
green_empl	annual salaries spent on employees dedicated to environmental protection (euros)	72,687	197,800
dgreen_empl	= 1 if the firm has employees dedicated solely to environmental protection	0.29	
lagCP	lagged amount of investment in CP (euros)	172,434	1,363,780
llagCP	natural logarithm of lagCP+0.001	-3.22	9.33
lagEP	lagged amount of investment in EP (euros)	116,943	1,074,032
llagEP	natural logarithm of lagEP+0.001	-4.57	8.51
taxes	sum of environmental taxes (euros)	70,788	1,925,554
dtax	= 1 if the firm paid environmental taxes	0.05	
taxes_air	air pollution taxes (euros)	24,872	930,665
dtaxes_air	= 1 if the firm paid air pollution taxes	0.04	
taxes_waste	waste taxes (euros)	1,510	31,149
dtaxes_waste	= 1 if the firm paid waste taxes	0.11	
other_taxes	other environmental taxes (euros)	44,405	1,684,801
dtax_other	= 1 if the firm paid other environmental taxes (not air, not waste)	0.06	
subsidies	subsidies and grants received for adoption of eco-innovations (euros)	3194	81,489
dsubsidies	= 1 if the firm received subsidies	0.03	
tax_credits	tax credits received for adoption of eco-innovations (euros)	9,018	261,007
dtax_credits	= 1 if the firm received tax credits	0.03	

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

	lnCP	lnCP	lnCPair	lnCPenc	lnCP	lnEP	lnEP	lnEPair	lnEP
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
dtax	0.31	0.31	-0.22	0.43**	0.32	0.10	0.11	0.13	0.05
	(0.28)	(0.28)	(0.21)	(0.21)	(0.29)	(0.27)	(0.27)	(0.18)	(0.28)
dsub	1.59***	1.56***	0.56	1.08***	1.38**	1.21***	1.21***	0.77**	1.15**
	(0.45)	(0.45)	(0.36)	(0.36)	(0.55)	(0.41)	(0.41)	(0.32)	(0.48)
dtcred	3.67***	3.67***	2.17***	0.23	4.23***	0.84	0.83	0.82	0.13
	(0.57)	(0.57)	(0.53)	(0.51)	(0.74)	(0.54)	(0.54)	(0.53)	(0.70)
dtax # dtcred					-1.04				1.53
					(1.13)				(1.09)
dtax # dtsub					2.11*				-0.69
					(1.12)				(1.09)
dtcred # dtsub					-0.14				0.71
					(1.27)				(1.36)
dtax # dtcred #dtsub					-4.93**				2.36
					(2.27)				(2.65)
dgreen_empl	1.09***	1.08***	0.60**	0.76***	1.09***	1.37***	1.40***	0.75***	1.40***
	(0.36)	(0.35)	(0.28)	(0.19)	(0.36)	(0.36)	(0.36)	(0.21)	(0.36)
denv_cert	0.61**	0.61*	0.04	0.45*	0.61**	0.11	0.08	0.04	0.08
	(0.31)	(0.31)	(0.24)	(0.23)	(0.31)	(0.29)	(0.29)	(0.18)	(0.29)
llagCP/llagEP	x	x	x	x	x	x	x	x	x
size group 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	x	x
N	14,715	14,715	14,715	14,715	14,715	14,715	14,715	14,715	14,715

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

Table 3.3: Extensions and Robustness Checks: Balanced Panel Dataset and Different Time Frame (2010-2014) and Innovation Dependent Variable

	Balanced Panel Data		2010-2014		Innovation Dependent Variable	
	lnCP	lnEP	lnCP	lnEP	lnRD	lnRD
	(1)	(2)	(3)	(4)	(5)	(6)
dtax	0.43	0.08	0.54	-0.36	0.06	0.05
	(0.37)	(0.01)	(0.42)	(0.40)	(0.37)	(0.16)
dsub	2.71***	1.68***	1.19**	1.23**	-0.05	-0.05
	(0.06)	(0.62)	(0.60)	(0.57)	(0.26)	(0.26)
dtcred	4.35***	1.97**	3.29***	1.27*	-0.23	-0.22
	(0.79)	(0.78)	(0.73)	(0.67)	(0.31)	(0.31)
dgreen_empl	0.68	0.71	0.14	2.11***	0.33	0.37*
	(0.54)	(0.48)	(0.66)	(0.68)	(0.21)	(0.21)
denv_cert	0.48	0.71	1.21**	-0.16	0.10	0.10
	(0.41)	(0.48)	(0.52)	(0.48)	(0.15)	(0.15)
lagged dep var	x	x	x	x	x	x
size dummies	x	x	x	x	x	x
firm FE	x	x	x	x	x	x
time FE	x	x	x	x	x	x
sector dummies	x	x	x	x		x
N	9,125	9,125	6,958	6,958	14,715	14,715

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

Table 3.4: Extensions and Robustness Checks: Random effects Tobit model and Fixed effects logit model

	Random Effects Tobit Model Model		Fixed Effects Logit Model	
	lnCP	lnEP	dCP	dEP
	(1)	(2)	(3)	(4)
dtax	1.77**	2.81***	0.14	0.12
	(0.56)	(0.63)	(0.09)	(0.10)
dsub	4.35***	4.34***	0.47***	0.48***
	(0.93)	(1.07)	(0.14)	(0.15)
dtcred	9.167***	4.35***	1.05***	0.21
	(0.95)	(1.10)	(0.17)	(0.16)
dgreen_empl	11.55***	11.59***	0.45**	0.68***
	(1.05)	(1.20)	(0.18)	(0.21)
denv_cert	0.73	0.03	0.27**	0.06
	(0.56)	(0.064)	(0.11)	(0.12)
lagged dep var	x	x	x	x
size dummies	x	x	x	x
firm FE/RE	x	x	x	x
time FE	x	x	x	x
sector dummies	x	x	x	x
N	14,715	14,715	14,715	14,715

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.

Table 3.5: 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)
dtax	-0.48 (0.43)	0.16 (0.41)
dsub	1.36* (0.71)	0.89 (0.93)
dtcred	3.15*** (0.91)	0.89 (0.67)
dgreen_empl	1.783*** (0.91)	0.73 (0.66)
denv_cert	0.91* (0.47)	0.48 (0.46)
lagged dep var	x	x
size dummies	x	x
firm FE	x	x
time FE	x	x
sector dummies	x	x
N	14,715	14,715

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

4 The heterogeneous effects of environmental taxation

4.1 Introduction

Governments and researchers around the world recognize that environmental taxes - especially carbon pricing - are not only effective initiatives to stimulate cost-effective pollution mitigation, improving the quality of air/water and consequently reducing negative health impacts but also an important stimulant for low-carbon, energy efficient innovation (World-Bank, 2018). Indeed, countries around the world become bolder and bolder these days in introducing various environmental taxes, even despite the industry lobbying and dramatic newspaper titles [1]. Among the ones that have become the most successful in Europe, we could point out to NOx tax in Sweden which decreased the emissions by over 30% or the landfill tax in the UK that helped to reduce the amount of waste sent to landfill from 50 million tonnes in 2001 to 12 million tonnes in 2015 [2]. Within the Spanish context, environmental taxes are still fiercely opposed and applied only at the regional level. Admittedly though, several Autonomous Communities do try to push new ones into existence as for example in Catalonia, which is about to introduce a new vehicle tax in 2020 [3].

To assess the desirability of such taxes, it is relevant to understand how they affect firm behaviour. With that aim, scholars study the effect

[1] https://www.theguardian.com/environment/2017/sep/04/emissions-carbon-tax-profits-polluters-Paris-targets, 07.02.2020

[2] https://meta.eeb.org/2017/11/23/the-5-most-successful-environmental-taxes-in-Europe/; 07.02.2020

[3] https://www.electrive.com/2019/11/01/catalonia-introduces-carbon-tax-for-polluting-vehicles/, 07.02.2020

of environmental regulation on several outcomes, not uncommonly finding inconclusive evidence. Indeed, the current state of literature is clear about the positive effects that environmental taxes have on firms innovative activity in cleaner technologies (Aghion et al., 2016; Acemoglu, Akcigit, et al., 2016; Acemoglu, Aghion, et al., 2012), pollution reduction (Greenstone, 2004; Stoerk, 2018; Mardones and Flores, 2018), and technology adoption (Bakhtiari, 2018) but with respect to the effect on the impacts on firms competitiveness, and employment (Yamazaki, 2017) results are still inconclusive as pointed out by Jaffe, Peterson, et al. (1995) and more recently by Dechezleprêtre and Sato (2017). In their review, they underline that the recent empirical literature on firms' competitiveness, proxied by trade flows, industry locations (entries and exits) still find little evidence to support the claim that environmental regulation has large adverse effects on firms. Additionally, due to data scarcity, there seems to be an insufficient number of rigorous impact analysis of environmental policies.

Considering this data obstacle, this paper contributes to the literature on the effectiveness of environmental market-based instruments, by studying the effect of environmental taxation without and in combination with public financing on firms investment in pollution abating and energy efficient technologies. To that aim, the following paper uses a novel panel dataset of 2,562 Spanish manufacturing firms across 30 sectors between 2008-2014 collected by the Spanish Institute of Statistics through the annually carried out "Survey of Environmental Protection Expenditures".

In Spain, the manufacturing sector is an important contributor to air pollution and waste. With regards to air-pollution alone in 2017 it represented 47% of the non-methane volatile organic compound, 43% of all sulphur dioxide emitted, 37% of carbon monoxide, 15% of nitrogen oxides as well as 15% of total particles (PM2.5). The aggregated cost of industrial pollution in Spain is estimated at around EUR 6.5-10.0 billion. Industrial sector is also the third largest source of GHG emissions, accounting for 21% of the total sum (INE, 2017; OECD, 2015). Spain is a good representative of environmental pollution at the European level as among the 28 member states it produces 8% of all total greenhouse gas emissions, which is quite substantial (EC, 2019). At the top of that, Spain is an interesting example of a state, which does not have consolidated environmental policy in the form of environmental taxation at the national level. Instead, regional governments of Autonomous Communities (ACs) can introduce such environmental taxes, should they wish to. This results in relatively high heterogeneity of implementation and subsequent environmental tax rates across regions in Spain, making it a good set up for empirical investigation.

This paper thus exploits the regional heterogeneity of environmental tax implementation with panel dataset of 2,562 Spanish manufacturing firms. First, we investigate how different levels of environmental taxes (air pollution, waste and others) affect investment in green technologies. To that aim, we divide firms into four categories: those that did not have paid any environmental taxes and three groups paying *low*, *medium* and *high* levels. Further, we perform categorical treatment matching of firms to study the heterogeneous effects of different levels of taxation. We match firms on observable characteristics such as size, sector, previous green investment and organizational capabilities and perform categorical treatment matching to compare the effects of not only between paying low, medium or high environmental taxes or not, but also between low and medium, low and high and medium and high levels of environmental taxation. Consequently, we assume that once we match firms on observables most of the differences between taxation levels come from regional differences in tax implementation. Second, this paper uses also propensity score matching technique to investigate the effects of a policy-mix between environmental taxes and public financing in the form of subsidies and fiscal incentives.

Our main estimates indicate that, on average, low levels of environmental taxation do not induce adoption of green technologies. However, as the level of environmental taxation increases, the effect becomes statistically significant and increases further. Additionally, we find that even at low levels environmental taxation can be effective if combined with public financing. In that case, the effect is stronger than from providing public financing alone. However, the synergic effect disappears for high levels. The high taxation alone is sufficient to encourage adoption of green technologies among firms.

This paper contributes to the large literature on the impact of environmental policy on firms behaviour. [4]. Within this field, considerable attention has been given to the drivers of green technology adoption - the literature on eco-innovations - (Triguero, Moreno-Mondéjar, and Davia, 2013; Demirel and Kesidou, 2011) but those usually limit themselves to focusing on correlations, rather than provide enough of evidence for causal inference. In fact, to date, there seems to be an insufficient amount of more rigorous empirical studies on the effects of market-based instruments such as done by (Martin, De Preux, and Wagner, 2014).

However, among this plethora of papers, there is surprisingly little evidence showing causal inference on market-based instruments such as environmental taxes on manufacturing firms. And while the role of environmental taxes - carbon tax especially - on innovative activity is proven theoretically, the role that environmental taxes might have on the adoption of green technologies is not supported by the empirical literature. Even if it seems rather intuitive that, environmental taxes will motivate companies to invest in cleaner technologies to reduce their emission fees, it is not quite clear, whether firms actually invest in cleaner technologies as a result of those taxes, or what level of the environmental tax is high enough to motivate firms to invest. Martin, De Preux, and Wagner (2014) were the first ones to study the causal inference of a carbon tax on a manufacturing sector in the UK. In their paper they find evidence in favour of implementing carbon tax, as in the case of the UK the moderate tax on energy encouraged electricity conservation and reducing energy intensity without affecting employment, productivity or gross output. This paper aims to fill the gap in the environmental economics literature by focusing on instrument choice on the adoption of new technologies. While the effectiveness of environmental taxes in inducing innovation and adoption of technologies has been addressed before, it is still far

[4] For a review of the current state literature on the impact of environmental regulation on competitiveness please see Dechezleprêtre and Sato (2017)

from reaching conclusion on the appropriate level of such tax, which is crucial from the policy making side.

Even more scarce is the evidence on the effectiveness of a policy-mix between environmental policy instruments, though in recent years it started to develop dynamically. Most of the scholars have focused on complementarities of policy-mixes (Mohnen and Röller, 2005), on a combination of policies that form composite set to see how they interact (Costantini, Crespi, and Palma, 2017; Uyarra, Shapira, and Harding, 2016; Flanagan, Uyarra, and Laranja, 2011) and whether there exists an increased effectiveness of their interaction (Marino et al., 2016; Reichardt and Rogge, 2016; Guerzoni and Raiteri, 2015; Cunningham et al., 2013; Popp, 2006; Hascic et al., 2009; Fischer, Parry, and Pizer, 2003). That being said, there exists only one theoretical paper on the combination of environmental taxes with investment subsidies for green technologies. Christiansen and Smith (2015) agree that firms can arrive at a much more efficient outcome if the regulator combines emission tax with an investment subsidy or some other type of environmental regulation. They believe that the existing uncertainty about the future, hinders firms' decisions. Additionally, emission taxes might not be flexible enough, and so the firms need further encouragement to adopt environmentally friendly technologies. In our paper, we analyse the impact of a policy-mix between environmental taxes and different types of public financing on firms decision in green investment. To the best of our knowledge we are the first to investigate this relationship empirically.

Furthermore, ever since the seminal paper by Almus and Czarnitzki (2003), researchers have been increasingly using quasi-experimental setting as an empirical method to investigate the effectiveness of market-based policy instruments and investigating casual inference rather than assessing simple correlations e.g. subsidies at stimulating innovative performance across firms (Marino et al., 2016; Guerzoni and Raiteri, 2015). In fact, Greenstone and Gayer (2009) believe it is mostly through quasi-experimental approach that we can improve our understanding on the core environmental economics questions. However, those techniques admittedly raise several challenges for internal validity due to sample selection, data limitations and others. Within the context of public policy and green innovation quasi-experimental papers, Guerzoni and Raiteri (2015) argue that matching methodologies may suffer due to uncontrolled unobservable variables that can act as "hidden treatments" in the analysis. Marino et al. (2016), while studying the additionality of subsidies on firms' investment in R&D, tried to address this existing bias by addressing sources of unobserved heterogeneity. To control for firm specific time invariant characteristics, they take first differences in the outcome variable. They also perform matching in each observational year between treated and controls, to make sure that comparisons include all observable within-firm changes occurring on an annual basis. Following their methodology, thus using simple and categorical treatment matching, we study the heterogeneous effects of environmental taxation, in and without public financing.

Arising from the literature review above, we have identified several gaps in the literature and we would like to therefore answer the following research questions. Are low levels of taxation ineffective at inducing green technologies [5]? Is there a positive relationship between the level of taxation and the level of green investment? Do the effects of environmental taxes differ for different types of green investment? Does the policy-mix between environmental taxes and public financing more effective than the use of a single instrument?

The remainder of the paper is organized as follows. Section 4.2 offers a description of heterogeneity of Spanish environmental taxes at the regional level. Section 4.3 presents data and descriptive statistics while Section 4.4 describes the empirical model and the methodology used. Section 4.5 discusses the empirical findings. We conclude and present policy implications in Section 4.6.

[5] As presented by anecdotal stories, firms generally prefer to pay taxation at low levels rather than invest in green technologies.

4.2 Heterogeneity of environmental taxes in Spain

Kyoto protocol might not have been a successful endeavour at the international level, especially assessing it 30 years later but it certainly put the environmental pollution and climate change at spotlight as a growing concern. As a result of it, in the 1990s European Commission for the very first time had advised universal adoption of several environmental taxes across the member states. Many countries followed up on the advice such as Netherlands, Ireland and Slovenia [6], but also outside of EU such as Switzerland [7] - all implementing third generation green taxes, with their revenues financing energy efficiency investments, climate change mitigations etc. Spain, however, did not follow this recommendation at the central level, making it voluntary for the Autonomous Communities (ACs) of Spain to introduce (or not) such taxes at the regional level (Freire-González and Ho, 2018).

Almost 30 years later, we can observe how Spain has made remarkable progress in overall environmental performance. Yet, it is also fair to say that significant challenges remain. While the carbon intensity decreased significantly (OECD, 2015), water and waste pollution still pose a significant challenge. Spanish CO_2 emissions have reduced at a modest rate of -3.2% in 2018, compared to an increase of 7.4% in the previous year Eurostat (2019) and Eurostat (2018), at the same time Spain is still recovering from the financial crisis of the 2008 and so the European Commission once again urges Spain to implement more ambitious environmental policy instruments. More specifically, to increase the green taxes on the regional level as well as to reduce subsidies "damaging" the environment (EuropeanCommission, 2017). EC also points out to the fact that revenues from environmental taxes in Spain are the lowest in

[6] Netherlands introduced a surcharge on energy taxation in 2013, date accessed: 01.03.2020, available online: https://ec.europa.eu/energy/sites/ener/files/documents/nl2016energyefficiency annualreport1en.pdf

[7] Switzerland introduced a tax on CO2 emissions in 2008, date accessed: 01.03.2020, available online: https://lenews.ch/2018/10/28/switzerland-leads-the-world-on-taxing-carbon/

the EU-27 (accounting for the 1.8% of GDP in comparison to EU's average of 2.46%). Lastly, within its report EC calls for introduction of a national tax on waste or harmonizing the current regional taxes arguing that positive effects could easily be accelerated if Spain had a consolidated national environmental policy. Admittedly, many agree that Spanish government makes only limited use of environmental taxes and call for more decisive green tax reform (Böhringer, Garcia-Muros, and González-Eguino, 2019; Labandeira, Labeaga, and López-Otero, 2019).

As we have mentioned earlier, in spite of the lack of initiative at the central level, a few regional governments decided to introduce a range of environmental taxes related to the industry. ACs used the legal space of introducing new taxes that can only be created in fields of taxation, which was not previously occupied by the central government (Sole-Olle, 2013). Regional environmental taxes that apply to industrial firms include, apart from the taxes on water use and sanitation charge, the taxes on air pollution emissions (Figure 4.1), waste generation and storage and other environmental taxes that are mainly taxes on installations and activities that have an environmental impact (Figure 4.2). It seems, the impact of regional environmental taxation have been limited. Researchers blame not only the low rates of those taxes, but also inequality in treatment and coordination problems between different governance levels (Labandeira, Labeaga, and Rodriguez, 2004; Gago, Labandeira, Picos, et al., 2007; Gago, Labandeira, Labeaga, et al., 2019).

The differences in environmental taxation between regions are substantial and some Autonomous Communities have been more active than others in this field (OECD, 2015; Gago, Labandeira, Labeaga, et al., 2019). Although the Autonomous Communities have progressively introduced environmental taxes, there are still quite a few ACs without any environmental tax. Additionally, there exists a substantial heterogeneity of the time of introduction, existence of environmental taxes and their rates across the regions. Some of the regions have introduced all types of environmental taxes we are concerned with, that are air pollution tax, waste tax and taxes on activities that have an environmental impact while some regions, for example Cantabria and Madrid have only taxes on waste. More information about the dates of introduction of specific taxes in different Autonomous Communities is provided in Table 4.1.

Local air-pollution tax to industrial firms were introduced in five ACs starting with Galicia in 1995, while similar taxes have been introduced in Castilla-La Mancha, Andalusia, Murcia and Aragon in 2001, 2003, 2005 and 2007, respectively. Interestingly, all those five regions are among the less developed. Afterwards, Valencia in 2012 and Catalonia in 2014 approved laws to introduce air-pollution taxes although in Catalonia the revenues from these taxes begun in 2015. The amount collected for these taxes in our period of analysis, 2008-2014, has been around 22,5 million euro annually. The Galician air-pollution taxation could be a good example for the rest when it comes to the extent of taxation - they charge on the emissions of sulphur oxides and nitrogen oxides - substances known for leading to acid rains as well for having some of the revenues transferred to a contingency fund for environmental catastrophes (Gago, Labandeira, Picos, et al., 2007). Air pollution taxes in all autonomous regions are rather similar in the way they are constructed although with different rates and exemptions (Gago et al., 2019). Specific taxes on different combinations of emissions above a certain threshold are considered, once the threshold is reached the tax rate is applied per tonne. That being said, air pollution taxes have been often criticized for two main reasons. One, they are believed to be too low to have any real effect on adoption of eco-innovation among the firms, though many argue that since they deal with local pollutants (such as SO and NOx) heterogeneity of tax rates are justified in this case of the environmental tax. Two, many believe that imposing additional carbon taxes at the regional level is difficult to justify, given that ETS is already present for several sectors, emissions are diffusive in nature, and their global effects (OECD, 2015; Gago, Labandeira, Labeaga, et al., 2019).

Concerning waste taxation, the industrial sector has improved slightly in reducing waste. In 2010 the amount of industrial waste amounted to 49.2 million tonnes, 22% less than in 2000 but 27% more than in 2009 (OECD, 2015). The decrease is explained by a reduction in mostly non-hazardous waste generated by the extractive industries and the manufacturing sector. Only five ACs introduced some kind of waste collection charges or taxes on the landfilling of industrial waste and they collected around 6,6 million euros annually in the period 2008-2014.

Finally, between 2008-2014 five Autonomous Communities introduced other taxes on activities that have an environmental impact. Extremadura was the first region to introduce such tax in 1997, Asturias, Castile and Leon, La Rioja and Valencia soon followed and introduced similar taxes in the years 2011 and 2012. More recently, Aragon in 2016 and Catalonia in 2017 have also enriched their regional fiscal scheme by environmental taxes. All of those taxes are set at different rates and on different types of pollutants but what they have in common is that most of them focus on activities with the environmental impact such as the production, storage, transportation, transformation, and supply of electricity and fuels. Although energy firms are particularly affected, incomes from these taxes are collected from all manufacturing industries. The amount collected in our period of analysis from industry and energy firms was around 25 million euros annually.

4.3 Data

In this section, we report on the available data used to run the following estimations. We also discuss descriptive statistics and preliminary evidence concerning the link between environmental taxation and the adoption of green technologies.

4.3.1 Data Source and Cleaning

The data we use in this empirical analysis was collected by the National Institute of Statistics of Spain (INE) for "*The Survey on Industry Expenditure on Environmental Protection*". The objective of the survey is to gather firm level data on environmental protection expenditures across 30 manufacturing sectors for all regions in Spain. The primary activity of the company is defined as one which gives the greatest added value across all autonomous regions. According to INE, sample was stratified to provide representative results for some sectors, for others - comprehensive. SIEEP provides also information on the size (includes all establishments hiring 10 and more remunerated employees) and several capital environmental expenditure, investment and research data. The firm level data is available between 2008 and 2014, creating 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 provided we chose the most suited for our investigation, which are briefly described below. INE ensures the quality of the data by employing CCU (centralized collection unit), which is dedicated to obtaining all the information from the questionnaire. Once survey is created, errors are detected and corrected. Unclear answers are double checked through a phone interview.

4.3.2 Variables

For our dependent variables, we use investment in end-of-pipe technologies (lnEP) and investment in cleaner production technologies (lnCP) both in log terms, as our two proxies for process eco-innovation. Both those variables measure the total amount of money spent on adoption of a given technology. As pointed out by the literature on eco-innovation drivers, since different eco-innovations have different characteristics, they might also react differently to treatment and so it is important to distinguish between types of green technologies that firms decide to adopt (Horbach, 2008; Frondel, Horbach, and Rennings, 2007; Triguero, Moreno-Mondéjar, and Davia, 2013; Demirel and Kesidou, 2011). Consequently, in this analysis we do not only capture which firms decided to eco-innovate but also we pay attention to the amount of money that they decided to invest in pollution abating and energy efficient technologies. End-of-pipe technologies are known for reducing air pollution alone without interference in the production process, while cleaner production technologies may either reduce air pollution and/or decrease energy consumption by changing the production process.

Our main variable of interest is our "treatment": environmental taxation level, which is observed at the firm level for each year. Due to anonymity reasons INE has not provided regions that each firm belongs to, which makes our analysis more challenging. Nonetheless, given heterogeneity of implementation of environmental taxes across regions in Spain, we have divided environmental taxation into three terciles. We believe by this rule, we divide the amounts rather objectively to later compare the effects of for example jumping from low to medium level of taxation. Additionally, we also use a secondary treatment "public aid". Which is the amount of money that a firm has received in tax incentives, subsidies, grants and other types of public financing in a given year.

We also use a wide range of firms pre-treatment characteristics such as: lagged investment in CP and EP (following the literature on the persistence of innovation), expenditure on environmental protection activities such as hiring employees dedicated to environmental protection, dummies associated with size and sectoral dummies. Several covariates typically appear in the related literature. Especially, the size dummies account for potential common demand and supply shocks or idiosyncratic shocks to a given company, while sectoral dummies are good for controlling for sectoral characteristics of production and pollution creation. We believe that other covariates might help with controlling for firms time invariant characteristics such as path dependency (Aghion et al., 2016). More specifically, size dummies are defined as follows: firms between 20-49, between 50 and 99, between 100 and 299, between 300 and 500 and above 500 employees. This classification is justified by the structure of Spanish manufacturing dominated by medium size companies. With regards to sector dummies, we have access to 30 different sectors defined by 2-digit-industry NACE code, which we decide to pool into 10 more general larger sectors of similar characteristics.

4.3.3 Descriptive Evidence

Figure 4.3 presents the averages of environmental taxes: aggregated, air-pollution taxes, waste taxes and other environmental taxes for each year and all observed firms. Consistent with what we stated in the section describing the Spanish heterogeneity of environmental taxation, we observe not only differences between year to year but also the level of taxation for each type of pollution. We notice an increase in the level of taxation especially from 2011 on. Even though environmental taxes in Spain are considered to have quite low tax rates, Spanish manufacturing firms pay much more in those taxes than they receive back in the form of public financing for green investment as can be seen in Figure 4.4. Additionally, we can see that in contrast to the increase in environmental taxation in 2011, the amount of public aid has decreased significantly in 2011. This possibly might be related to the planned phase-out of an investment tax credit in 2011, and the firms inability to adjust their budgets, which decreased the amount of public aid received. With regards to the amount of money invested in both technologies between 2008 and 2014, we can see a jump between 2008 and 2010, however between 2010 and 2014 the investment levels remain constant in spite of the financial crisis being prevalent in that time (Figure 4.5). That being said, the percentages of firms deciding to adopt both green technologies decrease gradually but not in a drastic way as can be seen in Figure 4.6.

With regards to the sectoral distribution of the firms within our sample, there exists some heterogeneity in the amounts of taxes paid but not substantial. Please see Figures 4.7, 4.8 and 4.9 for specifics. As can be seen in Figure 4.10 the sector that is taxed the most and the difference is quite stark is sector 35 - corresponding to Electricity, gas, steam and air conditioning supply - while sectors 6,9,12 are hardly taxed - from the extraction of crude petroleum, mining support activities and manufacture of tobacco products, respectively. For more detailed explanation of the sectoral division please see Table 4.2. The remaining sectors seem to be rather uniformly affected, with some minor differences. When we divide the taxes into more fine categories, air pollution tax, waste tax and other environmental tax we can see that while both air pollution taxes and other environmental taxes prevail for sector 35, it is not the case for waste tax. Additionally, there exist differences focusing on different taxes. For instance sector 19 (Manufacture of coke and refined petroleum products) is highly taxed by air pollution taxes relative to other sectors, but paying much less of waste and other environmental taxes. Lastly, similar conclusions can be derived from Figure 4.11, while some sectors do not seem to receive much public funding, the others receive substantially more. This underlines two observations, one is the need for matching the firms on sectors - which we do, as well as testing our hypothesis also using specific taxes and not only aggregated amounts - which is the type of analysis we perform also.

The following descriptive statistics and results refer to our final sample. Table 4.3 describes the main variables employed in the analysis, which makes it either to compare companies expenditures when they are only under regional environmental taxation (1983 firms), they are only recipients of public financing in the form of subsidies, tax credits and others (499 firms), when they are recipients of both economic instruments (213 firms) and none (firms 8788). The first two variables listed are our treatment variables: environmental taxation and public aid. The next set of variables are out outcome variables, which are represented in nominal values as well as log terms. The remaining listed variables are our pre-treatment covariates used for matching (excluding sectoral dummies). Most of the pre-treatment variables are rather similar when we compare between the groups, however, it is worth noticing that levels of investment are much higher when firms are under both policy regimes.

Tables 4.4 and 4.5 present a similar structure as the previous table and facilitate comparisons between the terciles of the distribution of firms under environmental tax only (*small environmental tax, medium environmental tax and large environmental tax*) and under both policy regimes, respectively. It turns out that firms paying larger amounts of environmental taxation are larger companies from highly polluting industries such as the chemical sector, and former large investors in green technology. When we compare Tables 4.4 and 4.5, it is easy to notice the results are consistent across two groups of companies. Additionally, we include the descriptive statistics of terciles of environmental taxation per capita for further robustness checks. The results in Table 4.6 look similar to our previously analysed in Table 4.4. This type of evidence, is a promising start for our causal inference analysis and the synergistic impact of both policy instruments.

4.4 Methodology

This section discusses the estimation strategies implemented in our empirical assessment of environmental taxation in Spain in the absence and in combination with public financing in the forms of subsidies and investment tax credits. Employing recent advancements in program evaluation analysis we have complemented the general matching with the categorical treatment matching (both pscore and exact version). To provide some insights into the methodology as well as to discuss the strengths and weaknesses of each method, we discuss them separately.

In the previous section we have analysed thoroughly the regional differences in the rates of environmental taxation. In the following section we will assume that once we match firms on their pre-treatment characteristics - such as size, sector, their previous green investment activity and organisational capabilities such as having green employees - the difference between firms' environmental tax arises from the regional heterogeneity of environmental taxation. Quite naturally, for investigating the effect of environmental taxes on adoption of green technology it would be ideal to use borders between regions as environmental tax discontinuities (and apply RDD) or at least to use regions as an instrumental variable (IV). Regions, should be exogenous to innovation levels yet relevant for environmental taxation levels - as we have shown in the Section 4.2. However, as it is often the case with observable data, we are faced with its numerous limitations. Given the lack of access to information of firms belonging to regions, we have decided to use the information on the heterogeneity of environmental tax rates across the Spanish regions.

We will be using Propensity Score Matching (PSM) proposed by Rosenbaum and Rubin (1983). More specifically, in the first step we implement both simple and categorical treatment matching as used by Marino et al. (2016), thanks to which we can compare not only between treated and non-treated but also different levels of treated. In the second step, we run a categorical treatment matching model, which aids with the conclusion on the appropriate treatment level.

4.4.1 Propensity Score Matching

The evaluation of technology policy has evolved rapidly over the years. However, the traditional problems of evaluations of such policies, which include endogeneity and sample selection (Afcha and García-Quevedo, 2016) remain. We believe that self-selection is not a threat to our study, as we assume plants are too difficult to be moved across the ACs and so if a given local governance introduces a tax rate - the firm is forced to pay it. The second problem, however, endogeneity comes from the fact that the variables used to measure these effects of public interventions can be endogenously determined if we assume that firms making a greater effort in case of existing environmental policy stringency.

Most recent studies use non-parametric matching techniques to ensure the maximum degree of similarity between control and treated groups. Matching techniques allow comparison of two potential results, Tax1 for those that were required to pay an environmental tax, T=1, and Tax0 for those firms that did not have to pay an environmental tax, T=0. Matching is based on the conditional independence assumption.

The data for the period 2008-2014 are treated as pooled data, thus observations for the same firms in different years are considered as independent observations. After describing variables with missing values, Propensity Score Matching as defined by (Rosenbaum and Rubin, 1983) is run, thus providing a sample of treated and control firms, matched on the set of variables.

We define the PSM as the condition probability of being treated, given a vector of covariates X:

$$p(X) = P(T = 1|X) = E(T|X) \tag{4.1}$$

where D is a dummy variables, indicating exposure to the treatment that takes values D=(0,1).

$$ATT = p(x)|T = 1E[Y(1)|T = 1, P(X)] - E[Y(0)|T = 0, P(X)] \tag{4.2}$$

where:
Y(1) represents the expected outcome for taxed firms
Y(0) represents the outcome for non-taxed firms

However, such a simplistic effect of environmental taxation, would not take into account the heterogeneous effects that may exist at different levels of environmental taxation, thus not informing us fully on the relationship between the policy instrument and firms' investment levels. In the next section, we will therefore implement categorical treatment matching to investigate environmental taxation further.

4.4.2 Categorical Treatment Matching

Research shows that environmnetal taxation should increase the level of investment into development of green technologies (Aghion et al., 2016). However, what is not quite clear is the recommended level of environmental taxation that should be implemented (Acemoglu, Akcigit, et al., 2016). Additionally, coupling information on whether or not the firm has paid environmental taxation with the exact amount it has paid opens a new perspective of the analysis based on categorical treatment matching.

The categorical treatment matching evaluates the expected treatment category firms may belong to given their pre-treatment characteristics. Estimations are based on the comparison of firms with similar scores but belonging to two different categories. In our study, we define these categories as terciles of the distribution of environmental taxation (low, medium, large). We expect terciles to provide us with an objective division of taxation expenditures paid by firms and therefore we assume it is not subject to any potentially misleading categorisation criteria (in our robustness checks we also look at the terciles of the distribution of the taxation per capita and we no longer match on size of the firm). In fact, we face the trade-off between the number of groups analysed with the observations available in each group. The bigger number of groups analysed given the available number of observations, the less efficiency of the estimates, ultimately risking the complete loss of feasibility due to the lack of a common support group.

As observed by Marino et al. (2016) the categorical treatment matching estimation method is very useful as it allows for comparisons not only between two categories of treated groups (e.g. small versus medium) but also between treated and untreated. Something that would not be possible in the continuous treatment/dose response case alone. Hence, categorical treatment matching aids in understanding whether the assessed average treatment effect masks substantial heterogeneity between different levels of taxation.

Similarly to Marino et al. (2016), we use the variables Y^0, Y^1, Y^2, Y^3 for 4 mutually exclusive treatment categories, where the 0 category is exclusively composed of untreated, the 1-,2- and 3-category are the small, medium and large environmental taxation level payers. We can observe only a realization of the potential outcome vector. The remaining ones being counterfactuals. Typically, to estimate different treatment effects, the unconfoundness and common support assumptions must be satisfied. On one hand, unconfoundeness assumption requires the treatment indicator to be independent of the realized outcomes, on the other hand, the common support makes sure we find the right match within the comparison group. This is done by computing the propensity scores.

Implementation of the categorical treatment matching consists of running the same number of logit estimations as the number of categorical effects we are interested in. Therefore, conditional on the pre-treatment firm level characteristics, it is possible to compute the treatment effects between different environmental tax category groups. Also, to ensure the highest quality of the matching, counterfactuals are selected by the caliper method set at 0.01, which is a border for which the matching is allowed. In our analysis, we use several different methods for controlling for quality of matching, the results hold for all of them.

We have also intended to perform a continuous treatment matching to arrive at an "optimal" level of taxation within our analysis. As pointed out by Bia, Mattei, et al. (2007) dose-response matching is considered natural in the context of the firm level analysis, since the treatment variable is naturally continuous rather than binary or categorical. Continuous treatment matching enables comparison of firms exposed to a specific level of investment and is generally quite attractive since it allows for smoothing of the treatment, which then, in turn, allows for improvement in the precision of the inference. The estimation strategy is based on weak unconfoundness assumption. Unfortunately, after attempting this analysis, which could have enriched our investigation even further, we have realized that our treatment variable environmental taxation is not normally distributed, which excludes it from the possibility of implementing the dose-response matching.

4.5 Results

This section presents results based on our simple and categorical matching evaluation schemes. Multiple treatment approach has been used since we believe the average treatment effect masks substantial heterogeneity across the taxation level groups. Eventually, we have decided on three main categories, and so we have divided our treatment into terciles of the distribution of our treatment variable: environmental taxation. Our decision was not dictated by any ex-ante knowledge. In contrast, we believe that separating the treatment variable into terciles is a rather objective rule.

4.5.1 Validity of the matching

The next important step is confirming the validity of the matching. The main goal is to determine, whether we can observe similarity in the joint distribution of covariates corresponding to the control and treated groups. To ensure that both groups are indeed properly balanced, we follow a common procedure of estimating the standardized bias, before and after the matching (Rosenbaum and Rubin, 1983). In our case, the main values for the variables of interest do not present significant differences between controls and treated groups for all three levels of environmental taxation. For all of our outcomes and treatments, the average bias is below the recommended level of 25%. Examples of some of the kernel density plots only for the lnEP outcome variable are presented in Figures 4.12, 4.13, 4.14 and 4.15.

4.5.2 Heterogeneous Impacts of Environmental Taxation

This section presents results based on our simple and categorical matching evaluation schemes. Table 4.7 summarizes the estimates obtained by means of simple and categorical treatment matching method for our outcome variables: log level of investment in cleaner production technology (lnCP) and end-of-pipe technology (lnEP). For all of those estimates, we report the average treatment effect on treated. The caliper is equal to 0.01 and standard errors are shown in parentheses. All standard errors are robust to firm heteroskedasticity.

The tables are constructed in a way that facilitates comparison of the effects between the categories. In columns we refer to companies, which did not pay environmental taxation (NT), paid small amounts of tax (ST) and medium amount of tax (MT), subsequently, we can see what happens if such firms are matched with generally having to pay the tax (T), having to pay small amounts of tax (ST), medium amounts (MT) and large amounts (LT), which are presented in rows. Consequently, for each effect we can match firms on observables and compare the effect. With regards to the most simple matching case, we can see a large and statistically significant effect of environmental taxation on adoption of energy efficient/cleaner production technologies presented in Table 4.7a (lnCP). On average, the set of tax firms invests approximately 338% more in cleaner production technologies than non-taxed firms. However, the moment that we split the levels of taxation, it turns out that environmental taxation at low levels (average of EUR 665 a year per firm) is ineffective at stimulating adoption of green innovation, as proven by statistically insignificant coefficient of the treatment effect between non-taxed (NT) and small-taxed (ST). Several other conclusions come into view. First, as we increase the level of taxation to around EUR 7,378 per year, the effect becomes positive and statistically significant. Showing that firms taxed at the middle level invest over 100% more in green technology, than those not subject to any environmental tax. Additionally, if we increase the tax even further, the effect more than doubles and remains statistically significant. What is more, there are large positive effects of increasing the tax rates of firms that already pay some kind of environmental taxation, proving that path dependency also exists in our sample of companies.

We can observe similar results for end-of-pipe technologies (pollution abating lnEP) presented in Table 4.7b. The effect of taxation in general is rather large and much more profound than in case of cleaner production technologies. Intuitively this makes sense since generally pollution abating technologies are considered inferior and much cheaper to cleaner production technologies. Therefore, as environmental taxation is introduced firms are more willing to invest in cheaper alternatives. The effect of environmental taxation follows the same pattern as for the previous outcome variable. Tax is not effective at low levels, however, as we increase the level of taxation the effect becomes quite large and statistically significant. However, it seems that if we increase the level of taxation once a firm is taxed in the case of end-of-pip technologies, we do not observe any increase in investment levels. Suggesting that once a firm has invested in filters or scrubbers, it does not need or is not willing to purchase any new eco-innovations.

4.5.3 The Policy-Mix: Environmental taxes and Public Financing

In the second step, we compare the effectiveness of environmental taxation versus public aid versus both policy instruments combined as presented in Table 4.8. As we can quickly observe, it is not always the case that the combination of environmental taxation with public financing always brings increased effectiveness. On the contrary, when we look at the effect of the policies, in general, we do not seem a synergic effect. However, once we look at low levels of environmental taxation - it seems clear that if the regulator decides to combine it with public aid, we do see increased effects for both green technologies. The situation looks a bit more complicated for medium and large levels. Once environmental taxation is sufficient enough, the additional support of public financing does not improve the investments levels as significantly, at some cases even decreasing the coefficient (as in the case of end-of-pipe technologies), which makes us conclude that combining large levels of taxation with public financing might be unnecessary, taxation alone seems to provide a sufficient incentive already.

4.5.4 Extensions: Specific Taxes, Specific Technologies

In the next section, we would like to see whether significant differences exist compared to the main results, when we consider more specific types of green investment such as cleaner production technologies aimed at air pollution (lnCPair) as well as cleaner production technologies aimed at reducing energy consumption alone (lnCPenc). The estimates of the categorical treatment matching ran on those two outcome variables are presented in Tables 4.9a and 4.9b. We can observe that for specific types of technologies which, we assume significantly reduce air pollution and energy consumption, even low environmental taxation is significantly increasing investment in those technologies, by more than 399% and 161%, respectively. Again, we are not surprised by this result this energy consumption reducing technologies can be considered quite advanced and expensive, at the same time both air-pollution taxes and other environmental taxes are the ones creating the highest expenditure for the companies, it, therefore, makes sense that when investigated separately even the small levels of taxation are successful at encouraging adoption of specific green technologies. This result might underline the underestimation of the effectiveness of the main results due to the aggregate approach of our analysis. Similarly to main results, however, the investment in green technologies still increases as we jump to higher levels of environmental taxation and we can also see evidence of path dependence as shown by positive statistically significant coefficients on the effects between different levels of taxation.

We have run a similar analysis on the end-of-pipe technologies reducing specifically air pollution, which we believe we could interpret as technologies such as filters and sulphur scrubbers, however, due to a small number of observations we could not balance the observations perfectly and our average bias was above the recommended 25% level, consequently, we have decided to exclude it from the analysis.

4.5.5 Robustness Checks

We carry out several robustness checks to examine the sensitiveness of our analysis. Firstly, we carry out categorical treatment matching using growth of investment in cleaner production ($growthCP = lnCP[t] - lnCP[t-1]$) as well as growth of investment in end-of-pipe technologies ($growthEP = lnEP[t] - lnEP[t-1]$) to control for time invariant firm characteristics. We believe those results could inform us on the true effect on the firms while controlling for firm fixed effects in our sample. We find that results generally hold, as the low levels of environmental taxation remain ineffective at inducing adoption of green technologies, while the medium level of taxation is the strongest, suggesting that while firms might invest in green technologies, they do not increase their levels from year to year, results in Tables 4.10a and 4.10b. Additionally, it appears that the effectiveness of policy-mix between environmental taxation and public aid on growth of CP and EP is increased also (see Table 4.11). In this case, for end-of-pipe technologies the effect is the largest for medium levels of environmental taxation with existing public financing, while to increase growth of cleaner production technologies, one needs only low levels of environmental taxation with available public financing (though other levels of taxation are successful as well). The robustness check of a specific type of technologies that is cleaner production technologies aimed at pollution reduction (Table 4.12a) and reducing energy consumption show statistically significant results, that however, we assume is related to the decrease in the number of observations while differencing the outcome variable (Table 4.12b). The coefficients, admittedly insignificant, are still mostly positive.

Secondly, We use also a modified treatment variable. Instead of using direct environmental taxation level, which is endogenous to many factors and match firms on their characteristics including the size dummies, we instead create a new variable called environmental taxation per capita ($env\_taxpc = env\_tax/size$). Consequently, we check the sensitivity of the results to the definition of the treatment variable, thus losing an important matching variable and therefore matching precision e.g. size. Descriptive Statistics of terciles of distribution of environmental tax per capita can be found in Table 4.13. We find that results are generally robust. For the outcomes in log terms, the effectiveness of environmental taxation increases with the level of taxation, the environmental taxation per capita is successful even at the low levels in case of lnCP. For the outcome variables in the growth rates, environmental taxation is successful at encouraging adoption of cleaner production technologies but not end-of-pipe technologies.

Also, we perform a robustness check using a variable related strongly to environmental innovation though not adopting the environmental technology in a given year: private environmental expenditure on research and development (lnRD). We find no positive or statistically significant effects of either environmental tax with or without the aid of public financing, see Tables 4.14a and 4.14b. This result suggests that while environmental taxation at current levels is inducing adoption of green solutions it does not encourage firms engaging in private environmental R&D.

Lastly, we have performed difference-in-difference analyses to investigate whether the implementation of specific regional taxes in specific years has affected firms' responsiveness in green investment. We have not found any evidence to support the claim. This might have been caused by the fact that taxes have been anticipated years before its implementation, making it easier for firms to adjust their investment more smoothly.

4.6 Conclusions

While there exists an understanding that environmental taxes should be more present to reduce industrial emissions and push green technology adaptation, the empirical evidence is scarce. Additionally, we are not aware of any paper studying the impact of policy-mix between an environmental tax and public financing on manufacturing. In this paper, we are trying to address those gaps.

This paper is aimed at evaluating the effectiveness of environmental taxes in Spain at different levels of taxation, in the absence and in combination with public finance - an equally important market-based instrument addressing the market failure of firms. The evaluation is performed with regards to whether the implementation of such an environmental policy instrument in Spain is successful at encouraging the adoption of green technologies among manufacturing firms. With that goal in mind, we use an extensive panel data set of 2562 firms between 2008 and 2014 and we perform both inter and intra group assessment of the outcome of the policy. Our results are robust to different measures of the outcome variable, different ways of defining our treatment variable as well as taking our outcome variable in first differences, which controls for time invariant firms characteristics.

Our results suggest that environmental taxation is generally effective at encouraging the adoption of both types of green technologies. That being said, once we split our treatment to different categories, we find that low levels of environmental taxation do not induce further investments in process eco-innovations (EUR 299 per year). Therefore, we show that the average treatment effect masks substantial heterogeneity across the taxation level groups. Results also consistently show that increasing the amount of tax increases also the subsequent adoption of green technologies. In the sample of fully supported environmental tax payers, it seems to emerge that firms that are required to pay around EUR 2,500 per year already exhibit significantly higher investment in green technology than under lower amounts of taxation.

Additionally, our findings seem to suggest that even low levels of environmental taxation (around EUR 665 per year) can be effective at inducing investment in green technology if combined with public financing. However, once again the effect is the largest when environmental taxation is at the medium level (EUR 7,378). That being said, if the regulator is reluctant to increase the taxation level in fear of hurting firms' competitiveness, even low levels of taxation can be effective in combination with public support. Large levels of environmental though very effective on its own, are not strongly encouraged with combination of public financing.

Overall findings seem to suggest a substantial re-design of modulation of environmental taxation. Although this result has shed some light on the heterogeneous effects of environmental taxation, it also asks for further research to investigate the policy-mix of environmental taxation with different specific types of public finance such as subsidies and investment tax incentives.

This overall assessment indicated that an evaluation of the targets of environmental taxation is desirable, if not necessary, should Spain want to follow European Commissions' advice to consolidate the national green taxes. The analysis is especially informative, because our sample is representative of the time of downturns and economic stagnation, given the financial crisis in place. If environmental taxation is seen as a valid policy instrument, public attention should inevitably be directed towards encouraging companies to invest in new energy efficient technologies especially, which will decrease their production costs substantially - while also preserving the environment. Lastly, it is clear that Spanish government makes only limited use of environmental taxation. Should they wish to implement such taxes at the national level, they could be very successful at both pushing industry towards green technology adaptation and collecting significant revenues, which could later be recycled by transferring it to environmental funds or simply redistributed back to firms in form of subsidies for green investment as suggested by Böhringer, Garcia-Muros, and González-Eguino (2019).

We admit that our study suffers from several limitations. Admittedly, due to data restrictions, the first and the most important limitation is the lack of regional location of each firm, making it impossible to locate which region each firm belongs to, and therefore which taxes are the firms required to pay and at what rate; this information would also help to control for all the time invariant regional characteristics. Additionally, the information on location would allow us to verify whether firms respond with location choice decisions through entries and exists as a response to environmental taxes. Here, however, we claim that the previous literature supports our assumption that while tax policy affects employment outcomes, it does not affect strongly the location decisions (Holmes, 1998; Rathelot and Sillard, 2008; Duranton, Gobillon, and Overman, 2011). Lastly, the merger with other databases, if would have been allowed, would enrich our dataset with additional firm characteristics, which would then result in a more satisfactory matching.

With regards to further research, firstly, it would be interesting to investigate if and how did the specific environmental taxes affect employment outcomes, more specifically the firms' size, number of employees dedicated to environmental protection and wages. Did the firms hire additional green workers, did they reduce their regular staff, and hence did the environmental taxes affect Spanish competitiveness in manufacturing? It would also be beneficial to investigate, whether indeed the firms, did not respond to environmental taxation introduction with altering plant location. Those questions remain a platform for further research.

4.7 Figures and Tables

Figure 4.1: Regions of Spain with taxes directed at air-pollution. Source: self-made based on data from Ministry of Environment.

Figure 4.2: Regions of Spain with any environmental taxes. Source: self-made based on data from Ministry of Environment

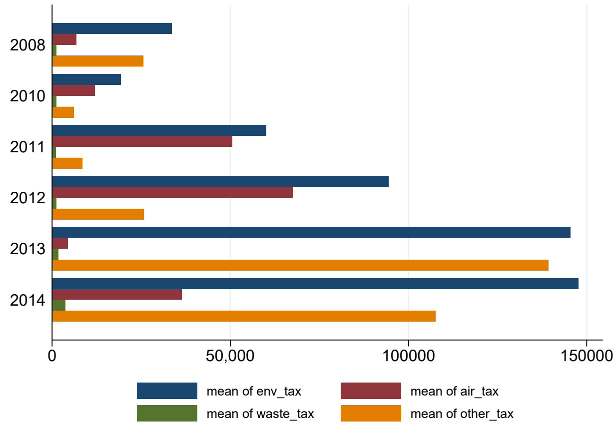


Figure 4.3: Yearly average environmental taxes: aggregated, air-pollution, waste and others.

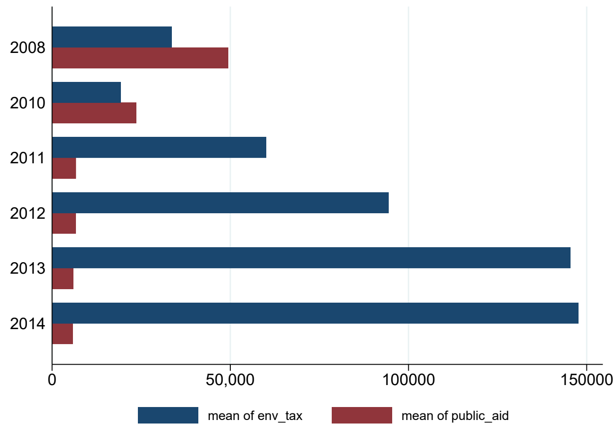


Figure 4.4: Yearly average aggregated environmental taxes and public financing.

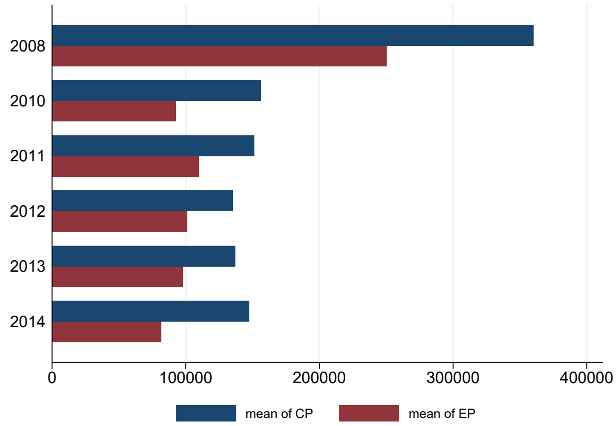


Figure 4.5: Yearly average aggregated investments in CP and EP technologies.

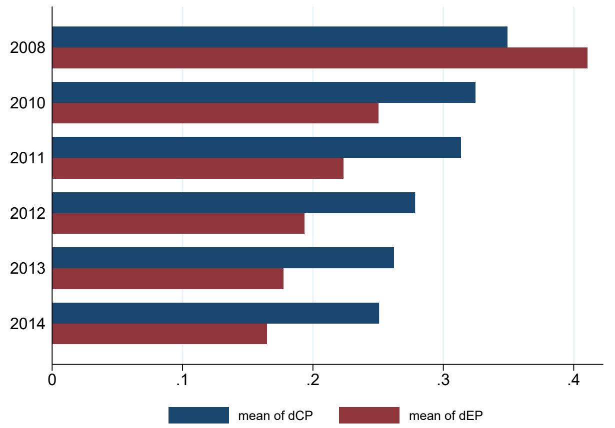


Figure 4.6: Yearly average percentage of firms investing in green technology adoption, both CP and EP.

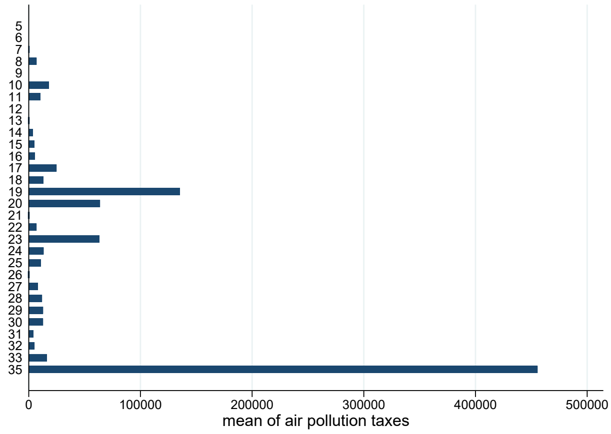


Figure 4.7: Sectoral distribution of mean of environmental taxes in our time frame 2008-2014.

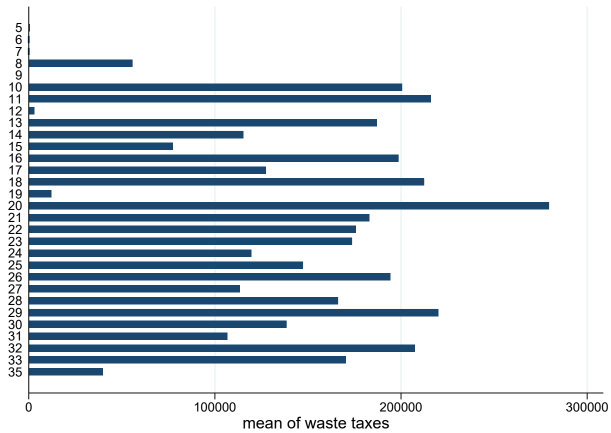


Figure 4.8: Sectoral distribution of waste taxes in our time frame 2008-2014

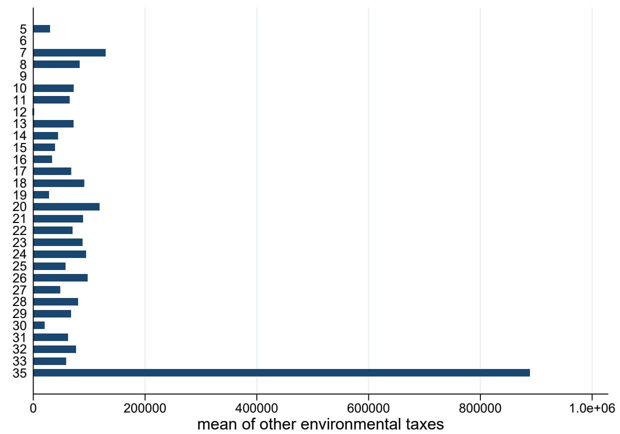


Figure 4.9: Sectoral distribution of other environmental taxes in our time frame 2008-2014.

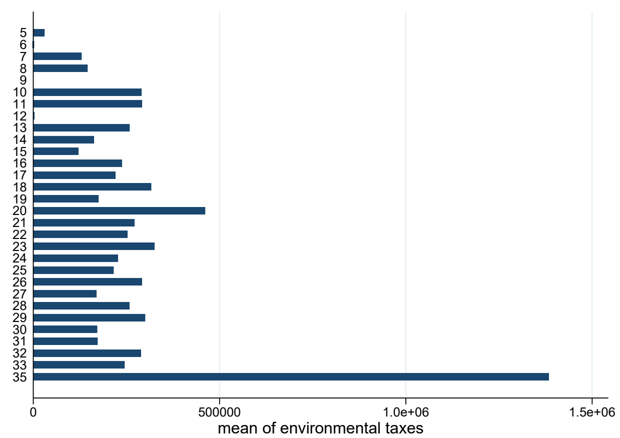


Figure 4.10: Sectoral distribution of aggregated environmental taxes in our time frame 2008-2014.

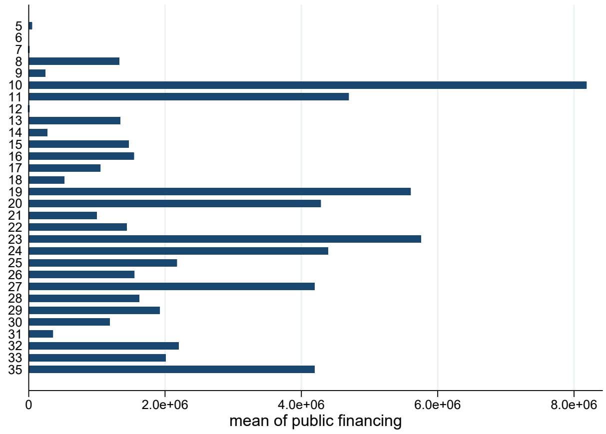


Figure 4.11: Sectoral distribution of aggregated public financing in our time frame 2008-2014.

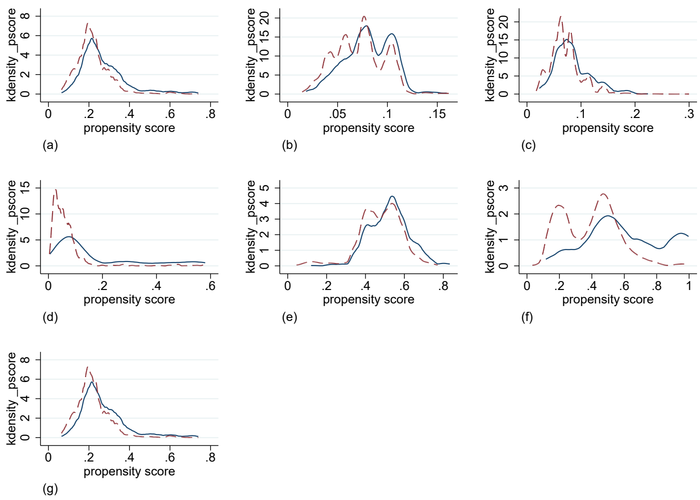


Figure 4.12: Kernel density plots for treated and control groups. Outcome: investment in lnEP. Treatment: environmental tax alone. Treated groups are denoted with a blue solid line, while the control groups are denoted with red dotted line. Caliper at 0.01. The graphs (a) to (g) correspond to pairwise relationships between treated and not treated, small dose and control, medium dose and control, large dose and control, medium dose and small dose, large dose and small dose, and large dose and medium dose, respectively.

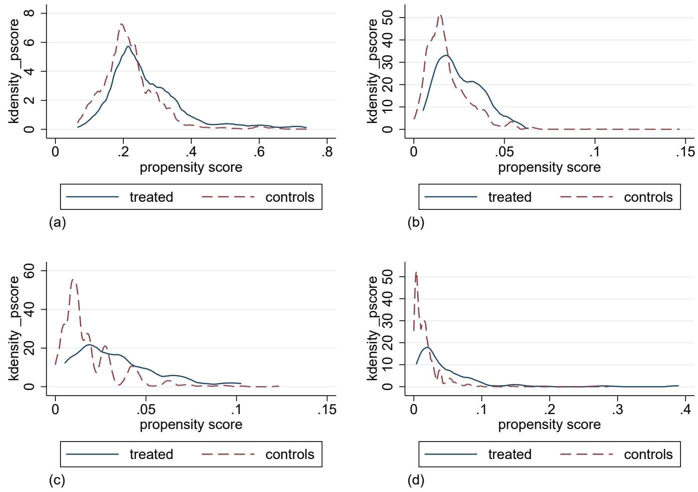


Figure 4.13: Kernel density plots for treated and control groups. Outcome: investment in lnEP. Treatment: public financing alone. Treated groups are denoted with a blue solid line, while the control groups are denoted with red dotted line. Caliper at 0.01. The graphs (a) to (d) correspond to pairwise relationships between treated and not treated, small dose and control, medium dose and control, and large dose and control, respectively.

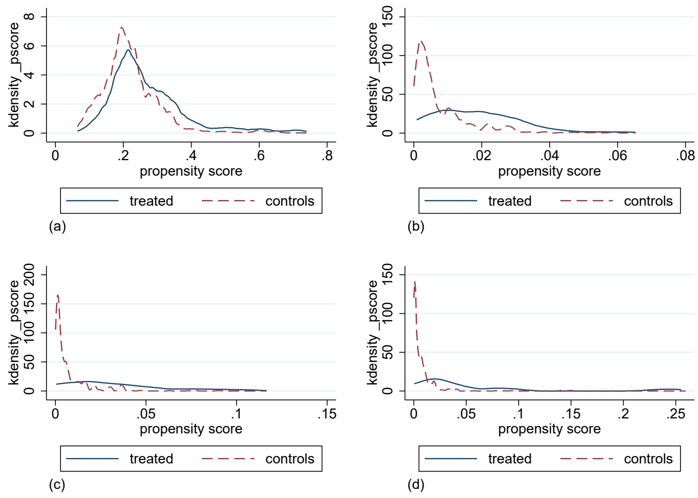


Figure 4.14: Kernel density plots for treated and control groups. Outcome: investment in lnEP. Treatment: both policy instruments. Treated groups are denoted with a blue solid line, while the control groups are denoted with red dotted line. Caliper at 0.01. The graphs (a) to (d) correspond to pairwise relationships between treated and not treated, small dose and control, medium dose and control, and large dose and control, respectively.

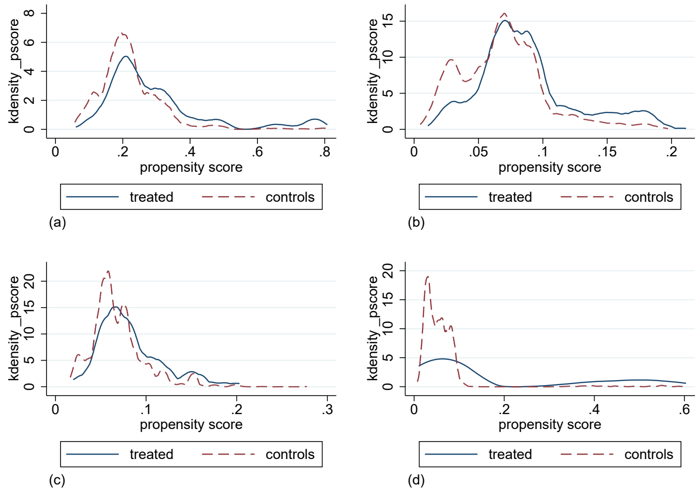


Figure 4.15: Kernel density plots for treated and control groups. Outcome: investment in lnEP. Treatment: environmental tax per capita. Treated groups are denoted with a blue solid line, while the control groups are denoted with red dotted line. Caliper at 0.01. The graphs (a) to (d) correspond to pairwise relationships between treated and not treated, small dose and control, medium dose and control, and large dose and control, respectively.

Table 4.1: Dates of introduction of environmental taxes across Autonomous Communities.

ACs	**Air tax**	**Waste tax**	**Other env. tax**
Andalusia	2003	2005	
Catalonia	2014		
Madrid		2003	
Valencia	2012		2012
Galicia	1995		
Castile and Leon			2012
Basque Country			
Castilla-La Mancha	2000		
Canary Islands			
Murcia	2005	2005	
Aragon	2005		
Extremadura			1997
Bealearic Islands			
Asturias			2011
Navarra			
Cantabria		2009	
La Rioja			2012

Note: Environmental taxes that apply to industrial sectors. Dates refer to the year of approval of the referent laws. Source: OECD (2015) and Gago, Labandeira, Labeaga, et al. (2019)

Table 4.2: Sectors within our sample.

NACE code	Name
5	Mining of coal and lignite
6	Extraction of crude petroleum and natural gas
7	Mining of metal ores
8	Other mining and quarrying
9	Mining support service activities
10	Manufacture of food products
11	Manufacture of beverages
12	Manufacture of tobacco products
13	Manufacture of textiles
14	Manufacture of wearing apparel
15	Manufacture of leather and related products
16	Manufacture of wood and of products of wood and cork
17	Manufacture of paper and paper products
18	Printing and reproduction of recorded media
19	Manufacture of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c.
29	Manufacture of motor vehicles, trailers and semi-trailers
30	Manufacture of other transport equipment
31	Manufacture of furniture
32	Other manufacturing
33	Repair and installation of machinery and equipment
35	Electricity, gas, steam and air-conditioning supply

Note: All firms belong to one of those sectors. Source: European Commission, date accessed: 12.05.2020, https://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Table 4.3: Descriptive Statistics: Firms under environmental taxation, public aid, both instruments and none.

	Environmental Tax			*Just Public Aid*			*Both Policies*			*None*		
Variable	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*
Treatment Variable:												
Environmental Taxation	460506	5078692	1983	0	0	499	353489	3365070	213	0	0	8788
Public Aid	0	0	1983	188852	849631	499	374224	1815563	213	0	0	8788
Outcome Variables:												
CP	348815	2084006	1983	503504	2107823	499	1470506	3933342	213	85567	781029	8788
lnCP	-0.401	8,873	1983	5.279	9.205	499	8.167	8.654	213	-2.483	7.731	8788
EP	223943	1459807	1983	341587	2719085	499	617954	1579861	213	68423	655116	8788
lnEP	-1.469	8.391	1983	1.769	9.240	499	4.151	9.617	213	-3.558	6.943	8788
RD	3648	40428	1983	7231	49534	499	33445	185593	213	3072	53018	8788
lnRD	-5.978	3.764	1983	-5.538	4.678	499	-4.934	5.717	213	-6.270	3.163	8788
Pre-Treatment Variables												8788
lagCP	217238	1617921	1983	399123	2231087	499	531029	2391459	213	143120	1118740	8788
lagEP	168799	1136151	1983	185622	1388359	499	193891	803230	213	99627	990029	8788
lagGRexp	118151	313181	1983	109143	249221	499	148619	412704	213	79088	22642	8788
Size 1 (10 - 49)	0.04	0.20	1983	0.01	0.10	499	0.01	0.12	213	0.04	0.18	8788
Size 2 (50 - 99)	0.09	0.29	1983	0.09	0.28	499	0.05	0.21	213	0.15	0.36	8788
Size 3 (100 - 299)	0.57	0.50	1983	0.54	0.50	499	0.46	0.50	213	0.59	0.49	8788
Size 4 (300 - 499)	0.15	0.36	1983	0.18	0.39	499	0.26	0.44	213	0.13	0.33	8788
Size 5 (>500)	0.13	0.34	1983	0.17	0.38	499	0.19	0.40	213	0.09	0.28	8788

Table 4.4: Descriptive Statistics: Terciles of Environmental Taxation

	1st Tercile			*2nd Tercile*			*3rd Tercile*		
Variable	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*
Treatment Variable:									
Environmental Taxation	299	223	661	2500	1437	661	1378718	8728740	661
Public Aid	0	0	661	0	0	661	0	0	661
Outcome Variables:									
CP	40787	225340	661	96978	490529	661	908680	3504075	661
lnCP	-2.785	7.451	661	-0.960	8.478	661	2.540	9.714	661
EP	39602	298025	661	104894	1375362	661	527333	2068506	661
lnEP	-3.458	6.937	661	-2.015	7.867	661	1.065	9.526	661
RD	1540	17030	661	1479	13130	661	7926	66470	661
lnRD	-6.087	3.499	661	-5.994	3.635	661	-5.855	4.129	661
Pre-Treatment Variables									
lagCP	72812	414193	661	80788	461279	661	498115	2712573	661
lagEP	37906	249625	661	79886	711224	661	388606	1798558	661
lagGRexp	73645	178977	661	70416	119322	661	210393	485270	661
Size 1 (10 - 49)	0.05	0.23	661	0.02	0.13	661	0.06	0.23	661
Size 2 (50 - 99)	0.09	0.28	661	0.08	0.28	661	0.10	0.30	661
Size 3 (100 - 299)	0.64	0.48	661	0.60	0.49	661	0.46	0.50	661
Size 4 (300 - 499)	0.13	0.33	661	0.17	0.37	661	0.16	0.37	661
Size 5 (>500)	0.08	0.27	661	0.12	0.33	661	0.20	0.40	661

Table 4.5: Descriptive Statistics: Terciles of firms under both policy instruments: environmental taxation and public aid.

	1st Tercile			*2nd Tercile*			*3rd Tercile*		
Variable	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*
Treatment Variable:									
Environmental Taxation	665	554	71	7378	5706	71	1052424	5792351	71
Public Aid	102082	187274	71	257007	541771	71	763582	3067830	71
Outcome Variables:									
CP	277890	513274	71	935291	1714438	71	3198336	6236310	71
lnCP	6.713	8.662	71	7.541	8.965	71	10.249	8.029	71
EP	208204	549070	71	491544	1755060	71	1154115	1923386	71
lnEP	1.704	9.404	71	4.261	9.214	71	6.490	9.755	71
RD	32652	226335	71	317	2108	71	67367	225402	71
lnRD	-4.887	5.735	71	-6.261	3.111	71	-3.655	7.277	71
Pre-Treatment Variables									
lagCP	108960	395496	71	243054	765629	71	1241074	3975155	71
lagEP	78024	277670	71	124159	859928	71	379496	1041107	71
lagGRexp	69816	67363	71	97145	129752	71	278897	684299	71
Size 1 (10 - 49)	0.01	0.11	71	0.01	0.11	71	0.01	0.11	71
Size 2 (50 - 99)	0.03	0.17	71	0.06	0.23	71	0.06	0.23	71
Size 3 (100 - 299)	0.52	0.44	71	0.30	0.50	71	0.23	0.42	71
Size 4 (300 - 499)	0.25	0.43	71	0.29	0.46	71	0.23	0.42	71
Size 5 (>500)	0.18	0.39	71	0.14	0.35	71	0.25	0.44	71

Table 4.6: Descriptive Statistics: Environmental Taxation per capita. Robustness Check.

	Environmental Taxation per capita			*1st Tercile*			*2nd Tercile*			*3rd Tercile*		
Variable	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*	*Mean*	*St. dev*	*N*
Treatment Variable:												
Environmental Taxation	445672	4996849	2049	542	1172	659	3286	5916	658	1348391	8742766	658
Public Aid	0	0	2049	0	0	659	0	0	658	0	0	658
Outcome Variables:												
CP	371859	2158645	2049	79862	423654	659	122648	657478	658	836172	3475914	658
lnCP	-0.263	8.932	2049	-2.265	7.858	659	-1.033	8.465	658	2.027	9.624	658
EP	237440	1475100	2049	112865	1401125	659	71368	364406	658	485336	2053550	658
lnEP	-1.272	8.506	2049	-3.051	7.277	659	-2.163	7.866	658	0.728	9.384	658
RD	3863	41944	2049	1673	17141	659	2167	20459	658	7039	64749	658
lnRD	-5.9297	3.856	2049	-5.983	3.713	659	-5.936	3.765	658	-6.033	3.779	658
Pre-Treatment Variables												
lagCP	246796	1729986	2049	74441	413868	659	83097	464838	658	492001	2717242	658
lagEP	183381	1139028	2049	37655	243098	659	88095	853370	658	376401	1737961	658
lagGRexp	118247	310148	2049	73652	170000	659	80178	180248	658	200989	473328	658

Table 4.7: Main Results: The effect of environmental taxes on the outcome variables.

(a) Outcome Variable: lnCP

	NT	ST	MT
T	3.380***		
	(0.877)		
ST	-0.168		
	(0.287)		
MT	1.044***	3.743***	
	(0.331)	(0.985)	
LT	2.662***	4.477***	5.704***
	(0.434)	(0.925)	(0.851)

(b) Outcome Variable: lnEP

	NT	ST	MT
T	5.920***		
	(0.518)		
ST	0.396		
	(0.262)		
MT	1.319***	0.653	
	(0.308)	(0.991)	
LT	1.628***	1.537	0.877
	(0.386)	(1.015)	(1.165)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

Table 4.8: Comparison of the effectiveness of public aid, environmental taxes alone as well as environmental taxes given that the firm has received public aid (outcome variables: lnCP & lnEP)

	Just Environmental Tax		*Just Public Aid*		*Both*	
	lnCP	*lnEP*	*lnCP*	*lnEP*	*lnCP*	*lnEP*
T	3.380***	5.920***	7.739***	2.591***	7.006***	2.650***
	(0.877)	(0.518)	(0.541)	(0.835)	(0.451)	(0.765)
S	-0.168	0.396	9.065***	2.230*	13.620***	4.383***
	(0.287)	(0.262)	(0.751)	(1.230)	(1.028)	(1.593)
M	1.044***	1.319***	12.625***	5.894***	13.910***	7.318***
	(0.331)	(0.308)	(0.757)	(1.223)	(1.238)	(1.660)
L	2.662***	1.628***	13.542***	5.656***	15.098***	4.923***
	(0.434)	(0.286)	(0.921)	(1.330)	(1.286)	(1.818)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level. There are 1,983 observations of firms under environmental tax alone, 499 observations of firms under the public financing alone, 213 observations of firms under both policy regimes, and 8,878 observations of firms that have not been affected by environmental policy instruments.

Table 4.9: Extensions: The effect of specific environmental taxes on specific green investments.

(a) Outcome Variable: lnCPair, treatment: air pollution tax

	NT	ST	MT
T	6.200*** (0.473)		
ST	3.991*** (0.687)		
MT	4.201*** (0.867)	0.652 (1.528)	
LT	7.190*** (1.256)	4.790** (2.111)	1.318 (2.067)

(b) Outcome Variable: lnCPenc, treatment: other environmental tax

	NT	ST	MT
T	3.544*** (0.328)		
ST	1.616*** (0.356)		
MT	2.139*** (0.404)	1.710*** (0.582)	
LT	2.747*** (0.515)	2.672*** (0.646)	2.027** (0.951)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors are shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

Table 4.10: Robustness Checks: The effect of environmental tax on outcome variables in first differences.

(a) Outcome Variable: growthCP

	NT	ST	MT
T	0.217*** (0.308)		
ST	-0.358 (0.424)		
MT	1.195*** (0.451)	3.142*** (1.309)	
LT	0.732 (0.560)	0.143 (1.386)	3.299** (1.374)

(b) Outcome Variable: growthEP

	NT	ST	MT
T	1.109*** (0.281)		
ST	0.327 (0.379)		
MT	1.992*** (0.406)	0.930 (1.231)	
LT	1.546*** (0.509)	0.046 (1.327)	1.010 (1.566)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors are shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

Table 4.11: Robustness: Outcome variables growthCP, growthEP, treatment: both environmental tax and public aid

	growthCP	*growthEP*
T	10.853***	4.164***
	(1.264)	(1.489)
ST	11.179***	0.836
	(1.699)	(2.042)
MT	11.074***	7.594***
	(1.926)	(2.217)
LT	10.255***	3.594*
	(1.869)	(2.171)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

Table 4.12: Robustness: The effect of specific taxes on the outcome variables in first differences.

(a) Outcome Variable: growthCPair, treatment: air pollution tax

	NT	*ST*	*MT*
T	0.608		
	(0.407)		
ST	0.624		
	(0.685)		
MT	-0.061	-0.453	
	(0.900)	(1.480)	
LT	0.189	0.045	-1.650
	(0.850)	(1.707)	(1.945)

(b) Outcome Variable: growthCPenc, treatment: other environmental tax

	NT	*ST*	*MT*
T	0.279		
	(0.450)		
ST	0.196		
	(0.349)		
MT	0.130	0.120	
	(0.536)	(0.660)	
LT	0.230	1.300	1.324
	(0.601)	(0.953)	(0.860)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors are shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

Table 4.13: Robustness Check: Outcome variables: lnCP, growthCP, lnEP, growthEP, Treatment: environmental taxation per capita alone

	lnCP	*growthCP*	*lnEP*	*growthEP*
T	7.319***	5.032***	2.202**	1.491
	(0.563)	(0.922)	(0.835)	(1.024)
ST	4.599***	2.715**	1.571	0.917
	(1.781)	(1.067)	(0.921)	(1.302)
MT	5.768***	4.624***	1.809**	1.903
	(0.436)	(1.061)	(0.915)	(1.233)
LT	7.459***	4.483***	1.632*	0.708
	(0.673)	(1.059)	(0.927)	(1.164)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

Table 4.14: Robustness Checks: The effect on private environmental R&D

(a) Treatment: environmental tax alone

	NT	*ST*	*MT*
T	-0.01		
	(0.425)		
ST	0.232		
	(0.141)		
MT	0.107	0.015	
	(0.147)	(0.542)	
LT	0.285	0.176	0.075
	(0.275)	(0.558)	(0.483)

(b) Treatment: both policy instruments

	NT
T	-0.209
	(0.413)
ST	0.281
	(0.972)
MT	-1.067
	(0.853)
LT	0.395
	(1.297)

Note: We hereby report the average treatment effect on treated. The caliper is equal to 0.01. Standard errors shown in parentheses. All standard errors are robust to firm heteroskedasticity. *** denotes significance at the 99% level, ** denotes significance at the 95% level and * denotes significant at the 90% level.

5 Environmental investment tax incentives. How do firms respond?

5.1 Introduction

Environmental investment tax incentives are not a very popular policy instruments, even though it may offer an interesting alternative to environmental taxation, which despite its cost-effectiveness and efficiency, is still fiercely fought with by the industry. Firms commonly fear to lose their revenues and the media coverage supports that image by publishing dramatic titles [1]. However, in the absence of any form of environmental pressure, firms are reluctant to invest in green technology, blaming high fixed costs and the resulting capital market failure. Could environmental investment tax incentives be successful at encouraging green investment? How effective are such tax credits on the adoption of green technology?

Tax incentives despite being existent in the public policy reforms for years are not very well researched. Providing tax relief for different purposes is a common practice within the European Union and other developed countries to improve economic outcomes and incentivise firms to increase their investment level. However, until now there was no evidence of tax incentives causal effect on environmental investment.

While it is true that Hall and Jorgenson (1967) began a large liter-

[1] The Guardian (2017) "The proper carbon tax would wipe out billions in polluters profits", accessed on 12.02.2019, https://www.theguardian.com/environment/2017/sep/04/emissions-carbon-tax-profits-polluters-paris-targets

ature on the effect of tax incentives on firm investment there indeed exists a consensus that fiscal incentives do increase investment as shown by the empirical research using surveys by Hassett and Hubbard (2002) and more recently, by Ohrn (2019) or Zwick and Mahon (2017). However, within the innovation literature scholars have focused mainly on the responsiveness and the effects of R&D tax incentives on the level of R&D (Bloom, Griffith, and Van Reenen, 2002; Rao, 2016; Thomson, 2017; Marino et al., 2016) and innovation outcomes (e.g. level of patenting) (Dechezleprêtre, Einiö, et al., 2016; Howell, 2017) rather than firms' adoption of environmentally friendly innovation.

This paper investigates the effect of one particular environmental investment fiscal incentive – EI tax credit – and determines its impact on both firm green investment and employment. To understand the influence on employment in detail, I distinguish between a firm's general employment and employees dedicated to environmental protection activities within the firm alone. The analysis is done using comprehensive firm level data, allowing us to control for firm fixed effects. The central outcome of interest for a policy such as EI tax incentives are the resulting investments in green technologies. The only sources of data for environmental protection expenditures of firms are confidential usually annual firm level surveys maintained by the statistical agencies. Access to these is highly restricted, which also explains why studies of this kind are not common if existent at all. This paper uses administrative panel data of 2,567 Spanish manufacturing firms to shed more light on the issue. Because of the nature of EI tax credits, there is also considerable concern regarding its impact on the innovativeness of firms itself (private environmental R&D) - fearing that it takes away the funds from the firms' innovativeness abilities - as well as its economic outcomes - among them employment. Our dataset provides one of the most reliable sources for this kind of information and we explore these outcomes as well.

I study a large-scale national tax incentive program in Spain, which started in 1996 and finished in 2015. Due to data availability, I focus on the 2008-2014 time window. For identification, I use two strategies.

Firstly, I exploit the policy change that happened in March of 2011, when after a planned phase-out of the Environmental Investment (EI) tax credit in January of 2011, the government has decided to suddenly bring it back to benefit the private sector for a few more years. However, it changed the conditions through which the tax incentive was incentivising investments in technologies that are energy efficient rather than solely pollution abating. I implement, therefore, a difference-in-difference design comparing firms that did receive the tax credit before and after the policy change. Secondly, I use an Instrumental Variable (IV) approach to take advantage of the fact that I have a continuous treatment variable available. The IV used is the amount of tax credit received by the firms in 2008 in combination with the difference-in-difference approach. And so in the first stage, I study the effect of the policy change in the combination of receiving a certain amount of tax credit in 2008 on the amount received in the post-policy change period. In the second stage, I study the effect of the tax credit on green investment and employment.

The results suggest that the policy change that happened in 2011, resulted in decreased levels of green investment, despite the higher tax credit rate implemented. One, due to the stricter requirements of the tax credit itself - firms were finding it much more difficult to finance their pollution abating investments. Two, due to the unexpected re-introduction, much confusion within the regulation setting, and possibly budgeting adjustment period. We see no evidence of the effect of the policy change on the employment and private environmental R&D. With regards to the overall assessment of the EI tax credits, in the second part of the analysis, it becomes apparent that EI tax incentives did increase investments in different types of green technologies. It was particularly successful at encouraging adoption of technologies reducing air pollution both at the end of the production pipe and through the production process. The tax incentives program has had also indirect positive effects on employment and private environmental R&D.

To verify that these results are not driven by the research design or its implementation, I consider various robustness checks. First, for the first part of the analysis, while plotting the raw data and estimating the effect year by year, there is overall no differential pre-treatment behaviour of treated compared to untreated establishments. Second, all regressions include industry and year fixed effects, some of them also firm fixed effects that control for time, sector and firm level shocks. Third, the results are robust to different time frame (2011-2014) and across different measures of our variables of interest. Fourth, I carry out several estimations using alternative treatments such as the implementation of various regional environmental taxes, to make sure they did not affect investment in that period. Fifth, I also combine difference-in-difference analysis with propensity score matching, to match firms on the pre-treatment observable characteristics. With regards to the second part of the analysis, I provide coefficients for a different instrumental variable used, and I perform analysis within the 2010-2014 time window. The results generally hold.

With these results, I contribute to several strands of the literature: the literature on the environmental economics, corporate tax incidence literature and the literature on the evaluation of place-based policies. There is a long-lasting interest in estimating the responsiveness of firms to changes in existing policies. To the best of my knowledge, this is the first study that empirically analyses the direct environmental investment incentive program. This is beneficial since the prior policy discussions mostly relied on theoretical arguments and descriptive evidence, which argued that the program was inefficient (OECD, 2010). Given the pressure from the European Commission to eliminate environmental investment tax credits in Spain completely, it is worth pointing out to certain changes that Spain could make within the fiscal policy and still encourage green investment. One important concern was that the use of subsidies for investment projects that would have been done anyway. My results show that indeed for end-of-pipe technologies, that might have been the case. However, it seems the EI tax incentive in place was also quite successful at financing cleaner production technologies, especially those at reducing energy consumption and air pollution.

The paper is structured as follows. Section 5.2 presents literature review. Section 5.3 explains the Spanish institutional setting of Environmental Investment tax credits. Sections 4.4 and 5.5 present the data and methodologies used, while Section 5.6 discusses the results. Section 5.7 concludes and presents policy recommendations.

5.2 Literature Review

Surprisingly, the empirical literature concerned with firms' responsiveness to changes in environmental investment tax incentives is, to our knowledge, non-existent. Indeed, there is a consensus that fiscal incentives increase investment (Zwick and Mahon, 2017) but within the innovation literature (not even environmental innovation) scholars have focused on the responsiveness and the effects of R&D tax incentives on the level of R&D (Bloom, Griffith, and Van Reenen, 2002; Rao, 2016; Thomson, 2017; Busom, Corchuelo, and Martínez-Ros, 2014) and innovation outcomes e.g. level of patenting (Dechezleprêtre, Einiö, et al., 2016; Howell, 2017) rather than firms' adoption of innovation.

Even the literature studying the effectiveness of environmental investment tax incentives is quite scarce. Encouraging adoptions of green technologies can be done indirectly through introduction of environmental taxes (Pigou, 1920; Aghion et al., 2016) or directly through the provision of subsidies or tax credits on environmental protection investments. The latter ones hopefully address the capital market failure firms can be faced with and would result in newer greener solutions to environmental challenges. Environmental investment tax credits specifically, in theory, lower the after-tax costs of innovation both from capital and labour perspective by providing a tax deduction for all eligible environmental protection investments. It thereby reduces the costs of undertaking innovation and diminishes the barrier to innovate by providing an incentive (Meyer, Prakken, and Varvares, 1993).

The empirical evidence on the effect of production tax credit (Roach, 2015), renewable energy subsidies (Murray et al., 2014) and energy infrastructure subsidies (Metcalf, 2010) are far from reaching an agreement, not only in industry setting but also residential context (Walsh, 1989; Germeshausen and von Graevenitz, 2019). In fact, while the paper by Metcalf (2010) emphasized the crucial role that the production tax credit had played for wind energy investment in the US, the results of Roach (2015) are less optimistic, concluding that the production tax credit for wind was much more successful in the deregulated rather than in the regulated electricity markets. Alarmingly also, Murray et al. (2014) estimated that over $10 billion spent in tax incentives (production tax credit and investment tax credit on renewable energy and use of biofuels) had a small impact on the reduction of greenhouse gases and have ultimately led to an increase of emissions in some cases. There exists also one paper on the effectiveness of environmental investment tax incentive on levels of investment and coal consumption (Mao and Wang, 2016). To this aim, authors use an identification strategy by Greenstone (2002) on the panel data set of universe of Chinese firms between 2007-2011. Their results show that tax incentive does not seem to be popular, as the mechanisms hurt interests of firms, however, it does seem to protect the environment by limiting coal consumption - yet only among firms connected to the central government. Lastly, according to Sánchez (2007), tax incentives typically entail less administrative costs than subsidies for both public administration as well as the firms themselves. Additionally, tax credits, in theory, distort the market the least, as its the companies that decide whether to use such tax deduction (it is also automatically granted if the application qualifies), rather than the state deciding which projects to subsidise. That being said the literature on the effectiveness very often suffers from self-selection problems - certain firms' natural willingness to apply for investment tax credits is not easily measured and so the papers do not effectively assess the causality of specific reforms. Papers using quasi-experimental analysis in the context of green investment are to my knowledge non-existent.

Another fear that also exists is concerned with the fact that even if tax credits do increase investment, the eligibility for the tax deduction is usually limited to known technologies and hence it decreases the use of private information that the environmental taxes take advantage of. Additionally, as tax deductions are not uniformly applied, they are usually sought by companies that would be interested in innovating anyway, and since they are funded from the public capital, tax deductions are criticized for being wasted on companies that do not need additional incentives to innovate. Indeed, literature has spent a lot of time and effort trying to evaluate innovation fiscal policies such as R&D tax credits and still cannot agree on whether there is evidence of input additionality or crowding out (Marino et al., 2016).

That being said, as we have pointed out before there exist a few articles studying the causal effects of R&D tax incentives and subsidies on R&D investment (Bloom, Griffith, and Van Reenen, 2002), and patenting activity of firms (Dechezleprêtre, Einiö, et al., 2016; Howell, 2017) using the quasi-experimental approach. More specifically, Dechezleprêtre, Einiö, et al. (2016), for example, uses RDD approach and the asset-based size threshold for eligibility of R&D tax subsidies to study the effect on patenting activities of British firms. They find a remarkable result showing that the business R&D would be 10% lower in the absence of the tax relief scheme. Howell (2017), on the other hand, investigates R&D grants on patenting and commercialization - also using RDD. She finds that the effects are stronger for more financially constrained firms - hence, showing that R&D grants seem to address capital market failure. They also point out to the fact that certification, where the award contains information about firm quality, likely does not explain the grant effect on funding. Instead, the grants seem to reduce investor uncertainty by funding technology prototyping.

Focusing on firms' behavioural responses to fiscal incentives, Zwick and Mahon (2017) estimate the effect of temporary tax incentives on equipment investment using shifts in accelerated depreciation. They find that the incentive worked increasing the investment even up to 16.9 percent, though small firms responded 95 percent more than big firms. Second, firms respond strongly when the policy generates immediate cash flows. To that aim, they use a big panel data and analyse it using difference-in-difference analysis. Ohrn (2019) using a modified difference-in-difference model finds out that even small incentives that marginally decrease present value investment costs have large impacts. Lerche (2019) also studies the effects on tax incentives and investment and employment. His results based on the German data are in agreement with both Zwick and Mahon (2017) and Ohrn (2019). Neicu, Teirlinck, and Kelchtermans (2016), on the other hand, study behavioural additionality effects to wage-based R&D with and without R&D subsidies. They find that find that initiate additional R&D projects and tip the R&D - balance more towards research relative to development. This might point out to the fact that tax credits push firms' towards activities characterized by the most severe market failures. However, to our knowledge, there are no papers on behavioural responses of firms regarding firms' adjustment behaviour to a new policy and the decay/enhancement of their budget adjustment over time.

Lastly, we cannot forget about increasing literature on environmental policies using the quasi-experimental approach (Calel and Dechezlepretre, 2016; Wagner et al., 2014; Martin, De Preux, and Wagner, 2014). More specifically, Calel and Dechezlepretre (2016) as well as Wagner et al. (2014) use difference-in-difference in combination with matching to study the causal effect of EU ETS.

Having this in mind, the following paper plans to fill the gap in the literature on the firms' responsiveness to tax-incentive policy changes using quasi-experimental approach. Following Ohrn (2019), Howell (2017), and Zwick and Mahon (2017) I use difference-in-difference estimator as adopted by the Wagner et al. (2014) and Calel and Dechezlepretre (2016) to study the policy change introduced in Spain in March of 2011.

In the second stage, through an instrumental variable approach, we estimate the effect on green investment as a result of a 1% increase in a tax credit, identifying the local average treatment effect. To measure the effect of tax credits on investment and employment outcomes, researchers are faced with a challenge of finding an exogenous measure of tax incentive that would present sufficient variation in favour of robust identification, such as exogenous variation in eligibility used to instrument for tax rate by Martin, De Preux, and Wagner (2014). This paper takes a new approach based on exploiting randomness of receiving a tax credit in a certain amount in 2008 on the fact that a company will receive a tax credit in a certain amount in a post 2011 time period.

5.3 Environmental Investment Tax Credit in Spain

Ever since becoming the EU member state, Spain has made a remarkable economic and environmental progress. Within 2000-2015 alone, the carbon intensity of the Spanish economy went down by 20% (OECD, 2015).

In the early 90s, the European Commission (EC) started encouraging its member states to implement environmentally friendly policy instruments to incentivize green behaviour of firms. Instead of introducing environmental taxes at the national level, however, the Spanish government decided to implement environmental investment tax credits (e.g. EI tax credits).

As a result, environmentally related tax credits in Spain had been a result of a central effort rather than a regional one in comparison to for example environmental taxes (OECD, 2010). The Law 13/1996 [2] introduced two provision notes to the Spanish Corporate Income, initially for one year, after the completion of the first year - Law 66/1997 [3] extended their application indefinitely. One provision was concerned with a tax credit on research and development expenses, while the other one was related to a tax credit for eligible environmental protection investments aimed at reducing air, noise, water pollution and industrial waste. In this paper, I will analyse the latter.

The EI tax credit was set at 10% of total investment cost in any technology, which was considered as environmentally friendly. For a given firm's investment in green technology to qualify for such a subsidy, the firm had to show that it went beyond what was legally required. Having said that, many agree that the Spanish phrase used in the law, which translates to "investments (. . .) for the improvement of existing regulation" was too vague and has subsequently led to implementation difficulties. As a consequence, firms despite investing in more complex cleaner production technologies, more and more frequently were using

[2] Law 13/1996, 30.12.1996, on Fiscal, Administrative and Social Measures
[3] Law 66/1997, 20.12.1997, on Fiscal, Administrative and Social Measures

this tax incentive to finance end-of-pipe technologies, which were slowly becoming a part of existing environmental regulations (OECD, 2010) [4] .

The legal condition that the investment was to exceed the legal technological requirements, implies that green technology adoption was in principle undertaken voluntarily. In that sense, the EI tax credit effectively reduced the price and payback period of investments, and increased its internal rate of return, thereby addressing the capital market failure – a concept popular in the theoretical literature on fiscal incentives (Zwick and Mahon, 2017).

As mentioned before, EI tax credit was a result of a central effort rather than a regional one. The application of the tax credit depended upon the certificates issued by the regional governments of each Autonomous Community (AC), where procedures were similar, but they were not identical. However, according to OECD (2008) despite the participation of regional authorities in the process of approving the environmental investments, regional dispersion of the tax credit was virtually the same regarding the number of declarations presented. Additionally, OECD (2008) has found a positive correlation between the environmental investments made by firms at the regional level and the deductions approved in each region – excluding Madrid – probably suffering from the big-city effect and the location of headquarters. That being said, the evidence points into an assumption that the regional differences were not substantial as to affect the firm level analysis.

The EI tax credit had been successfully used by the firms for almost two decades until it was assessed as inefficient by the Spanish government. The official statistics showed that 68% of all investments that were financed through the fiscal incentive were end-of-pipe technologies, the remainder being used for financing integrated cleaner production technologies. This proportion was much higher than Spanish firms' environmental investments overall, suggesting that the EI tax credit had

[4] Pollution abating technologies such as filters and scrubbers. For more distinction between end-of-pipe technologies and cleaner production technologies please see Frondel, Horbach, and Rennings (2007).

an important role in influencing the type of technology, but not necessarily the degree of investment (OECD, 2008; OECD, 2010).

As a result, the government had announced in 2006 a progressive phase-out of the EI tax credit. Officials have argued in Memoria Justificativa of the Law 35/2006 [5] that these investments "in many occasions are no longer optional for companies, but compulsory (...). Today, it would be a paradox for the State to provide tax incentives for some investments, which are compulsory according to environmental legislation". Regarding the phase-out, it was planned as a yearly depreciation of the EI tax credit by 2% from 2006, when it was still equal to 10% until 2011, when it was planned to disappear completely (art. 39.1 Royal Legislative Decree, 4/2004). The pending EI tax credits could be used after the phase-out was completed (OECD, 2008).

Surprisingly, however, without any previous warning, to mediate the economic downturn related to the financial crisis of 2008 and to boost environmental investment, Spanish government through the Law 2/2011 [6] decided to re-introduce the EI tax credit in March of 2011 – three months after it was phased out completely. The mentioned tax incentive was re-introduced in the form that was supposed to be much stricter towards making sure it finances cleaner production technologies rather than end-of-pipe technologies. The EI tax credit was re-introduced at a stable 8% level and remained in that form until the end of the financial crisis, that is until 2015, when it was eliminated completely with the new Law of Corporate Tax 27/2014 [7]. The expected changes and actual changes are presented in Table 5.1. It includes the anticipated tax credit rates - descending from 6% in 2008 and 2% in 2010 to 0% in 2011, and the actual rates which have increased to 8% in 2011 and remained that way for the next years.

What makes this EI tax credit reform especially interesting is that it generated a lot of confusion until the very last moment and while in-

[5] Law 35/2006, 28.11.2006, modifying the Corporate Income Tax Law
[6] Law 2/2011, 03.03.2011, Article 92(1) of the Sustainable Economy Law
[7] Law of Corporate Tax 27/2014, 27.11.2014

troduced – it was specifically done with an intention to favour energy efficient over pollution abating technologies. In the empirical analysis, I focus on industrial firms as the main benefiters of the program and consider the period between 2008 and 2014 to compare firms' behaviour before and after the change in this policy instrument. Ultimately, I investigate, whether the financing indeed did favour cleaner production technologies, rather than end-of-pipe technologies. The study by Barreiro Carril (2015) focusing on the legal aspects of the EI tax credit, has assessed the reintroduction of the tax credit very positively, claiming that Spanish authorities have adopted a "very restrictive interpretation when acknowledging the right to the credit" but to this day there has been no empirical research supporting that claim. Additionally, I perform a first quasi-experimental econometric analysis of the effectiveness of environmentally friendly tax incentives at encouraging adoption of green technologies directly but also affecting indirectly green employment and green R&D.

5.4 Data

As it commonly happens while working with quasi-experimental approaches, and in my case especially due to the confidential nature of the database itself, I have to face several constraints of data availability. In this paper, I use data provided for the first time by the Spanish Institute of Statistics (INE) gathered over the span of 7 years between 2008-2014 through the Survey on Industry Expenditure on Environmental Protection (SIEEP). The main purpose of the annual survey is the assessment of current expenditures and investments of the Spanish industry, done to reduce negative environmental effects. SIEEP provides also information on the size (includes all establishments hiring 10 and more remunerated employees) and several capital environmental expenditures, e.g. green investment or environmental private R&D. The firm level data is currently available at request and from a secured room between 2008 and 2014. It is an unbalanced panel data set for 2,562 companies. Each company has at least 4 observations across 7 years. Out of all 26 variables provided, we chose the most suited for our investigation, which are briefly described below. INE ensures the quality of the data by employing CCU (centralised collection unit), which is dedicated to obtaining all the information from the questionnaire. The underlying data are collected for administrative purposes and firms are obliged to fill out the survey forms truthfully by law. Industrial firms with more than 10 employees have to report on an annual basis. Each firm receives a firm identifier, which allows for tracking the same company from year to year. In case any doubts arise, the INE employees make phone interviews to clarify any questions related to the answers should they have any, errors are detected and corrected.

Due to firm anonymity, INE constrains much of research efforts. Inter alia, they do not provide information on regions that each firm belongs to, which makes it impossible to control for regional fixed effects. Additionally, INE also does not allow for merging the data set with any other data sources, which constrains the scope of research activities and research questions considered. While it is true, that the study could gain much from merging the given data set and getting additional control variables from a Panel de Innovación Tecnológica (PITEC) for instance, we have not been permitted to do that. In light of that, I still believe that the dataset in its form is suitable for analysis of firm investment and employment. Additionally, I believe a sufficient amount of variation is captured by the fixed effects, size of the dataset, and the available variables.

The dataset used for this analysis contains data for 2,562 industrial firms. Each firm belongs to one of 30 different sectors reported at the two-digit level. For the heterogeneous part of the analysis, I have aggregated firms in various groups depending on their size (big, medium, small) and NO2 pollution levels (high, medium-low, low). The division into three NO2 pollution levels is done based on the amount of NO2 pollution produced by each sector in the period 2008-2014.

5.4.1 Variables

The SIEEP survey covers many treatment and outcome variables. Most importantly, the dataset is unique in the way that it does not only provide information on whether a given company has received an EI tax credit but also what was the amount of the tax credit received (in thousands of euros). Within the time frame of data available to us, that is 2008-2014, the data does not contain values for the tax credit for 2009, since it was not included in the survey questions for that year. I, therefore, drop 2009 from the analysis altogether.

Secondly, SIEEP provides information on different types of environmental investments. The survey distinguishes between the cleaner production technologies (CP) and end-of-pipe technologies (EP), which already is quite unique given the different goals that those two types of technologies have. Cleaner Production technologies are known as superior energy efficient technologies, that change the production process and ultimately reduce the use of natural resources. End-of-pipe technologies, on the other hand, are added at the end of the production line and solely reduce the pollution output at the end of the production process. Additionally, however, we also have access to more specific subtypes of each technology such as: cleaner production technologies aimed at reducing the air pollution (CPair), cleaner production technologies reducing the energy consumption (CPenc) and end-of-pipe technologies focused on reduction air pollution alone (EPair).

Among other important variables, is the firm' number of employees (size). Additionally, companies are asked how many employees they hire dedicated to environmental protection activities (grsize) and how much money the company spends on salaries dedicated to those green employees (grsalary). We also have access to the amount of money each firm invested in private environmental R&D (RD), amount of money spent on environmental management systems (ems), environmental certifications (ec) and others.

5.4.2 Descriptive Evidence

In the following section, I present descriptive statistics, for the main variables of interest, I use number of observations (N) and their means. Additional statistics provide yearly and sectoral averages.

Figure 5.1a shows the yearly percentage of firms receiving the EI tax credit, it appears less than 4% of companies receive the tax credit, suggesting that the EI tax credit did not seem to be a common policy instrument. Given the nature of this study - assessing a sudden policy change in 2011, we expect annual fluctuations both in tax credit amounts received and green investments carried out by the firms. Indeed, this is what we can observe in Figures 5.1 a and b. Firstly, it appears that while the tax credit has not been a common policy instrument in 2008 averaging around 7%, this percentage of firms using the EI tax incentive has decreased over the years and remained constant at below 4% level. The amounts received through the tax credit on an annual basis follow a similar trend decreasing substantially from 2008 to 2011 and then remaining at a constant level. Additionally, firms have quite substantially decreased their investments in both green technologies (CP and EP) from 2008 to 2010, while from 2010, it remained rather constant. The trends remain for the more specific technologies such as EPair, CPenc and CPair, though the differences from year to year might not be as drastic as can be seen in Figure 5.2. This is very reassuring for our analysis in the light of the fact that years 2010-2014 were the years when the financial crisis could have affected their investment levels and deteriorate it even further, yet it seems on average the investment levels remained stable.

Additionally, Figure 5.3 presents the average amounts of money received through tax credit at the sectoral level. The graph makes it clear that the only sector that seems to receive much more tax credits than others is sector 19 - dedicated to the manufacturing of coke and refined petroleum products. This is quite interesting since while it is true that the manufacturing of petroleum is quite pollutive, this specific tax incentive was not officially encouraging any sector to adopt green technologies.

Among the other sectors, the amount of tax credit received does not vary substantially. Admittedly, there are several ones, which do not seem to benefit from the tax credit at all - those are related to mining activities (sectors 5-7), as well as a few, which receive almost no tax credits, those are related to manufacturing of tobacco, textiles, and leather products (sectors 12-15). The remaining sectors have received tax credits in our time frame up to 50,000 euros.

With regards to the means of our variables - those are presented in Table 5.2 for two groups, firms that received a tax credit ($dtaxcred = 1$) and have not received it ($dtaxcred = 0$). While, the average firm size in our sample is quite high amounting to 287 employees, for firms that have received a tax credit that mean increases up to 432 employees. This suggests that it is mostly the large companies that use or can afford to use the EI tax incentive studied in this paper. This might be associated with the fact that large companies can afford a larger number of employees dedicated to environmental protection activities, as expressed in the green size means for both groups, 1.812 and 4.793 for non-receivers and receivers, respectively. There exists also a substantial difference between the mean investment in green technologies between benefiters of the EI tax credit and the rest, as shown in the numbers for instance in EP investments: 97,000 euros vs. 610,000 euros, for both groups. That being said, as is presented in the Figure 5.4 the distribution of firms size is similar for both firms having received an EI tax credit and not having received it, though admittedly, the tale of the distribution is fatter on the higher end for the firms under the tax incentive scheme. Table 5.3 shows descriptive statistics for different firm sizes: small (up to 50 employees), medium (50-200) and large (more than 200). We can observe some differences between the two groups.

Significant differences are also reported when contrasting investment levels before and after policy change - the so-called parallel trends. Figure 5.5 present us with parallel trends for our variables of interest, both investment and employment outcomes. We can observe a noticeable change in behaviour after the policy change was introduced. We can see that for several variables - namely the most crucial ones the parallel trends hold quite firmly.

Lastly, for each out the outcome variables, for robustness reasons we look at three measures of our variables: 1 - amount of money invested in each technology in thousands of euros in absolute terms, 2 - the natural logarithm of the amount invested (we add 0.10 to each variable before turning it into a logarithm) and 3 - the amount invested in per capita terms. The last one is calculated as: $invest\_pc = \frac{invest_t}{size_{t-1}}$. The size is taken in the t-1 period to avoid simultaneity.

This helps us to see whether our results hold for all three measures of our outcome variables. As will be shown in the result sections, we will ultimately focus on the logarithm value of the investment variables, as it turns out to be the most robust and also the most standard measure, and easiest to interpret.

5.5 Estimation Strategies

The estimation strategy is guided by the identification strategy, data available and the described change in the EI tax credit in March of 2011. To analyse this behaviour, I start with the comparison of outcomes before and after the policy change using regression model. Exploiting the exogenous re-introduction of the tax credit as well as the fact that the before mentioned tax credit did not have any specific eligibility criteria, I have decided to use difference-in-difference estimator and an instrumental variable. To provide some insights into the methodology as well as to discuss the strengths and weaknesses of each method, I discuss them separately. Quite naturally, ideally for investigating the effect of a tax incentive I would have preferred to use some kind of eligibility criteria and the RDD design. However, as it is often the case with observable data, we are faced with its numerous limitations. Given no eligibility criteria, I have decided to combine instead two quasi-experimental approaches.

Firms that decide to benefit from voluntary policies such as this one, might suffer from self-selection, and hence the choice of appropriate methodology becomes even more stringent. By exploiting the fact that the environmental investment tax deduction suffered an unexpected re-introduction at the moment they were supposed to be phased out in Spain, we can assess its impact on different types of production process eco-innovations using a difference-in-difference model. Unlike Propensity Score Matching, the difference-in-difference estimator allows to control for unobserved heterogeneity that may lead to selection bias such as natural willingness of certain type of companies to use EI tax credits and non-random popularity of this policy instrument across different sectors.

Instrumental Variable approach on the other hand, is useful in solving the common problem of omitted variable bias (OVB). IV methods introduce a set up to address the missing or unknown control variables, that under normal circumstances would bias the estimates. Thus, IV similarly solves that problem as randomised control trial (Angrist and Pischke, 2008). In the context of this study, IV approach is useful as it addresses the problem arising from the impossibility of merging the database with other sources.

5.5.1 Difference-in-Difference

By exploiting the fact that the EI tax credit was unexpectedly re-introduced to the Spanish Corporate Tax in March of 2011, we assess the impact of this sudden change using difference-in-difference - or more generally fixed-effects - model. We group companies into those treated (having received the tax credit), and untreated (not having received a tax credit). In the second step, we run regressions of firm level investments in end-of-pipe and cleaner production technologies. We control for time fixed effects to control for the introduction of the policy in 2011 and the effects of a business cycle that could have been important during the financial crisis. Additionally, we control for the firm/sector fixed effects to control for whether the firm has received a tax credit on environmental investment. Standard errors are clustered at the firm level throughout so that these standard errors are robust to arbitrary forms of error correlation within the firms. The empirical model, estimated by OLS, takes the following form:

$$ln\_invest_{i,t} = \alpha + \beta_1 dtaxcred + \beta_2 post2011$$
$$+\delta(dtaxcred * post2011)_{i,t} + \beta_3 X_{i,t} + \alpha_i + \alpha_t + \epsilon_{i,t}$$

where i refers to the firm and t to the year. Our outcome variable $ln\_invest_{i,t}$ is a log transformation of the green investment variables at the firm level. Those are: investments in CP and EP in a given year. We add 0.10 to all our dependent variables to include observations that would otherwise be associated with missing values. For a broader analysis of investment behaviour I look at various measures: investment in thousands of euros, investment per size and the natural log of investment. I also distinguish between different types of green investment such as EPair, CPenc and CPair. In the second step, I look at further outcome measures. Importantly, I look at the number of employees within the affected firms to understand changes in the labour force. For a broader analysis, I look also at only employees hired for environmental protection tasks alone and their salaries.

Within our estimation, firms can either be assigned to treated firms (dtaxcred=1) or controls (dtaxcred=0). The firms are considered as treated if they invest in green technology and through that they receive the tax credit, which translates into them being aware of its existence, eligible to receive it, and not being rejected. Our control firms, on the other hand, are firms that have not received the EI tax credit, and the reason for it can be three-fold, they were not aware of its existence, not eligible to receive it or being rejected. Our time dummy is post2011, it is equal to 1 for all the years after the policy change, 2011 including, and 0 for the years before the policy reform.

The $(dtaxcred * post)_{i,t}$ is the key variable. It is a dummy variable and it is an interaction between the policy dummy and tax credit dummy. It carries the difference-in-difference coefficient δ. It is our coefficient of interest, if specified correctly, it should be interpreted as a percentage increase/decrease in the outcome variables associated with receiving a tax credit post-2011. Quite naturally, we are also controlling for other firms' characteristics, which are captured in the matrix $X_{i,t}$. Firms/sector and time fixed effects are α_i and α_t, respectively. $\epsilon_{i,t}$ is assumed to be an idiosyncratic term. Standard errors are clustered at the firm level.

The presence of systematic differences between the treatment and control groups in the sample is not an issue because we rely on the difference-in-difference methodology, which does not require random assignment to treatment (Angrist and Pischke, 2008; Cameron and Trivedi, 2005). Difference-in-difference is based only on the assumption that the two groups follow the same trend in the absence of treatment. This is likely to happen in our setting because we include firm/sector and year fixed effects, which are not included in the standard difference-in-difference approach. Please see Figure 5.5 for the parallel trends.

In applying a difference-in-difference framework to the data it would be ideal to address the self-selection bias - as I have mentioned previously. If done so, the regression equation (1) specified correctly would provide an unbiased estimate of the average treatment effect. Our case does not satisfy exactly the ideal conditions because, there were no clear eligibility criteria and one can also expect green investments to produce positive externalities, for example, they create common knowledge spillovers. The increased awareness of innovation could make it be seen as more desirable in the eyes of the management. That being said we do not assume this effect to be large enough to lead to bias of the estimator, especially during the financial crises years.

Dynamic Specification and Heterogenous Analysis

Given the evidence of the significant impact of our policy change on investment levels, it is quite natural to wonder how the effect has evolved over time since the first year of implementation. Does the effect become increasingly strong or fade year by year? Have the firms adjusted their budgets relatively quickly and we could see decay of the negative effect? Or on the contrary, did the firms continue to invest less and less through the financing from the investment tax credit?

To provide some sense of the dynamics of the "treatment" effect using the data we have, I perform an exercise similar in spirit to the causality analysis in the paper by Autor (2003). The exercise also lends us insights into any behavioural effect that may be present. We do this by replacing the interaction dummy $(dtaxcred*post2011)_{i,t}$ with a series of lead dummies indicating the time passage relative to the policy implementation.

The specification we consider is the following:

$$ln\_invest_{i,t} = \alpha + \beta_1 dtaxcred + \gamma_1 inter_{2011}$$
$$+\gamma_2 inter_{2012} + \gamma_3 inter_{2013} + \gamma_4 inter_{2014} + X_{i,t+1} + \alpha_i + \alpha_t + \epsilon_{i,t},$$

where instead of a single interaction effect we have *inter*, which is the interaction dummy of treatment with each year. Those terms capture the post-policy trend. An ascending trend in the magnitude of the set of coefficients would suggest a slowly increasing trend and firms increased capability of using the tax credit successfully, while a descending trend would translate into the increasing reluctance/inability of firms to use tax-credits to finance environmental investments. All other variables remain the same as in the baseline specification.

Lastly, I will also perform several triple difference-in-difference analyses, this will allow me to observe how the policy change has affected firms across different firm sizes and pollution NO2 emitted. In this case, for each specific heterogeneous group dummy that we will use (hetergroup), we will use the following specification:

$$ln\_invest_{i,t} = \alpha + \beta_1 dtaxcred + \beta_2 post2011 + \beta_3 hetergroup$$
$$+\beta_4 dtaxcred * post2011 + \beta_5 dtaxcred * hetergroup + \beta_6 post2011 * hetergroup$$
$$+\delta(dtaxcred * post2011 * hetergroup)_{i,t} + \beta_7 X_{i,t} + \alpha_i + \alpha_t + \epsilon_{i,t},$$

where instead of the *inter*, which is the interaction dummy of treatment with each year, we use an interaction term between post2011 dummy, dtaxcred dummy and the heterogeneous group dummy. All other variables remain the same.

5.5.2 Instrumental Variable

To be sure, that we control for the self-selection of firms, it would be ideal to either use a natural experiment or firms eligibility criteria for the experiment - should it exist. However, in this case, none of those are available. Given such circumstances, it is an appropriate procedure to look for an exogenous instrument that would work as an external shock to the firm. Additionally, Instrumental Variable (IV) approach is also beneficial in this case, as it allows me to take advantage of the continuous character of the treatment variable. Out of the available dataset, I have constructed several instrumental variables e.g. a probability of eligibility index, sectoral investment shocks and combination of the two, however, they turned out to be very weak.

Ultimately, I have decided to use as an IV an amount of tax credit received in thousands of euros in 2008 in combination with the policy change. From the perspective of a single establishment, I can think of the policy change as an exogenous shock to my ability to receive a certain amount of tax credit, given my ability in the year 2008. Figure 5.6 represents the correlations between the amount of taxcredit2008 and log amounts of tax credits for the post-reform years, as we can see it is positive, showing that the relationships do exist. Consequently, by using the instrument, I sort out the companies between those that know the tax credit exists, they were eligible before - which is a proxy for being eligible in a given year, and firms that were not rejected before - which again is a proxy for not being rejected in a specific year.

Consequently, in the first stage, I run a regression of tax credit amount received by a firm in 2008, post2011 dummy and an interaction term of both on a natural logarithm of tax credit. In the second stage, I use this instrumented natural logarithm of the tax credit, to check its direct effect on green investments, as well as indirect effects on size (lnsize), green size (lngrsize), green salary (lngrsalary) and green private R&D (lngrRD). The identifying assumption for the validity of the $taxcred2008 * post2011$

as an instrument is that the amount of tax credit received in 2008 alone should be semi-random, in the sense that not all firms invest every year.

5.6 Results

This section presents all results from the regression analysis. As a direct outcome, green investment variables are the first set of results. Subsequently, I look at specific types of green investment, other types of variables such as employment, green employment. I follow with the results of the dynamic estimation and the heterogeneity analysis. Lastly, I look at the results of the IV estimations. both direct and indirect effects of EI tax credit.

5.6.1 Main difference-in-difference results

In the first step, I look at the results of various outcome measures for investment. In Table 5.4 the static results for total investment in cleaner production and end-of-pipe technologies are summarised. Columns (1), (2) and (3), the three measures investment in CP: investment in thousands of euros, natural log of investment and investment per lagged size, respectively, provide perspective to the overall change in investment, combining extensive and intensive margins. All the estimates are negative and all are statistically significant for EP technologies. For CP technologies, only the first measure in column (1) shows statistical significance at the 1% level. After the policy change, firms that receive the tax credit decrease their investment in EP by 0.646 compared to firms that did not receive such tax credit. Given the standard deviation, these estimate is considerable in economic terms. To better understand the adjustment behaviour I also look at intensive margin separately. There is a -3,431 decrease in investment per capita terms. When it comes to CP investment, it seems that the effect is not as clear at this level of investment aggregation. That being said, the investment in cleaner production seemed to have decreased much more in total terms, relative to the investment in end-of-pipe.

Given, the unclear results for CP technologies, in the next step I focus on changes in investment for specific types of green technologies. It might be that they follow different behaviour, thus making the results on the aggregate level unclear. In Table 5.5 I show results for one type of measure: natural log of investment in different types of technologies, namely: EPair, CPair and CPenc in columns (1), (2) and (3), respectively. The results presented, clearly show that our previous hypothesis was correct. The estimates for our variables of interest differ in signs, magnitudes and statistical significance. Logged investment in EPair decreases by 1.674, the coefficient is significant at the 5% level. Logged investment in CPenc increases by 1.249, though insignificantly due to a large standard error and we cannot find evidence for the effect on the logged investment in CPair. In the end, these results are not too surprising, since the policy change even though more generous when it comes to the tax credit rate, was actually planned to be harsher towards financing end-of-pipe technologies. In fact, we can see that the policy change was successful in making sure that the EI tax credit was financing to a lesser extent the EPair technology, substituting this amount with financing of CPenc instead. Lastly, it is interesting to observe that the effect for lnEPair is much larger than for lnEP in general, 1.674 versus 0.646. This suggests that the policy change was mostly directed at reducing financing of such technologies as filters, scrubbers that specifically reduce air pollution in contrast to other end-of-pipe technologies.

5.6.2 Dynamic Analysis

For a better understanding of the investment over time, I look at the dynamic specification. I present the results for all green investment types in Table 5.6 and Figures 5.7. Overall, the direct results from the dynamic analysis do not yield statistically significant results, possibly due to large standard errors arising from small disaggregation at the annual level. Firstly, all coefficients before the policy change are statistically insignificant at conventional levels. Without relying on confidence intervals, the movement of coefficients before and after the policy change is noticeable. In summary, there seems to be a decrease in investment volume among firms that received the tax credit after 2011. The effect occurs in the year directly after the policy change and generally stays negative for subsequent years, though the effect is admittedly insignificant. The effect becomes quite large and statistically significant only for lnEPair technology for 2014. For end-of-pipe technology aimed at air pollution reduction, the coefficient of interest is positive though statistically insignificant for 2011, however, switches negative in the following year, remaining negative until reaching a negative peak at the end of our time frame of the study. The behaviour of the cleaner production technology aimed at reduction of energy consumption seems to follow quite the opposite pattern, while the coefficient is negative for the prior year of 2010, it then becomes positive in 2011 until increasing even further in 2014. This again might suggest that the policy change was partially successful, partially as it did manage to finance to a lesser extent the lnEPair, though it did not succeed to increasingly finance energy efficient technologies.

While the results from the direct investment effects might leave us with a certain degree of dissatisfaction, I carry out a similar analysis also for the indirect effects on green employment and green salaries presented in Tables 5.7 and 5.8, for average treatment effects and dynamic effects, respectively, as well as Figures 5.7 visually presenting annual effects. The dynamic graphs allow further assessment for the parallel trends assumption and thus the causality of the estimates. Interestingly, in this case the dynamic analysis is much more informative to average treatment effects. With regard to the effect on lnsize, we cannot discuss it further, as it becomes quite clear the parallel trends do not hold in that specific case. In the case of lnRD, we do not find any statistically significant effects in either case. However, the trends for both green size and green salary are non-existent in the year before the policy change and the first year of the implementation, and so we can interpret the results as causal effects. While looking at average treatment effects in Table 5.7 only the coefficient on grsalary is statistically significant at the conventional level. That being said, as we decompose the effect to annual averages in Table 5.8 we can observe that both the grsalary and grsize both have several negative and statistically significant coefficients. The magnitude for lngrsize is quite close to 0, though statistically significant at conventional levels, that is why it might be overlooked at the average level. The dynamic analysis provides us here with increased precision of estimation.

5.6.3 Heterogeneous Analysis

Thus far, I have concentrated on the average effects. In the next step, I explore heterogeneity in the baseline estimates by stratifying firms by the characteristics of the sectors they belong to. I, therefore, also carry out a heterogeneous difference-in-difference analysis. I investigate whether the effect was more prominent across different firm size and NO2 pollution produced. I have decided to focus on NO2 pollution as it was considered one of the most dangerous pollutants in the context of Spain in that time [8]. Given the reduced sample sizes for the separate subgroups, it was frequently not easy to achieve statistically significant results given large standard errors. Nonetheless, significant results still appear.

Firstly, I have performed a division of firms into three group sizes: big (above 200 employees), medium (50-200) and small (below 50) and performed descriptive statistics for each of them. It appears that, while it is true that on average larger firms receive the tax credit, the small firms of less than 50 employees that do apply for the tax credit seem to receive it as can be seen in Table 5.3 again. The companies of more than 200 employees do not seem to receive much more of public aid through tax incentive, that being said they do invest significantly more in per capita terms as can be also seen. Large firms also seem to hire bigger amounts of green employees in per capita terms, which makes sense, since they can afford it much more than smaller establishments. One question that one may wonder is whether being a small firm makes it even more difficult for companies to invest in green technology in the post-2011 time period. The results from Table 5.9 and Figure 5.8 seem to point out to the fact that small firms of less than 50 employees have increased their level of investment in lnCP by 3.079 in contrast to the rest of the firms. The

[8] El Pais, "15 million Spaniards are breathing air the EU considers polluted", 07.12.2018, accessed: 20.06.2020, https://english.elpais.com/elpais/2018/12/05/inenglish/1544008632_514634.html

coefficient is statistically significant at the 1% level. On the other hand, the coefficient for the biggest companies of more than 200 employees is negative and statistically significant at the 5% level, suggesting that big firms have decreased their investment in CP as a result of the policy in comparison to smaller firms. With regards to lnEP technology, no statistically significant results are observed, once again underlining the importance of distinguishing between the two green technologies. One conclusion also arises, which shows that the policy change significantly aided investment in energy efficient technologies by small firms.

In the next part of my analysis, I also look at the high and low pollutants of NO2. I observe, however, no statistically significant results at conventional levels for NO2 when I look at investment on aggregate levels - as can be seen in Table 5.10. Only the more thorough analysis on the specific types of investments such as lnCPair and lnCPenc yield statistically significant results. The results are also quite reassuring. Indeed, they point out to the fact that perhaps it was the NO2 pollution that was being taken into consideration. Namely, as can be seen in Table 5.11 the coefficients on lnCPair and lnCPenc are 4.178 and 4.073, for investment by high NO2 polluting firms and medium NO2 polluting firms, respectively; while the coefficient on the lnCPair by the low NO2 polluting firms is equal to -5.506. All coefficients are statistically significant at conventional levels and quite substantial when it comes to their magnitudes.

To summarise, the unexpected policy change caused a decrease in the level of green investment and green employment among the Spanish firms in general terms. That being said, we can observe some heterogeneity in behaviour. Firstly, the investment in end-of-pipe technologies reducing air pollution alone decreased much more than the rest of the green technologies. As a result of the policy reform firms reduced also the number of employees dedicated to environmental protection activities and consequently amount of funds being spent on their salaries. Secondly, the investment in cleaner production technologies did not decrease but also did not increase, which makes this policy reform semi-successful. Thirdly, the policy change favoured small firms of less than 50 employees, also making it more difficult for bigger firms to finance their green investment. The heterogeneous analysis makes it clear that across different pollutants, within the context of NO2 pollution analysis brings some hopeful results of an increase in investment in CPenc and CPair among medium and high pollutants and decrease in CPair investment for low polluting firms.

5.6.4 IV Results

I complement the results from the difference-in-difference analysis with the use of novel instrumental variable to take advantage of the continuous nature of the treatment variable, namely the amount of the tax credit received in the first year of our sample - 2008. This approach allows us not only to investigate the effect of the policy change alone, but the EI tax credits overall over the years.

Before continuing with IV approach, Tables 5.12 and 5.13 provide information from simple OLS estimations lntaxcredit on the outcome variables in different measures across different technologies, respectively. Indeed, from OLS estimations alone it appears to be a positive correlation between the tax credit and the level of investment, no matter the measure being used or the technology type considered.

Table 5.14 shows IV results when different measures of green investment are considered. There exists a positive effect increasing a tax credit by 1% on all outcome green investments but end-of-pipe technologies in per capita terms. In Table 5.15 I present the results for different green investments and I consider only results in natural logarithm form. The point estimates suggest a positive impact of the EI tax credit on all green investment types. All but one estimates are statistically significant at the 1% level. That being said, the effects are the largest for the lnCPair and lnEPair, of 1.391 and 0.918, respectively. This result suggests that firms were incentivised externally to mostly invest in technologies that reduce air pollution. The coefficient on energy consumption reducing technology (lnCPenc) is twice smaller (0.407) though still statistically significant at the 1% level.

Lastly, in Table 5.16 I present the static results on other variables of interest such as size, green size, salary of the green employees and private green R&D in natural log terms. The point estimates suggest a positive impact of lowered capital costs on green employment and the green salaries but not on the general firm size. There is also a positive though the considerably small effect on private green R&D of 0.082. All coefficients are statistically significant at least at the 5% level. For the number of employees dedicated to environmental protection activities, there is an increase of 0.069. Given the small percentage of green employees within each firm, it comes as no surprise that this lowered capital cost does not succeed in effectively increasing the general firm size. That being said, the coefficient on the green salary is the largest of 0.102. There is a clear green employment effect. In magnitude, the coefficients are all very reasonable, suggesting that as a result of increasing the amount of tax credit by 1% the firm does not increase its size significantly, however, its number of green employees raises by around 7%.

5.6.5 Robustness Checks

For an additional test of causality of the results, I run several robustness checks both for the difference-in-difference analysis, as well as the instrumental variable approach. I will analyse them in turn.

Difference-in-difference

Firstly, to check the robustness of the difference-in-difference analysis, we use a variable related to green innovation, but non-related to the EI tax credit itself - the private environmental R&D. The results are not statistically significant. The standard error is significantly larger for our coefficient of interest (Table 5.17).

Secondly, we use a type of placebo, by choosing alternative treatments such as: air tax, waste tax, other environmental taxes and all of them aggregated as some of them were introduced in that time, by doing this we will also check whether some of the implementation of the taxes affected our results. Tables 5.18, 5.19, 5.20 and 5.21 present the coefficients of interest for different measures of investment as we have done in the main part of the analysis. The coefficients of interest are not statistically significant at conventional levels for any of the environmental tax and any type of measure of investment.

Thirdly, to check whether the results are sensitive to the time frame used I have performed the difference-in-difference analysis using only 2010-2014 period. The results hold as can be seen in Tables 5.22 and 5.23 .

Instrumental Variable

To study the robustness of the results of the instrumental variable approach I decided to use an alternative instrument. Namely, I used the lag amount of the tax credit invested ($taxcredit\_t - 1$), in combination with the difference-in-difference design. Given the fact that the correlation looked very similar for this instrument as for the taxcred2008, and while the taxcred2008 is more intuitive, I have decided against the lag in my main specification and used it as an additional robustness instead. The F statistic of the first stage is larger than 39 for all of our estimations, while clustering the standard errors at the firm level. I use this instrument on different measures of the green investment level (lag, natural logarithm, total) in Table 5.24 as well as for different investment types (lnCPair, lnCPenc, lnEPair) in Table 5.25 as it was done with our original instrumental variable namely taxcredit amount in 2008. The results hold, are positive and statistically significant at the conventional levels. Notably, the coefficients are much more conservative than in the previous case as can be seen in Table 5.25, however, the main conclusions hold. Namely, the coefficient is the highest for the lnCPair. Admittedly, we can also see a significant increase in the case of energy consumption reducing technology (lnCPenc).

We use our alternative IV to study the effect on employment and R&D, as presented in Table 5.26. As before, the F statistic of the first stage is larger than 40. It appears that the alternative instrument provides results that are similar, though slightly more generous for the observed effects. This time, all the effects remain positive and statistically significant at the 1% level. More specifically, the effect on the total number of employees within the firm becomes positive and statistically significant with a coefficient of 0.040. The effects on the number of green employees and their salaries increase to 0.157 and 0.209, respectively. The coefficient on the effect on private green R&D increases also to 0.145 (Table 5.17). Those results are in agreement with the previous results, suggesting that the increase in the tax credit amount does increase the number of green employees and their salaries, thus possibly increasing the total firm size - though perhaps not substantially.

Lastly, we limit our time frame to 2010-2014 to look at the behaviour of companies in the worst years of the financial crisis. The results hold for both direct and indirect effects, as well as while using our main IV and the alternative IV. Coefficients for all previously analysed variables of interests remain positive and statistically significant at the conventional levels (Tables 5.27 - 5.29).

5.7 Conclusions and Policy Recommendations

This is the first paper to empirically assess an environmental investment tax incentive program using Spanish data to estimate its causal impact on firms' behaviour e.g. green investment choices, employment and environmental R&D. To evaluate the success of this program I study it, first by assessing the policy change that happened in March of 2011, when it was re-introduced, aiming to favour energy efficient over pollution abating technologies; as well as estimating the local average treatment effects throughout the entire period of study (2008-2014) using instrumental variable approach. I, therefore, study both, the effect of policy reform, as well as a general proportional change between a 1% increase in the tax credit on the level of variables of interest, through the use of continuous nature of the treatment variable

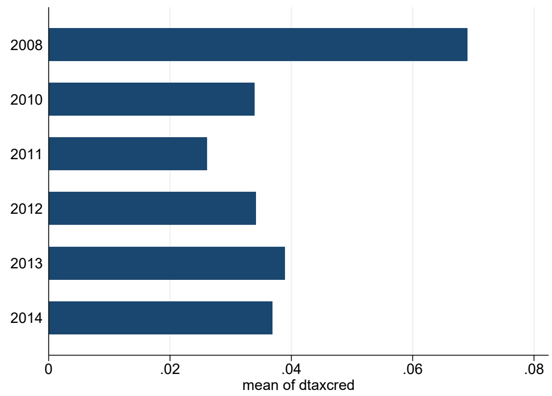
I find evidence that as a result of the policy change, firms did increase their investment in pollution abating technologies, also the air-pollution reducing ones, which is a considerable success of the policy change. That being said, there is no evidence to support the claim that the investment in cleaner production technologies has increased. Unfortunately, the policy change had also a few unexpected indirect effects, firms in response to the tax incentive regime in place reduced the number of their green employees as well as the expenditure related to salaries of green employees. After performing the heterogeneous analyses, it is very clear that firms respond differently depending on their size and amount of NO2 pollution they produce. Within the heterogeneous analyses specifically, small firms seem to have benefited the most from the policy change by increasing their investment in cleaner production technologies - as intended. While the big firms decreased it significantly.

In general terms, however, while studying the proportional effect of the EI tax credit on variables of interest, it becomes apparent that Spanish environmental investment tax incentive was successful at inducing all types of green investment, though, admittedly it favoured air pollution over energy efficiency technologies, not necessarily pollution abating versus cleaner production technologies, as per the concern of the government at the time. Additionally, I find further evidence that the increase in the amount of environmental investment tax credit results in a proportionate increase in the number of green employees and even private environmental R&D.

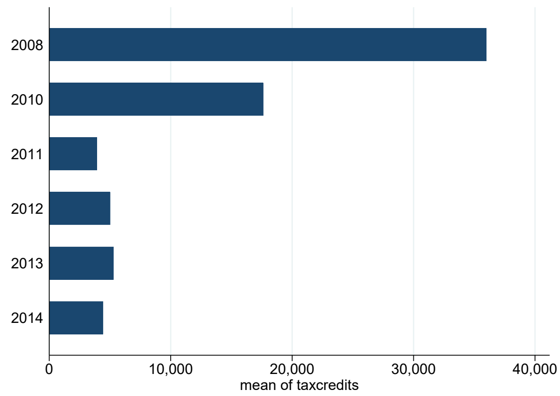
I have performed numerous robustness checks to verify the validity of the empirical design, the study, however, is still limited in several ways. First, the lack of eligibility criteria makes it impossible to control for natural willingness of certain firms to apply for an environmental investment tax incentives, which I tried to verify through the use of a combination of quasi-experimental approaches. Secondly, the impossibility to merge this dataset with other existing firm level databases constrains this analysis with the threat of omitted variable bias - which I try to address in the second part of the analysis.

With regard to the usefulness of this empirical analysis, it provides important implications for the policy makers. In stark contrast to the decision of the Spanish government on this EI tax credit, the results of my analysis seem to be quite encouraging. The results are also in agreement with previous literature, especially the work done by Ohrn (2019) as well as the report by OECD (2008). What we can learn for this green tax incentive is quite straightforward, adopting green depreciation incentives lead to increased business incentives and green employment outcomes, even during an economic downturn. Additionally, the government can be successful at modifying the existing tax incentives in place, such that they do discourage those technology choices that the central government considers undesirable. While the results indicate that the tax credit should have been redefined even further, this work does not justify its complete phase-out. The fact that there is an increased investment in cleaner production technologies for smaller firms is also very important, as those are exactly companies frequently faced with capital market failure - especially in the time of financial recession such as this one. It is a bit concerning to see no clear pattern of investment across pollution emitted by the companies - however - this remains a platform for further research. More research is also needed with respect to the assessment of whether this type of incentive is the most efficient way to improve firms' economic outcomes, and how did the tax credit affect also affected the employees over the short and long run. Especially, after the complete elimination of the tax credit in 2015. Lastly, even given the financial burden that tax deductions and subsidies entail, they might still be economically justified in some cases. For instance, when positive externalities appear, such as increased green private R&D, which is the case here.

5.8 Figures and Tables



(a) Yearly averages for percent of firms using the EI tax credit.



(b) Yearly average amount of the EI tax credit received.

Figure 5.1: Yearly averages for EI tax credit.

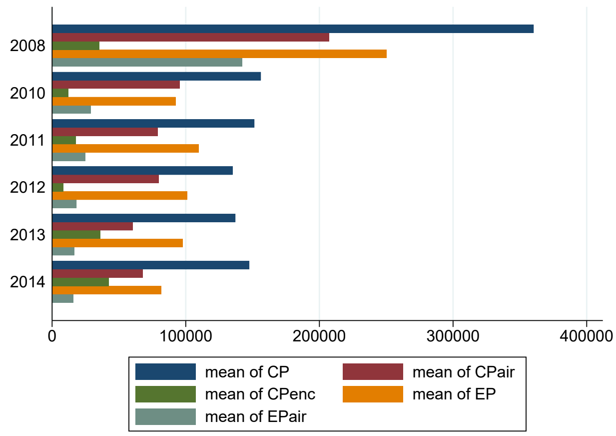


Figure 5.2: Yearly averages of investments in cleaner production technologies, cleaner production technologies aimed at air pollution reduction, cleaner production technologies aimed at energy consumption reduction, end-of-pipe technologies and end-of-pipe air pollution reducing technologies.

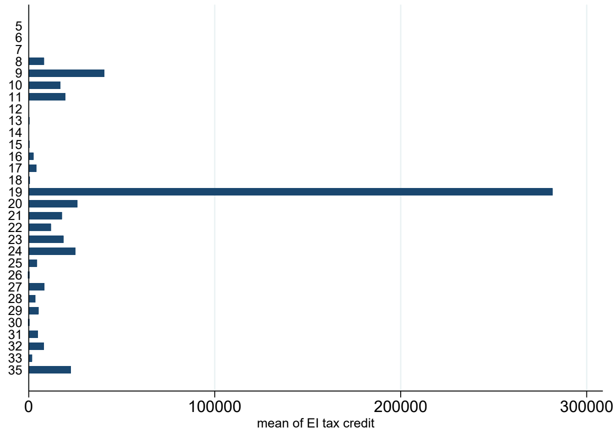


Figure 5.3: Sectoral averages of the EI tax credit amounts received.

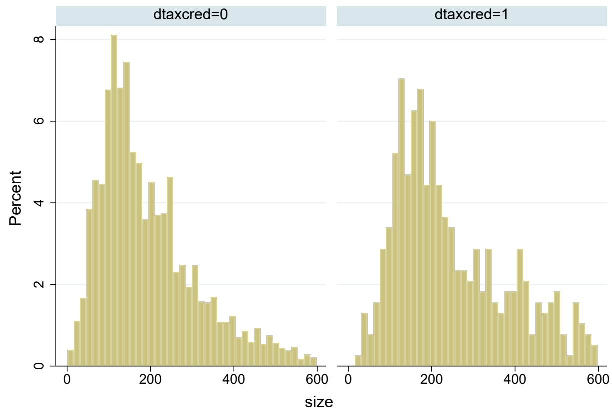
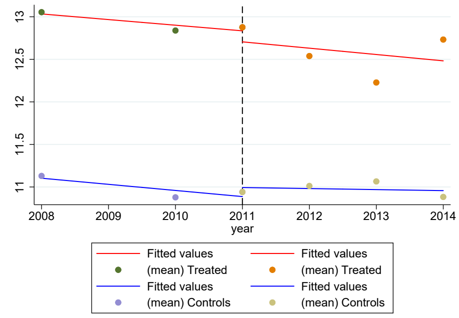
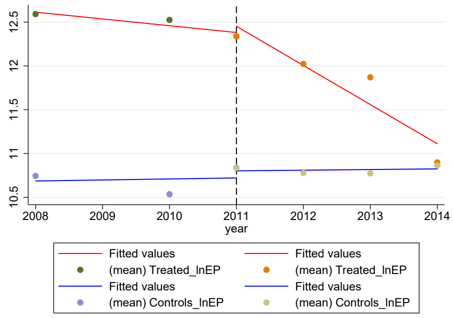


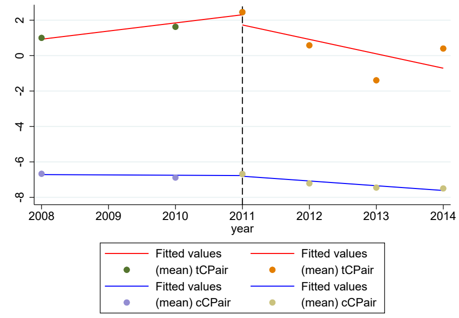
Figure 5.4: Percentage of firms size having and not having received an EI tax credit.



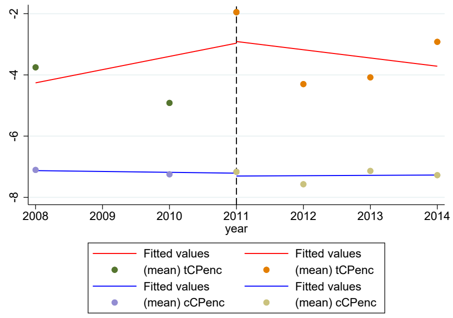
(a) CP



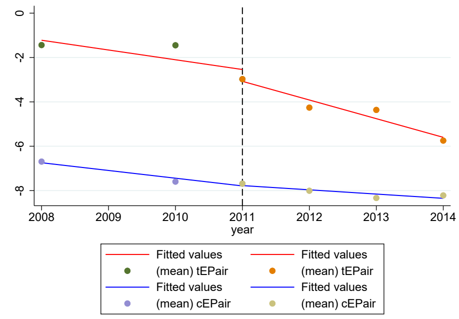
(b) EP



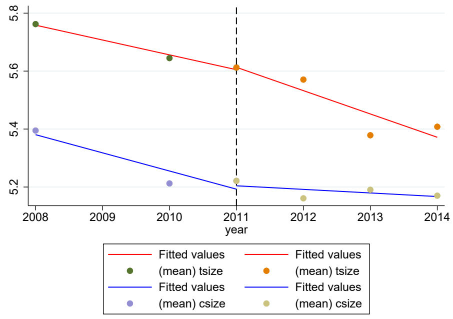
(c) CP air pollution



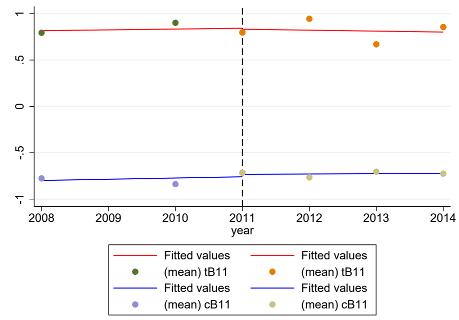
(d) CP energy consumption



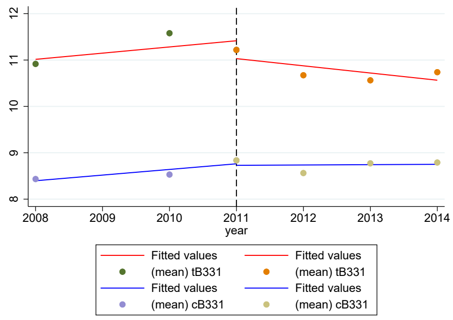
(e) EP air



(f) size

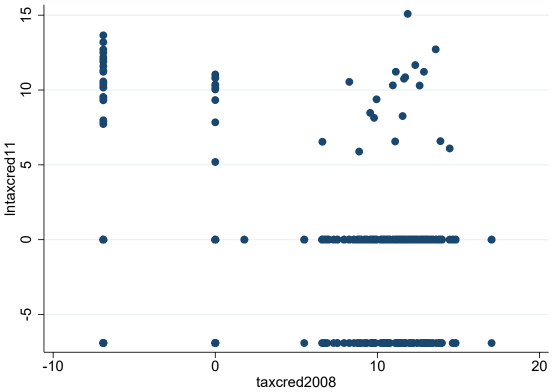


(g) green employees

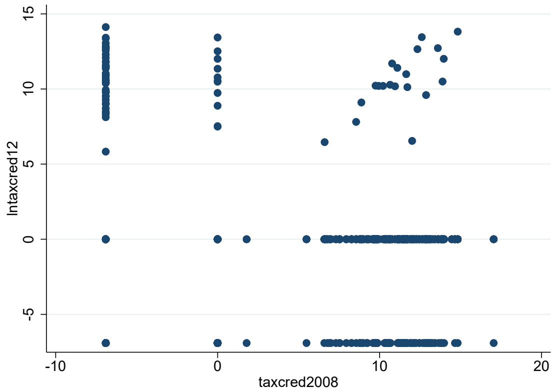


(h) green salary

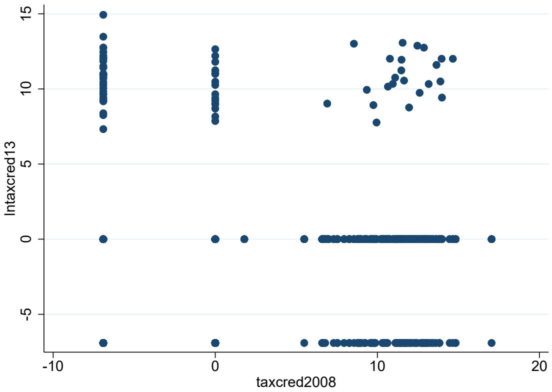
Figure 5.5: Parallel trends.



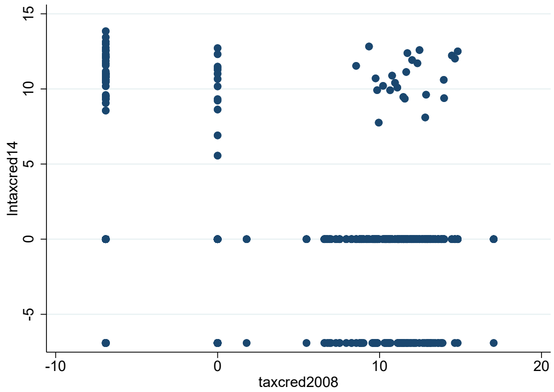
(a) lntaxcredit2011



(b) lntaxcredit2012

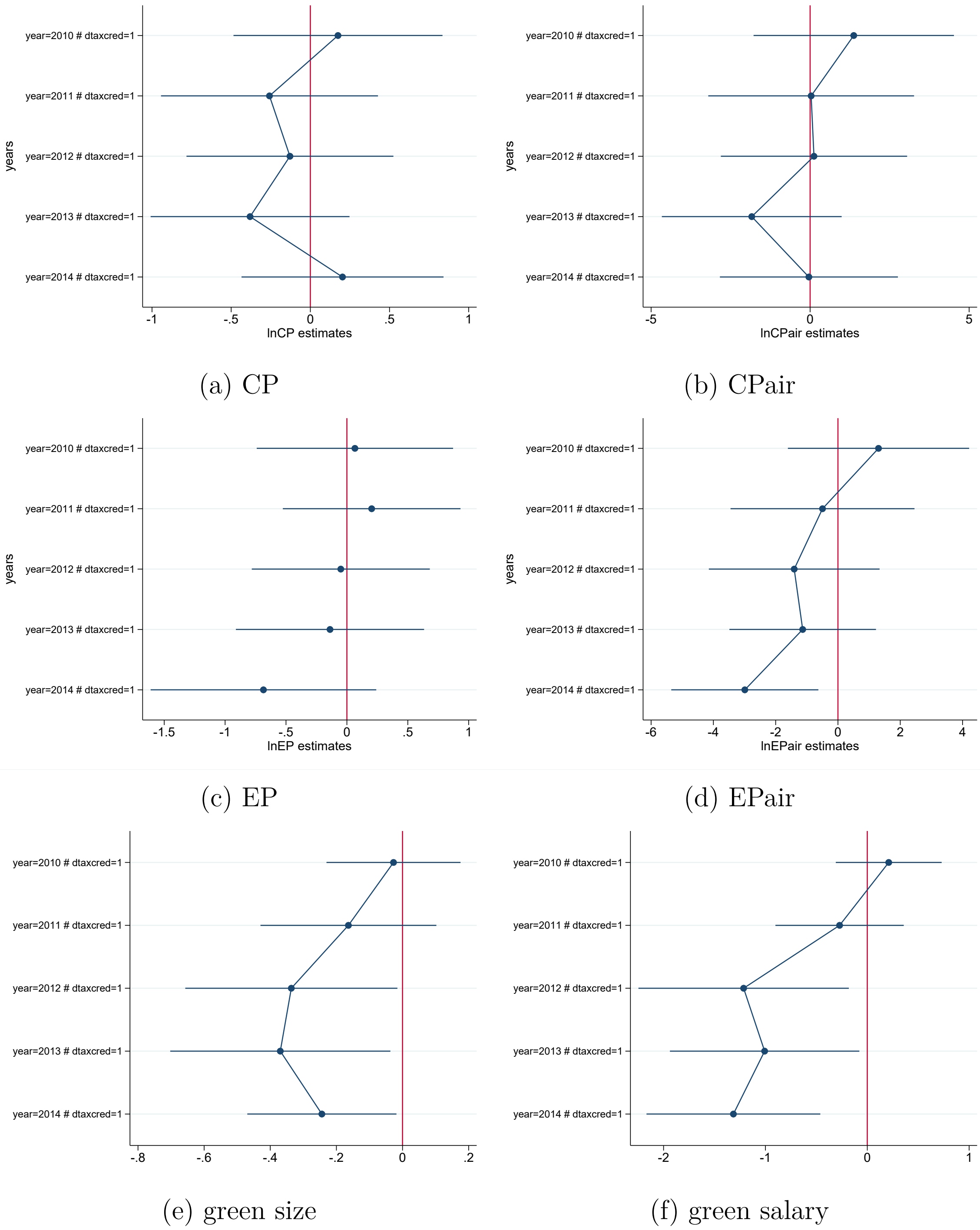


(c) lntaxcredit2013



(d) lntaxcredit2014

Figure 5.6: Correlation between the instrument (taxcred 2008) and the log of the tax credit amount for different years.

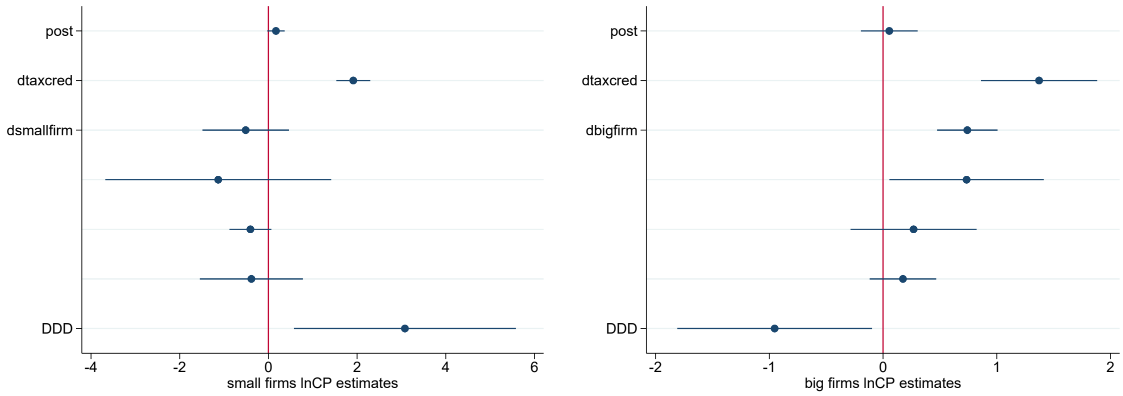


(a) CP (b) CPair

(c) EP (d) EPair

(e) green size (f) green salary

Figure 5.7: Dynamic effects for green investment and green employment outcomes.



(a) Small firms (<50)

(b) Big firms (>200)

Figure 5.8: Heterogenous effects on lnCP. Size.

Table 5.1: Tax Deduction Rates - planned versus actual.

Year	2008	2009	2010	**2011**	2012	2013	2014
Tax Credit Planned	6%	4%	2%	**0%**	0%	0%	0%
Tax Credit Actual	6%	4%	2%	**8%**	8%	8%	8%

Table 5.2: Descriptive Statistics

	dtaxcred = 0		dtaxcred = 1	
variables	N	mean	N	mean
tax credits	11,125	0	448	287,142
cleaner production	11,125	134,765	448	1,15E+09
cleaner production (air pollution)	11,125	66,982	448	765,717
cleaner production (energy consumption)	11,125	21,639	448	105,024
end-of-pipe	11,125	97,096	448	610,325
end-of-pipe (air pollution)	11,125	25,572	448	323,164
size	11,050	281	448	431.9
green size	11,125	1.81	448	4.793
green salary	11,125	70,462	448	230,181
green R&D	11,125	3,380	448	17,054

Table 5.3: Descriptive Statistics for different firm sizes.

	small		medium		big	
	N	mean	N	mean	N	mean
dtaxcred	434	0.0161	6,046	0.0288	5,069	0.0527
taxcredits	434	1,088	6,046	3,698	5,069	20,873
cleaner production	434	79,732	6,046	52,800	5,069	327,871
end-of-pipe	434	60,443	6,046	48,916	5,069	203,520
size	434	34.78	6,046	127.1	4,983	503.3
green size	434	0.912	6,046	1.140	5,069	2.961
green salary	434	24,358	6,046	42,930	5,069	121,640

Table 5.4: Difference-in-difference. Effects on different investment measures.

	(1)	(2)	(3)	(4)	(5)	(6)
	CP	lnCP	lagCPpc	EP	lnEP	lagEPpc
post2011	22,297	0.116	454.6	36,148	0.217*	601.7**
	(35,626)	(0.101)	(333.8)	(22,861)	(0.130)	(254.5)
dtaxcred	1.430e+06***	1.820***	12,973*	520,128***	1.570***	3,102
	(379,877)	(0.195)	(7,521)	(140,467)	(0.230)	(2,029)
diff	-831,845**	-0.263	-11,789	-370,645***	-0.646**	-3,431*
	(409,235)	(0.230)	(7,705)	(135,04)	(0.278)	(1,939)
Observations	11,487	3,352	11,442	11,487	2,603	11,442
R-squared	0.060	0.128	0.014	0.044	0.116	0.025

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.5: Difference-in-difference. Effects on specific green investments.

	(1)	(2)	(3)
	lnEPair	lnCPair	lnCPenc
post2011	0.0173	0.343*	-0.0475
	(0.157)	(0.189)	(0.181)
dtaxcred	5.302***	7.501***	2.384***
	(0.813)	(0.876)	(0.720)
diff	-1.674*	-0.0930	1.249
	(0.946)	-1.129	(0.895)
Observations	11,487	11,487	11,487
R-squared	0.046	0.067	0.038

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in the log of equipment investment. This measure is used for several types of technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.6: Difference-in-difference. Dynamic Direct Effects of EI tax credit on green investment.

	(1)	(2)	(3)	(4)	(5)
	lnCP	lnCPair	lnCPenc	lnEP	lnEPair
2010.year#1.dtaxcred	0.175	1.372	-0.707	0.0658	1.302
	(0.336)	(1.606)	(1.325)	(0.411)	(1.484)
2011.year#1.dtaxcred	-0.258	0.0330	0.838	0.203	-0.496
	(0.349)	(1.650)	(1.517)	(0.372)	(1.506)
2012.year#1.dtaxcred	-0.129	0.122	-1.450	-0.0500	-1.405
	(0.333)	(1.493)	(1.263)	(0.373)	(1.398)
2013.year#1.dtaxcred	-0.381	-1.835	-1.199	-0.139	-1.132
	(0.320)	(1.441)	(1.355)	(0.394)	(1.200)
2014.year#1.dtaxcred	0.203	-0.0383	0.246	-0.685	-2.991**
	(0.325)	(1.427)	(1.209)	(0.472)	(1.204)
Observations	3,404	11,573	11,573	2,656	11,573
R-squared	0.029	0.013	0.002	0.028	0.022
Number of newfirm	1,279	2,213	2,213	1,127	2,213

Note: Each coefficient is estimated from different regression following the dynamic specification. The dependent variables are the amount in the log of green technology investment. This measure is used for several types of technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1 Year and firm fixed effects included for all estimations.

Table 5.7: Difference-in-difference. Indirect effects of EI tax credit on other variables.

	(2)	(3)	(4)
	lnsize	lngrsize	lngrsalary
post2011	0.000547	0.0809*	0.140
	(0.0112)	(0.0437)	(0.105)
dtaxcred	0.182***	1.559***	2.645***
	(0.0684)	(0.137)	(0.228)
diff	0.0358	-0.0965	-0.775**
	(0.0631)	(0.157)	(0.380)
Observations	11,487	11,487	11,487
R-squared	0.410	0.065	0.042

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in the log form. This measure is used for several types of firm level variables. Standard errors in parentheses are clustered at the firm level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5.8: Difference-in-difference. Dynamic indirect effects of EI tax credit on other variables.

	(1)	(2)	(3)
	lnsize	lngrsize	lngrsalary
2010.year#1.dtaxcred	0.0595*	-0.0273	0.211
	(0.0350)	(0.103)	(0.265)
2011.year#1.dtaxcred	0.0638*	-0.164	-0.272
	(0.0374)	(0.136)	(0.321)
2012.year#1.dtaxcred	0.0589*	-0.336**	-1.214**
	(0.0350)	(0.164)	(0.527)
2013.year#1.dtaxcred	0.00700	-0.370**	-1.008**
	(0.0478)	(0.170)	(0.474)
2014.year#1.dtaxcred	-0.00775	-0.244**	-1.314***
	(0.010)	(0.048)	(0.122)
Observations	11,487	11,487	11,487
R-squared	0.181	0.006	0.006
Number of newfirm	2,211	2,211	2,211

Note: Each coefficient is estimated from different regression following the dynamic specification. The dependent variables are the amount in the log form. This measure is used for several types of firm level variables. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1 Year and firm fixed effects included for all estimations.

Table 5.9: Difference-in-difference. Heterogeneous effects of firm size on investment.

	(1)	(2)	(3)	(4)	(5)	(6)
	lnCP	lnCP	lnCP	lnEP	lnEP	lnEP
	small	med	big	small	med	big
ddd	3.079**	0.764	-0.953**	-1.674	0.327	-0.192
	(1.276)	(0.435)	(0.437)	-1.276	(0.611)	(0.599)
Observations	3,404	3,404	3,404	2,656	2,656	2,656
R-squared	0.090	0.124	0.130	0.112	0.132	0.137

Note: Each coefficient is estimated from different regression following the heterogeneous specification. The dependent variables are the amount in the log form. Those measures are used for different green technology investments. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5.10: Difference-in-difference. Heterogeneous effects of NO2 polluters on Investment.

	(1)	(2)	(3)	(4)	(5)	(6)
	lnEP	lnEP	lnEP	lnCP	lnCP	lnCP
	highNO2	medNO2	lowNO2	highNO2	medNO2	lowNO2
ddd	-0.473	0.646	0.405	0.0541	-0.0106	0.105
	(0.539)	(0.670)	(0.544)	(0.507)	(0.561)	(0.449)
Observations	2,603	2,603	2,603	3,352	3,352	3,352
R-squared	0.141	0.128	0.158	0.122	0.127	0.131

Note: Each coefficient is estimated from different regression following the heterogeneous specification. The dependent variables are the amount in the log form. Those measures are used for different green technology investments. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.11: Difference-in-difference. Heterogenous effects of NO2 polluting sectors on lnCPair and lnCPenc.

	(1)	(2)	(3)	(4)	(5)	(6)
	lnCPair highNO2	lnCPair medlowNO2	lnCPair lowNO2	lnCPenc highNO2	lnCPenc medlowNO2	lnCPenc lowNO2
ddd	4.178*	3.637	-5.506**	-2.420	4.073*	-0.979
	(2.466)	(2.617)	(2.204)	(1.875)	(2.349)	(1.756)
Observations	11,487	11,487	11,487	11,487	11,487	11,487
R-squared	0.089	0.081	0.096	0.032	0.032	0.032

Note: Each coefficient is estimated from different regression following the heterogeneous specification. The dependent variables are the amount in the log form. Those measures are used for different green technology investments. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5.12: Simple OLS. Different measures of green technologies.

	(1)	(2)	(3)	(4)	(5)	(6)
	lnCP	lagCPpc	CP	lnEP	lagEPpc	EP
lntaxcredit	0.0951***	411.9**	55,865***	0.0721***	120.7**	16,612***
	(0.00562)	(192.9)	(10,445)	(0.00761)	(48.28)	(3,907)
lnsize	0.651***	-64.65	229,983***	0.554***	-197.5	153,745***
	(0.0404)	(652.6)	(22,608)	(0.0432)	(327.9)	(17,130)
Observations	3,352	11,442	11,487	2,603	11,442	11,487
R-squared	0.170	0.012	0.069	0.181	0.018	0.071

Note: Each coefficient is estimated from different regression following the OLS specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.13: Simple OLS. Different green technologies.

	(1)	(2)	(3)	(4)	(5)
	lnCP	lnCPair	lnCPenc	lnEP	lnEPair
lntaxcredit	0.0951***	0.406***	0.168***	0.0721***	0.218***
	(0.00562)	(0.0295)	(0.0254)	(0.00761)	(0.0259)
lnsize	0.651***	1.284***	1.470***	0.554***	0.922***
	(0.0404)	(0.0909)	(0.0840)	(0.0432)	(0.0769)
Observations	3,352	11,487	11,487	2,603	11,487
R-squared	0.170	0.092	0.050	0.181	0.077

Note: Each coefficient is estimated from different regression following the OLS specification. The dependent variables are the amount in the log of equipment investment. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.14: Second stage IV. Different measures of green technologies. IV: taxcred2008

	(1)	(2)	(3)	(4)	(5)	(6)
	lnCP	CP	lagCPpc	lnEP	EP	lagEPpc
lntaxcredit	0.305***	268,243***	502.7***	0.208***	91,703**	172.5
	(0.0710)	(94,051)	(161.2)	(0.0689)	(45,953)	(149.6)
lnsize	0.619***	143,679***	145.5	0.590***	132,324***	-242.5
	(0.0715)	(32,333)	(112.2)	(0.0775)	(36,180)	(232.5)
Observations	2,833	9,972	9,930	1,991	9,972	9,930
R-squared	0.000	0.000	0.000	0.095	0.000	0.019

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.15: Second stage IV. Different green technologies. IV: taxcred2008

	(1)	(2)	(3)	(4)	(5)
	lnCP	lnCPair	lnCPenc	lnEP	lnEPair
lntaxcredit	0.305***	1.391***	0.407**	0.208***	0.918***
	(0.0707)	(0.290)	(0.173)	(0.0689)	(0.264)
lnsize	0.619***	0.968***	1.425***	0.590***	0.648***
	(0.0713)	(0.157)	(0.130)	(0.0775)	(0.134)
Observations	2,833	9,972	9,972	1,991	9,972
R-squared	0.000	0.000	0.037	0.095	0.000

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in the log of equipment investment. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.16: Instrumental Variable approach. Effect on size, green employees and green R&D. IV: taxcredit2008

	(1)	(2)	(3)	(4)
	lnsize	lngrsize	lngrsalary	lngrRD
lntaxcredit	-0.00988	0.0685***	0.102**	0.0819***
	(0.0135)	(0.0245)	(0.0451)	(0.0311)
lnsize				0.300*
				(0.722)
Observations	11,487	11,573	11,573	520
R-squared	0.023	0.047	0.043	0.166

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in the log form. Those measures are used both for employment and R&D outcomes. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.17: Robustness. DiD approach. The effect on private environmental R&D.

	(1)
	lngrRD
post	-0.333
	(0.287)
dtaxcred	1.217***
	(0.457)
_diff	0.565
	(0.648)
Observations	520
R-squared	0.104

Note: Each coefficient is estimated from different regression following the main specification. The dependent variable is the amount in the log of expenditure on environmental R&D. This measure is used for several types of technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.18: Robustness. DiD approach. Effects on different measures for aggregate environmental tax being the treatment.

	(1)	(2)	(3)	(4)	(5)	(6)
	CP	lnCP	lagCPpc	EP	lnEP	lagEPpc
post	18,633	0.114	381.2	39,081*	0.248*	508.1*
	(32,517)	(0.107)	(488.4)	(21,021)	(0.139)	(270.6)
dtaxes	487,573***	0.874***	3,771	264,569***	0.835***	1,538
	(145,883)	(0.185)	(2,864)	(79,175)	(0.178)	(1,281)
_diff	-196,523	-0.146	-2,599	-112,658	-0.205	-597.9
	(133,446)	(0.182)	(2,879)	(80,472)	(0.197)	(1,421)
Observations	11,487	3,352	11,442	11,487	2,603	11,442
R-squared	0.029	0.074	0.003	0.021	0.058	0.004

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in the log of equipment investment. This measure is used for several types of technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.19: Robustness. DiD approach. Effects on different measures for air tax being the treatment.

	(1)	(2)	(3)	(4)	(5)	(6)
	CP	lnCP	lagCPpc	EP	lnEP	lagEPpc
post	26,595	0.125	466.6	38,901*	0.237*	603.4**
	(32,354)	(0.103)	(416.3)	(21,069)	(0.132)	(240.3)
dairtaxes	2.165e+06***	2.279***	18,476*	901,897***	2.172***	9,190*
	(599,203)	(0.289)	(10,798)	(289,488)	(0.243)	(4,977)
_diff	-884,882	-0.529	-13,541	-393,456	-0.476	-4,951
	(567,040)	(0.306)	(10,869)	(310,249)	(0.257)	(5,574)
Observations	11,487	3,352	11,442	11,487	2,603	11,442
R-squared	0.074	0.114	0.005	0.034	0.096	0.006

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in the log of equipment investment. This measure is used for several types of technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.20: Robustness. DiD approach. Effects on different measures for other environmental taxes being the treatment.

	(1)	(2)	(3)	(4)	(5)	(6)
	CP	lnCP	lagCPpc	EP	lnEP	lagEPpc
post	-10,196	0.0599	65.16	22,879	0.207	430.7*
	(32,664)	(0.102)	(259.2)	(23,205)	(0.133)	(255.0)
dothertaxes	165,229	0.718**	2,124	202,250	0.687**	184.5
	(150,356)	(0.304)	(3,593)	(123,790)	(0.296)	(1,000)
_diff	-6,678	-0.00597	-1,843	-46,028	-0.0698	-18.59
	(174,210)	(0.343)	(3,594)	(103,196)	(0.341)	(1,128)
Observations	11,487	3,352	11,442	11,487	2,603	11,442
R-squared	0.019	0.057	0.002	0.016	0.044	0.003

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in the log of equipment investment. This measure is used for several types of technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.21: Robustness. DiD approach. Effects on different measures for other environmental taxes being the treatment.

	(1)	(2)	(3)	(4)	(5)	(6)
	CP	lnCP	lagCPpc	EP	lnEP	lagEPpc
post	12,712	0.109	-86.41	30,899	0.232*	354.5
	(31,853)	(0.105)	(278.8)	(19,918)	(0.134)	(266.6)
dwastetaxes	186,265	0.282	-751.9	104,007	0.152	-856.1
	(148,839)	(0.235)	(1,485)	(74,030)	(0.238)	(677.9)
_diff	-201,168	-0.344	840.2	-69,208	-0.204	767.9
	(138,875)	(0.233)	(1,584)	(80,871)	(0.243)	(724.6)
Observations	11,487	3,352	11,442	11,487	2,603	11,442
R-squared	0.018	0.048	0.002	0.014	0.037	0.004

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5.22: Robustness. DiD approach. Effects on different measures for 2010-2014 time period.

	(1)	(2)	(3)	(4)	(5)	(6)
	CP	lnCP	lagCPpc	EP	lnEP	lagEPpc
post	25,189	0.118	396.2	37,295	0.264*	543.0
	(44,952)	(0.127)	(1,463)	(30,784)	(0.158)	(766.8)
dtaxcred	1.489e+06***	1.888***	14,384***	570,164***	1.645***	4,228**
	(100,674)	(0.186)	(3,287)	(68,944)	(0.217)	(1,722)
_diff	-816,135***	-0.288	-11,422***	-351,634***	-0.612**	-3,079
	(127,234)	(0.234)	(4,151)	(87,133)	(0.286)	(2,175)
Observations	11,487	3,352	11,442	11,487	2,603	11,442
R-squared	0.042	0.110	0.004	0.021	0.068	0.004

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.23: Robustness. DiD approach. Effects on specific investments for 2010-2014 time period.

	(1)	(2)	(3)
	lnEPair	lnCPair	lnCPenc
post	0.0150	0.331*	-0.0711
	(0.157)	(0.189)	(0.181)
dtaxcred	5.066***	7.275***	2.409***
	(0.810)	(0.876)	(0.717)
_diff	-1.740*	-0.0940	1.407
	(0.938)	(1.126)	(0.894)
Observations	11,487	11,487	11,487
R-squared	0.060	0.076	0.031

Note: Each coefficient is estimated from different regression following the main specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.24: Robustness. Instrumental Variable approach. Effect on different measures of green technologies. IV: lagtaxcredit

	(1)	(2)	(3)	(4)	(5)	(6)
	lnCP	CP	lagCPpc	lnEP	EP	lagEpc
lntaxcredit	0.132***	90,565***	351.4**	0.100***	11,973	19.66
	(0.0148)	(26,286)	(156.6)	(0.0184)	(8,138)	(33.27)
lnsize	0.658***	207,410***	175.6	0.606***	163,047***	-218.6
	(0.0660)	(41,787)	(128.9)	(0.0771)	(37,550)	(238.6)
Observations	2,684	9,315	9,275	1,891	9,315	9,275
R-squared	0.158	0.032	0.013	0.190	0.073	0.022

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.25: Robustness. Instrumental Variable approach. Effect on different green technologies. IV: lagtaxcredit

	(1)	(2)	(3)	(4)	(5)
	lnCP	lnCPair	lnCPenc	lnEP	lnEPair
lntaxcredit	0.132***	0.650***	0.321***	0.100***	0.293***
	(0.0148)	(0.0797)	(0.0674)	(0.0184)	(0.0644)
lnsize	0.658***	1.232***	1.460***	0.606***	0.868***
	(0.0660)	(0.151)	(0.130)	(0.0771)	(0.128)
Constant	7.928***	-9.519***	-12.42***	7.529***	-10.36***
	(0.409)	(1.027)	(0.877)	(0.496)	(0.844)
Observations	2,684	9,315	9,315	1,891	9,315
R-squared	0.158	0.073	0.045	0.190	0.071

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in the log of equipment investment. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.26: Robustness. Instrumental Variable approach. Effect on size, green employees and green R&D. IV: lagtaxcredit

	(1)	(2)	(3)	(4)
	lnsize	lngrsize	lngrsalary	lngrRD
lntaxcredit	0.0403***	0.157***	0.209***	0.145***
	(0.00778)	(0.0134)	(0.0313)	(0.0523)
lnsize				0.267
				(0.186)
Constant	5.498***	0.291	10.17***	8.844***
	(0.0750)	(0.181)	(0.393)	(1.287)
Observations	9,315	9,360	9,360	386
R-squared	0.030	0.036	0.040	0.189

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in the log form. Those measures are used both for employment outcomes and R&D. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.27: Robustness. Instrumental Variable approach using data from 2010-2014. Effect on different measures of green technologies. IV: taxcred2008

	(1)	(2)	(3)	(4)	(5)	(6)
	lnCP	CP	lagCPpc	lnEP	EP	lagEPpc
lntaxcredit	0.305***	268,243***	502.7***	0.208***	91,703**	172.5
	(0.0707)	(94,051)	(161.2)	(0.0689)	(45,953)	(149.6)
lnsize	0.619***	143,679***	145.5	0.590***	132,324***	-242.5
	(0.0713)	(32,333)	(112.2)	(0.0775)	(36,180)	(232.5)
Observations	2,833	9,972	9,930	1,991	9,972	9,930
R-squared	0.000	0.000	0.000	0.095	0.000	0.019

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in absolute terms in euros, the log of equipment investment and the amount of investment in per capita terms. Those measures are used both for investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.28: Robustness. Instrumental Variable approach using data from 2010-2014. Effect on different green technology types. IV: taxcred2008

	(1)	(2)	(3)	(4)	(5)
	lnCP	lnCPair	lnCPenc	lnEP	lnEPair
lntaxcredit	0.305***	1.391***	0.407**	0.208***	0.918***
	(0.0707)	(0.290)	(0.173)	(0.0689)	(0.264)
lnsize	0.619***	0.968***	1.425***	0.590***	0.648***
	(0.0713)	(0.157)	(0.130)	(0.0775)	(0.134)
Constant	9.042***	-3.561	-11.69***	8.197***	-5.310***
	(0.542)	(2.199)	(1.424)	(0.584)	(2.016)
Observations	2,833	9,972	9,972	1,991	9,972
R-squared	0.000	0.000	0.037	0.095	0.000

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in the log of equipment investment. Those measures are used both for specific investment in cleaner production and end-of-pipe technologies. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

Table 5.29: Robustness. Instrumental Variable approach using data from 2010-2014. Effect on other variables. IV: taxcred2008

	(1)	(2)	(3)	(4)
	lnsize	lngrsize	lngrsalary	lngrRD
lntaxcredit	0.0403***	0.157***	0.209***	0.145***
	(0.00778)	(0.0134)	(0.0313)	(0.0523)
lnsize				0.267
				(0.186)
Observations	9,315	9,360	9,360	386
R-squared	0.030	0.036	0.040	0.189

Note: Each coefficient is estimated from different regression following the IV specification. The dependent variables are the amount in the log form. Those measures are used both for employment outcomes and R&D. Additional controls are firm size, sector and year dummies. Standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1

6 Conclusions

This PhD thesis provides abundant empirical evidence on the effectiveness of environmental policy instruments alone and as a policy-mix, looking at its effect on green investment and employment. Finally, it also studies the social welfare outcomes of the implementation of the two environmental policy instruments – environmental taxes and public financing. The most direct and obvious conclusion that can be extracted from this thesis is that properly designed policy-instruments are necessary to incentivise firms to invest in green technologies, especially if we want to encourage investment in cleaner production technologies over pollution abating technologies, which is not an easy task to do.

I refer to the industrial and energy firms because on one hand, they contribute significantly to air pollution, waste pollution and address resource scarcity, making it even more important for them to invest in technologies that would significantly address the negative externalities. In this regard, this thesis contributes to the literature on causal evidence of environmental policy instruments on firm behaviour, as well as social welfare outcomes arising from different policy scenarios.

More specifically, the second chapter of this thesis contributes to the literature on social welfare outcomes arising from the different environmental policy scenarios. In the analysed model we are faced with the asymmetry of decision making. While the regulator favours green investment, which reduces the total pollution level, firms prefer to keep producing using their dirty technology in the symmetric scenarios. The question that arises, therefore, is how such an equilibrium can be induced? It might be the case that with more money being directed at R&D, technologies would become more efficient and cheaper, making it more desirable for firms. From the policy perspective, especially investment in private environment R&D is highly encouraged.

Our model could be extended along different dimensions. First, it would be interesting to investigate the social welfare outcome if firms could be faced simultaneously with uniform emission fee and investment subsidy. It is interesting if in that case, firms would be incentivised to invest in green technology even if the emission fee would not be taxed at the optimal level. Also, another interesting extension would be to analyze companies within the market competing over heterogeneous goods e.g. in the manufacturing sector, where similar green investments are made by the firm.

In the third chapter of this thesis, I contribute to the literature on drivers of eco-innovations by identifying crucial regulatory factors and firms' organizational capabilities for encouraging enterprises to invest in green technologies. 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.

Firstly, environmental taxation in Spain seems to be rather ineffective at stimulating investment in greener technologies, both for end-of-pipe as well as for cleaner production technologies. We argue that in the Spanish context this might be caused by relatively low rates, environmental taxes might not be doing their task effectively. At the same time, firms react positively to investment subsidies and investment tax incentives. Tax credits seem to be especially successful at financing cleaner production technologies while subsidies are positively related to both EP and CP investments. 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.

Additionally, we can conclude that organization capabilities matter for investment in green technologies. Admittedly, hiring green employees is a strong factor pushing each firm towards green investments, while the relationship between green procedures and certifications is not clear.

Those results are interesting both for policymakers and managers of companies committed to investment in environmental technologies. Results provide evidence that public incentives produce better stimulus than taxation at low rates; so policymakers 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 the environment, and ultimately, we believe will drive improvements in the greening of firms' performance.

The fourth chapter of this thesis is aimed at evaluating the effectiveness of environmental taxes in Spain at different levels of taxation, in the absence and in combination with public finance - an equally important market-based instrument addressing the market failure of firms. The evaluation is performed with regards to whether the implementation of such environmental policy instrument in Spain is successful at encouraging adoption of green technologies among manufacturing firms.

Our results suggest that environmental taxation is effective at encouraging adoption of both types of green technologies. That being said, once we split our treatment to different categories, we find that low levels of environmental taxation do not induce further investments in process eco-innovations. Therefore, we show that the average treatment effect masks substantial heterogeneity across the taxation level groups. Results also consistently show that increasing the amount of taxation increases also the subsequent adoption of green technologies. In the sample of fully supported environmental tax payers, it seems to emerge that firms that are required to pay around EUR 2,500 per year already exhibit significantly higher investment in green technology than under lower amounts of taxation.

Additionally, our findings seem to suggest that even low levels of environmental taxation can be effective at inducing investment in green technology if combined with public financing. However, once again the effect is the largest when environmental taxation is at the medium level. That being said, if the regulator is reluctant to increase the taxation level in fear of hurting firms' competitiveness, even low levels of taxation can be effective in combination with public support. Large levels of environmental though very effective on its own, are not strongly encouraged with combination of public financing.

Overall findings seem to suggest a substantial re-design of modulation of environmental taxation. It is also clear that Spanish government makes only limited use of environmental taxation, should they wish to implement such taxes at the national level, they could ve very successful at both pushing industry towards green technology adaptation and collecting significant revenues, which could later be recycled by transferring it to environmental funds or simple redistributed back to firms in form of subsidies for green investment as also suggested by Böhringer, Garcia-Muros, and González-Eguino (2019). Although this result has shed some light on the heterogeneous effects of environmental taxation, it also asks for further research to investigate the policy-mix of environmental taxation with different specific types of public finance such as subsidies and investment tax incentives.

The fifth chapter of this thesis analyses, in turn, a large-scale national tax incentive program in Spain, which started in 1996 and finished in 2015. Due to data availability, I focus on the 2008-2014 time window. The findings seem to suggest that encouragement to eliminate the EI tax incentives from the Spanish Corporate Income Tax and fears that they were not successful enough was unwarranted. While it is true that the EI tax credit favoured pollution abating over energy efficient technologies, it did increase substantially investment – and even in the times of financial crises, when the capital market failure was particularly severe. The EI tax credit was found to have positive indirect effects on both number of green employees and private environmental R&D, which could have additional positive spill-over effects. With regards to the policy change, which was aimed at disincentivizing financing of pollution abating technologies and encouraging – it was assessed as semi-effective. While it is true that it did discourage investment in end-of-pipe technologies, especially those aimed at air-pollution reduction, we could not observe investment in cleaner production technologies increasing as a result. This could suggest that tax incentives should be more clearly defined, as to avoid (1) technological lock-down in old technologies, (2) encourage technologies that do change the production process and result in smaller usage of natural resources e.g energy consumption. One of the caveats of the studied EI tax credit was the confusion it created not only with respect to eligibility criteria but also the definition of technologies that it aimed to finance. Lastly, it is quite comforting to observe, however, that the tax incentive seemed to have addressed the capital market failure of small firms for the investment in cleaner production technologies. The results from the heterogeneous analysis also point out to the fact that this positive effect exists in stark contrast to the reduction in the investment suffered by the big firms.

The analysis in this doctoral thesis has some limitations. Firstly, the confidentiality rules of the Spanish Institute of Statistics (INE) prevent 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, pollution emissions etc. 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 or using geographic boundaries as a natural discontinuity.

There exists a platform for further research. Firstly, it would be interesting to investigate if and how did the specific environmental taxes affect the firms' size, and their location decisions. Did the firms hire additional green workers, did they reduce their regular staff, and hence did the environmental taxes affect Spanish competitiveness in manufacturing? Did they decide to move to regions with lower environmental taxes? More research is also needed in respect to assessment of whether the environmental investment tax incentives are the most efficient way to improve firms' economic outcomes, and how did the tax credit affect affected the employment outcomes both over the short and the long run.

The last point I would like to consider is the "big data" era we are living in. It is very surprising how little data availability there is on such an important public policy matter. Statistical offices in each country could take advantage of the plethora of data they gather at the firm level and use this massive information in combination with other existing databases to support research-based public policy. More research-based policy is not needed, it is critical, if we truly want to transition to a sustainable economy.

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