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To innovate or not - that is the question

A study investigating how the number of patents applications has been affected by the EU ETS

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Abstract

This thesis examines how patent applications (as a proxy measure for innovation) in regulated sectors were affected by the implementation of the European Emission Trading System (the EU ETS) in 2005. The studied EU ETS-regulated sectors are cement and manufacturing of iron and steel with aviation sector as a placebo check. To test this relationship, I apply a difference-in-differences strategy with a pooled data set between 2000 and 2016. The treatment group consists of Belgium, France, Germany, Italy, Spain and Sweden. While Canada, Mexico, Russia and Taiwan represent the control group. Patent data for the EU ETS-regulated countries is defined by applications to the European Patent Office, while for non-EU ETS regulated countries it comes from their respective national patent office. Fixed effects were employed to control for the presence of clusters in sectors and country. No relationship between patent applications and the chosen EU ETS-regulated sectors due to the EU ETS can be established in this thesis. This differs from the positive effect found in previous research. Such a conclusion in this thesis holds as the overall evidence for the three EU ETS-regulated sectors.

Key words: aviation, business enterprise investments, cement, difference-in-differences, emissions, environmental regulation, EPO, Espacenet, the EU ETS, GDP growth, gross domestic investments, innovation, IPC, manufacturing of iron and steel, OECD, patent applications, patents, Porter Hypothesis, R&D

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PS. The title is inspired from other EU ETS research that uses a Shakespeare quote in its title, albeit a different research area within EU ETS than this thesis.

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Abbreviations

BERD - Business Enterprise Investments on R&D

CPC - Cooperative Patent Classification

EEA - European Economic Area

EFTA – European Free Trade Associations

ENV-TECH – Selected Environmental-related Technologies

EPO - European Patent Office

EUAs – Emission Union Emission Allowances

EU ETS - European Union Emission Trading Scheme

GERD - Gross Domestic Investments on R&D

IPC - International Patent Classification System

JPO - Japan Patent Office

PACE - Pollution Abatement Control Expenditure

PATSTAT – Worldwide Patent Statistics (from EPO)

PCT – Patent Cooperation Treaty

PH - Porter Hypothesis

SIC - Standard Industrial Classification

USPTO - US Patent and Trademark Office

WIPO – World Intellectual Property Organization

1. Introduction

1.1 Background

Innovation has for decades been regarded as a key factor in minimizing the consequences caused by global warming. During the last thirty years, technological development occurred in a myriad of fields related to emission abatement (Andersson & Widegren, 2006; Calel & Dechezleprêtre, 2016; Kemp, 2000). At the same time, environmental regulations have become more common globally and aim to positively impact the ongoing environmental degradation. This in turn resulted in a growing body of research looking at the relationship between innovation and implementation of different types of environmental regulations (Jaffe et al., 2005; Martin et al., 2016; Popp, 2019). One popular focus in this research field is the European Union Emission Trading Scheme (the EU ETS). This scheme plays an important role for the EU in achieving its two main environmental goals (EC, n.d.a; EC, n.d.b). These are a climate-neutral EU by 2050 and reducing greenhouse gas emissions by 55 percent, in comparison to 1990 levels, before 2030. According to the European Commission (the EC), the EU ETS both encourages investments in low-carbon technologies and lower emissions over time. Porter Hypothesis further emphasise the importance of innovation by stating that a spur of innovation will occur as a result of the implementation of stricter environmental regulation such as the EU ETS (Porter, 1991). The research question in this thesis is thus: whether the implementation of the EU ETS has affected innovation, as proxied through patent application counts.

The EU ETS is regarded as the first large-scale emission trading scheme of its kind and was implemented in 2005 (EC, n.d.a.; EC, 2015). Altogether the scheme regulates about 40 percent of the total greenhouse gas emissions in the EU and works as a cap-and-trade scheme. Enforcing a cap on emissions means that a limit is set on the total number of EU ETS-regulated installations. The EU impose this limit by giving out a certain number of emission allowances (EUAs) to EU ETS-regulated industries. This limit (i.e. cap) is reduced over time across EU ETS-regulated sectors and thereby decreases emission levels in the long run. Another integral part of the EU ETS is the trading aspect, which means that EU ETS-regulated firms can trade their permits with each other. Such trading is possible when the EU ETS-regulated industries use fewer emission allowances than they got (sell the extra permits) or have less than they need (buy more permits). Besides that, the EU ETS sets a price on the emissions in its regulated industries. This act of putting a price on emission means that emissions as a negative externality become a cost for EU ETS-regulated firms.

Given that innovation by itself is a broad subject, further delimitation of the purpose of this thesis is needed. There are several ways of identifying innovation data. One common method is to use patents as a proxy measure for innovation trends, which is the method adopted in this thesis (Griliches, 1990; Jaffe & Palmer, 1997). Patents are described as "…grant their owner a set of rights of exclusivity over an invention (a product or process that is new, involves an inventive step and is susceptible of industrial application) …" (OECD, 2009, p. 18). OECD (2009) stated that patent application data is regarded as the best way of capturing innovation trends and thereby this thesis uses such data. Additionally, research & development (R&D) variables are included in this thesis as Griliches (1990) asserted that there is a strong positive link between R&D and patent counts. Gross domestic product (GDP) growth is applied in this thesis as there said to be a relationship between GDP growth and patent counts as well (Bel & Joseph, 2018; Griliches, 1984).

This thesis will therefore concentrate on two industries that partook in the EU ETS since its start, the cement and the manufacturing of iron and steel sectors. In addition to those sectors, the aviation sector (which partook in the EU ETS since 2012) is included as a placebo check (EC, 2015). Studying these sectors is also of interest from an environmental perspective, given the size of these sectors´ greenhouse gas emissions. The cement sector is 8 percent of the global greenhouse gas emissions, iron and steel 4 to 7 percent of the total on EU level (not including the UK), and 3.6 percent only from aviation out of the total EU level emissions (including the UK) (EASA, 2019; Pardo et al., 2018; Rogers, 2018).

To test for the treatment effect on the chosen sectors, the difference-in-differences method was used. As an identification strategy, the EU ETS-regulated countries were picked as the treatment group and non-EU ETS regulated countries as the control group. The chosen EU ETS-regulated countries were Belgium, France, Germany, Italy, Spain and Sweden. On the other hand, the selected non-EU ETS regulated countries were Canada, Mexico, Russia and Taiwan.[1] This data set based on yearly country-level statistics was used to evaluate whether the number of patent applications in EU ETS-regulated sectors was affected by the EU ETS.

[1] In an international context, there are several names used for many of the countries (Espacenet, 2021; OECD, 2021a; OECD, 2021b, 2021c). For Taiwan, two different names are given by EPO and OECD. While OECD applied the use of Chinese Taipei in their data sets, EPO used Taiwan. This thesis has chosen to adhere to the name Taiwan. When discussing South Korea later on, the thesis uses the name South Korea as it makes it clearer which Korea is referred to (most databases use Korea).

The contributions from this thesis are multifold. This thesis covers the aviation sector, which was not explored in previous EU ETS innovation research. While the cement and the manufacturing of iron and steel sector were included in earlier EU ETS literature such as Borghesi et al. (2015), other sectors such as pulp and paper were researched more thoroughly (Fontini & Pavan, 2014; Pontoglio, 2008; Rogge et al., 2011). Furthermore, this thesis differs by utilising a longer time series (2000 to 2016) whereas most EU ETS research so far focused on the first two phases (2005-2007 and 2008-2012). Having long time series for patent data is a strength of this thesis, given that the innovation process often takes time and thus certain types of innovation effects may otherwise not be included in estimated results (Bernard, 2006; Pontoglio, 2008). Besides that, the identification strategy in this thesis was not applied in previous EU ETS innovation research. A similar identification strategy was used by Franco and Marin (2017), but they explored the connection between patents and regulation on a broader level and not explicitly for the EU ETS. I thus argue that my thesis differs from and contributes to existing research in three areas: sectors, time series, and identification strategy.

This thesis finds no significant effect of the implementation of the EU ETS on patent applications for the studied sectors in the six chosen EU ETS-regulated countries (Belgium, France, Germany, Italy, Spain, and Sweden). Significant differences in patent application counts were observed among the countries and sectors. However, such differences are unrelated to the implementation of the EU ETS and these differences are controlled for using fixed effects, which account for characteristics of countries and sectors that remain constant over time.

1.2 Limitations

As patents may exclude competitors from the market where they are used, patents can distort the competitive environment (Jaffe et al., 2002; OECD, 2009). Therefore, competition policy is often utilised to combat these issues. According to the EC (2016), there have been concerns of competition effects in the European steel market regarding trading prices. The subject of competition and its relation to patents is not studied in this thesis. Nevertheless, it is plausible that innovation trends, as proxied by patent applications in this thesis, could have been impacted by a restrictive competition environment. This could not be examined in this thesis, because that the OECD patent database used in this thesis does not provide firm information.

Dechezleprêtre and Sato (2017) described that innovation is crucial for firms today to stay competitive. It is important to point out that underlying motivations for firms exist and could explain areas such as investment decisions that lie outside the scope of this thesis. Note that how EU ETS affected investment decisions regarding innovation in EU ETS-regulated firms was also previously discussed in the literature (for example Hoffmann, 2007; Pontoglio, 2008).

Moreover, Ambec and Barla (2006) asserted that firms could be negatively impacted by environmental regulations through higher costs and decreasing profits. Such an angle is another limitation of this thesis for two reasons. It is not discussed in the majority of the EU ETS innovation literature. Also, it is hard to disentangle that effect from the data applied in this thesis.

1.3 Disposition

This thesis is organised as follows. In chapter 2, a more detailed background is given for the EU ETS and patents. Then chapter 3 will describe the relevant theoretical framework. After that, chapter 4 provides an overview of the related previous literature. From there, chapter 5 introduces the data including the motivation of chosen variables and data limitations. Chapter 6 focuses on the econometric model and method applied in this thesis. In chapter 7, the results are provided and summarised. Subsequently, chapter 8 discusses the findings with relevance to earlier literature, data quality and from a broader perspective. Chapter 9 presents the overall conclusion and suggestions for future research. Lastly, follow the list of sources and appendices.

2. Overview of the EU ETS and Patents

2.1 The EU ETS

Central to this thesis is the connection between the EU ETS and patent applications. Therefore, this section will give an overview of the scheme so far and future changes.

The EU ETS covers over 10 000 installations in regulated industries (EC, n.d.a). For a detailed outlook on such industries, see below. As of 2005, 25 Member States partook in the EU ETS[2] with Bulgaria and Romania committing when they became part of the EU in 2007 (EC, 2015; EUROSTAT, 2020a). Three new countries joined the scheme (Iceland, Liechtenstein and Norway) during phase II (2008-2012) (EC, n.d.c).[3] Croatia became part of the scheme in

[2] The following countries were included in the EU ETS from 2005; Austria, Belgium, Cyprus, the Czech Republic (also referred to as, Czechia), Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and the UK (EC, 2015; EUROSTAT, 2020a).
[3] Because of these three countries joining the EU ETS as of phase II, then all the EEA-EFTA (European Economic Area-European Free Trade Association) countries were part of the EU ETS (EC, 2015).

January 2013, which was at the beginning of phase III (2013-2020).[4] From a legal perspective, it is important to highlight central directives for the EU ETS. Directive 2003/87/EC describes the system for trading with emission allowances within the EU (EUR-Lex, 2003). This directive 2003/87/EC was last updated in 2014 by the regulation (EU) No 42/2014 (EUR-Lex, 2014).

At the beginning of the scheme, the cap was set per country but from phase III (2013-2020) an EU-wide cap was used instead (EC, n.d.a). Stringency in the scheme is visible when comparing the permit allocations between each phase, because the caps become stricter with each phase (EC, n.d.a; EC, 2015). To date, the EU ETS has consisted of three phases and is currently in phase IV (2021) (EC, n.d.a). For a schematic table of each phase and corresponding regulated sectors, see appendix 1. Phase I (2005-2007), known as the pilot phase, offered the majority of the allowances for free and the applied caps were based on historical estimates (EC, n.d.c.). Through this, phase I created the infrastructure for future phases regarding, for example, monitoring and verifying emissions from the EU ETS-regulated industries. From the start of phase II (2008-2012), a lower cap on permits was imposed and the free allocation rate of permits was reduced to about 90 percent. Phase II also timed the first commitment period of the Kyoto protocol, which meant that countries partaking in the EU ETS had emission reduction targets to fulfil. In phase III (2013-2020), auctioning slowly started to replace free allocation (EC, n.d.a). However, free allocation in phase III was still offered to industries deemed to be at risk of *carbon leakage* (Stenqvist & Åhman, 2016). Carbon leakage occurs when EU ETS-regulated firms relocate their production to areas with less strict environmental regulations than the EU ETS (EC, n.d.e). Stenqvist and Åhman (2016) further described that phase III still used historical production size as a basis for allocating permits. As of 2021, the EU ETS is at its beginning of phase IV (2021-2030) (EC, n.d.a). This phase is set to keep the free allocation of EUAs as a solution to carbon leakage. The reduction of allowances is planned to increase faster than previous phases from 2021 and onwards (EC, n.d.a.; EC, n.d.d.).[5]

Since this thesis will investigate the effect of the EU ETS on patent applications through regulated sectors, a clarification regarding which sectors are regulated is thus in order. These sectors for phase I (2005-2007) are brick, cement clinker, ceramics, coke ovens, glass, iron and steel plants, lime, oil refineries, paper and board, and pulp (EC, 2015). Also, power stations and

[4] Croatia became part of the EU six months later in July 2013 (EC, 2015; EUROSTAT, 2020a). When discussing all EU Members after Croatia joining, the term EU-28 is often used (EUROSTAT, 2020a). Note that EU-27 exclude the UK.

[5] Note that the annual reduction rate of the overall number of permits will be at 2.2 percent starting in 2021 (EC, n.d.d; IETA, n.d.). This differs from the earlier rate of 1.74 percent during phase III (2013-2020).

other combustion plants are included if they exceed or equal 20 megawatts (i.e. ≥20 MW). This inclusion of power stations and other combustion plants does not cover hazardous or municipal waste installations. The aviation sector joined the scheme in 2012 (the end of phase II). In the four initial years (2012-2016) of its participation, the aviation regulation was set to only cover flights with its destination airport within the European Economic Area (EEA). According to EC (n.d.a), such a regulatory limit in the aviation sector was pushed forward to 31 December 2023 after which the EU ETS will cover non-EEA destinations as well. Croatia, which joined the scheme in January 2013, partook in the aviation regulation of the EU ETS from 2014 and onwards (EC, 2015). Phase II also included voluntary regulation of nitrous oxide (N_2O). From phase III (2013), regulations started to include aluminium, petrochemicals and aviation from 1.1.2014 [6] as well. In addition to that, phase III regulated certain nitrous oxide and perfluorochemicals (PFC) emissions.

Several concerns have been raised concerning the EU ETS. Following the 2007-2008 financial crisis, the production in EU ETS-regulated sectors decreased (EC, n.d.c; EC, 2015; Joltreau & Sommerfeld, 2018). This resulted in firms using fewer permits than they would have likely done under other economic circumstances, which lead to an oversupply of permits. As an oversupply threatens effective caps, carbon prices in EU ETS were pushed down. Furthermore, this caused concern regarding whether the EU ETS could achieve its goals of lowering greenhouse gas emissions if this continued. To solve the problem of surpluses of permits, the EU implemented the *market stability reserve* in 2019 (EC, n.d.d.). The goals of the reserve are both to tackle the long-term surplus of permits and to develop a higher resilience of the EU ETS. A higher resilience means that the EU ETS can better handle major shocks that may affect the scheme itself, which is possible by changing the amounts of auctioned permits.

Except for the market stability reserve, the EU also implemented two funds to facilitate the fulfilment of their two main environmental goals and the effectiveness of the EU ETS (EC, n.d.f.; EC, n.d.g). One of these is the *modernisation fund*, which started in phase IV to help 10 lower-income EU Member States reach climate neutrality (EC, n.d.f.).[7] The emphasis in the modernisation fund is twofold; advancements in energy efficiency and modernisation of energy systems in these countries. EU started with the plans of including an *innovation fund* in 2015

[6] Aviation from 1.1.1 2014 (EC, 2015): ammonia; nitric; adipic and glyoxylic acid production; CO2 capture; transport in pipelines and geological storage of CO2 aviation; aviation; CO2; N2O; PFC from aluminium productions.

[7] Member States included in the modernisation fund are Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia (EC, n.d.f).

and it is currently (2021) being pursued to raise innovation in low-carbon technologies in the EU (EC, n.d.g.; EC, n.d.h). It focuses on energy-intensive industries that could interfere with my chosen EU ETS-regulated sectors. As neither of the two funds and the market stability reserve overlaps with the time frame in this thesis (2000 to 2016), the impact of these policies on patent applications is deemed as non-existent for the estimated results in this thesis.

2.2 Patents

Since this thesis examines how patent applications were affected by the EU ETS, a background regarding patents will be provided. The main reason for this is that patents are a complex subject, which also intersects with several academic disciplines outside of Economics.

Patents are commonly regarded as a part of the larger field of intellectual properties rights (WTO, n.d.a). The legal background of a patent is given in the *Trade-Related Intellectual Property Rights (TRIPS) Agreement,* which was enforced on 1 January 1995 (OECD, 2009; WTO, n.d.b). Note that all Articles concerning patents is given in section 5 of the TRIPS agreement and consists of Article 27-34 (WTO, n.d.b; WTO, n.d.c). On a European level, patents are granted in a process described by the European Patent Convention (EPO, 2020). For other legal texts at the European level, refer to EPO (n.d.a.).

There are three main patent offices globally that follow different statutes; the European Patent Office (EPO), the Japan Patent Office (JPO), and the United States Patent and Trademark Office (UPSTO) (OECD, 2009). The patent application data used in this thesis are retrieved from both EPO and national patent offices.

EPO was established in 1977 and is responsible for patent registration in mainly European countries (EPO, n.d.b.; OECD, 2009). As of early 2021, EPO has 38 Member States of which several are not EU members (EPO, n.d.b.).[8] EPO also has agreements with extension and validation states (EPO, n.d.c; EPO, n.d.d).[9] The EPO agreements concerning both the extension and the validation states, and thereby its connections to the patent application effect due to EU ETS, are a limitation of this thesis. Thus, as noted earlier, this thesis concentrates on a selection

[8] EPO member states in alphabetical order: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Liechtenstein, Lithuania, Luxembourg, Latvia, Malta, Monaco, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, and the UK (EPO, n.d.a.).

[9] Agreements with extension states to date concern Bosnia and Herzegovina as well as Montenegro (EC, n.d.d). The validation states are Cambodia, Morocco, the Republic of Moldova, and Tunisia (EPO, n.d.c.).

of the EPO countries (and the EU Member States) that is named the EU ETS-regulated countries. Note that patent application data on non-EU ETS regulated countries comes from its respective national patent office. A description and motivation of chosen sectors and countries in this thesis are shown in section 6.3. In the EPO system, the duration for patents to be valid is 20 years (OECD, 2009). As EPO is not an EU institution, there does not exist a patent that is valid across the EU countries. For a patent to be valid in all EPO countries, it needs to be validated by each separate national patent office where the applicant/s wishes for the patent to be effective.

This thesis defines patents as patent applications by *priority date*, which captures the date when the first application of the patent was filed (OECD, 2009; OECD, 2021a). Another similar concept is the *grant date*, which states the date where the applicant receives their patent rights by the authorised body. This authorized body in this thesis is either EPO or the national patent offices. It is also possible to use the *application (or filing) date*, which is the exact date when an application is filed at a certain patent office. Using this data is problematic, due to it contains a bias depending on whether the patent is from foreigners or residential inventor/s as foreigners tend to take more time to process. Therefore, it is preferable to use the priority date.

Note that a publication of a patent application is made in the EPO system on average 18 months after the priority date has passed (EPO, n.d.e.). Then the applicants have a period of 6 months where they can decide to continue pursuing or not (i.e. quitting) their patent application process. It is also essential to understand the role of the filing date in the patent application process. In the EPO system, applicant x who files the patent application before applicant y has the advantage of getting the patent rights (OECD, 2009). This is called *first to file.*[10] More details on the limitations of using patents data within the scope of this thesis are found in section 5.4.

3. Theoretical Framework

Since the 1990s the relationship between technological change in form of innovation and environmental regulation has received increasing attention in empirical and theoretical research (Brännlund & Lundgren, 2009; Griliches, 1990; Jaffe et al., 2002; Jaffe et al., 2005; Popp, 2019). This chapter presents a theoretical framework of innovation in environmental regulation.

[10] The first to file principle is also central for patents grants at the JPO (OECD, 2009). USPTO differs from EPO and JPO as it grants patents based on the first to invent principle. The concept of first to invent makes it possible for one party to appeal based on the fact that they had made the invention at an earlier date but did not file for a patent.

3.1 Competitive Advantage and Growth Theories

Historically technology had a prominent role together with capital and labour when explaining economic phenomena such as economic growth. OECD (2009) stated that the concept of *competitive advantage* is crucial for patents. Competitive advantage is when a firm has or wants to achieve an advantage over its competitors, and this could result in higher profits than those of other firms in the same market (Porter, 1990). A patent is a legal procedure in which a firm can obtain a competitive advantage through a granted patent (OECD, 2009). Thus, patents by their construction are rooted in economic theory.

Technology is often central in economic growth theory. Two such growth theories are the Solow growth model and the endogenous growth model (Olsson, 2012). The *Solow model* assumes that economic growth occurs through capital accumulation. It further assumes constant returns to scale (CRS), that all factors of production have positive but diminishing marginal returns, and that output is a function of both capital and labour. Once an economy reaches its steady state (where investment equals depreciation rate), economic growth stops. The Solow model asserts that in this state future growth only occurs through exogenous change. For example, this can be a technological improvement. Romer later highlighted the importance of technological improvement through its role as an endogenous factor in the *endogenous growth model*. In the endogenous growth model, the growth rate can rise due to higher investments through, for instance, R&D for an indefinite period. Contributions from the two mentioned growth theories influenced this thesis and its perspective on innovation, as high rates of patent applications are often associated with periods of growth and long-term investments are needed for innovation to occur (Bel & Joseph, 2018). Besides that, it is clear from these theories that technology can impact economic growth and thus serves as another argument (notwithstanding environmental arguments) as to why studying innovation is important (Olsson, 2012).

3.2 The Hypothesis of Induced Innovation

The *Hypothesis of Induced Innovation* is considered fundamental for innovation theories such as the Porter Hypothesis (see section 3.3) (Dechezleprêtre & Sato, 2017; Funk, 2002). Hicks stated that "a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind – directed to economising the use of a factor which has become relatively expensive" (Hicks, 1963, p. 124). According to Dechezleprêtre and Sato (2017), this hypothesis could be translated to an environmental regulation context. They described that regulation enforces a higher price on polluting emissions than other production costs, which motivates these regulated firms to develop new emission-reducing technologies. Given that the EU ETS put a price on several types of emissions, this shows that a link exists between the hypothesis of induced innovation and this thesis (EC, n.d.a.; Dechezleprêtre & Sato, 2017). In this thesis, such incentives to innovate could exist for EU ETS-regulated firms that are facing higher prices on emissions (except for firms receiving free allocations of permits).

3.3 The Porter Hypothesis

Building onto the hypothesis of induced innovation, the Porter Hypothesis emphasized the spur of innovation in relation to environmental regulation (Dechezleprêtre & Sato, 2017; Porter, 1990; Porter, 1991, Porter & Van der Linde, 1995). Porter (1991) described the relationship between environmental regulation and innovation as "strict environmental regulations do not inevitably hinder competitive advantage against foreign rivals; indeed, they often enhance it" (Porter, 1991, p. 168). This is known as the *Porter Hypothesis (PH)*. Applying it to the context of this thesis, it argues that stricter environmental regulation such as the EU ETS increases innovation (as proxied by patent applications) in EU ETS-regulated sectors. Within environmental innovation research, the PH is often separated into a weak and a strong version to paint a more precise picture of which innovation effects are studied (Ambec et al., 2013). Ambec et al. (2013) defined its weak version as environmental regulation enhancing innovation when these regulations are properly designed. The strong version highlights the role of competitiveness by describing that environmental innovation can result in a firm having higher levels of competitiveness. The weak version of the PH is deemed most relevant to this thesis, since it focuses on whether or not environmental regulation spurs innovation.

3.4 The 3 Stages of Innovation

Schumpeter (1942) defined the innovation process as three different stages. In the first stage, *invention* transpires which is identified as a "…technical discovery of new things or new ways of doing things… " (Braunerhjelm & Svensson, 2008, p. 2). *Innovation* happens in the second stage when an invention such as a new good or service (from stage 1) undergoes successful commercialisation. Then, in the third stage, *imitation* (also called diffusion) takes place. This means that the technology is adopted at a broader level in the market. Although patents are not explicitly included in these stages, Braunerhjelm and Svensson (2008) examined this theory by using Swedish patent data.[11] The authors demonstrated that commercialisation occurs after

[11] This article is not included in the literature review as it does not analyse innovation regarding either environmental regulation or R&D measurements. The main reason is that Braunerhjelm and Svensson (2008), in contrast to the later included literature, goes into details about the three stages. Thus, it is possible to use their study to connect Schumpeter (1942) to this thesis.

patents are granted. As this thesis applies patent applications as a proxy for innovation, this thesis looks at patent applications as a part of the pre-second innovation stage. This classification becomes evident, considering that the data in this thesis do not reveal if patent applications were later granted and thereafter commercialised. Moreover, this thesis argues that the first stage is over once the patent application process begins. In reality, there might be less of a clear distinction between these stages. However, testing distinctions between the three stages lies outside the scope of this thesis.

4. Literature Review

This chapter highlights contributions from relevant earlier literature.

During the 1990s and early 2000s, a growing body of literature started to address the connection between patents counts as a measure of innovation and *pollution abatement expenditure (PACE)* (Brunnermeier & Cohen, 2003; Jaffe & Palmer, 1997; Lanjouw & Mody, 1996). A positive relationship between PACE and innovation was found both by Lanjouw and Mody (1996) and Brunnermeier and Cohen (2003). In contrast to these two studies, Jaffe and Palmer (1997) discovered no connection between PACE and environmental innovation. Additionally, Jaffe and Palmer illustrated that R&D spending was positively affected by lagged environmental compliance expenditure. Thus, the evidence from these three studies points to mixed evidence regarding the relationship between PACE and innovation.

Within the EU ETS, research concerning the first two phases was partly dominated by case studies (Anderson et al., 2011; Hoffmann, 2007; Pontoglio, 2008; Rogge & Hoffmann, 2010; Rogge et al., 2011; Schmidt et al., 2012). The majority of the case studies pointed out a low to moderate positive effect on innovation due to the EU ETS (Hoffmann, 2007; Rogge & Hoffmann, 2010; Rogge et al., 2011; Schmidt et al., 2012). These findings persisted across the following German sectors: electricity (Hoffmann, 2007; Schmidt et al., 2012), power (Rogge & Hoffmann, 2010), and pulp and paper (Rogge et al., 2011). Two influential non-German case studies were Pontoglio (2008) and Anderson et al. (2011), which looked into the Italian paper industry and Irish EU ETS-regulated firms respectively. The results from these two studies also displayed a modest positive innovation effect that varies in magnitude between the two studies. Hence, the evidence of low to moderate innovation effect is echoed in all mentioned case studies and thereby can be said to hold across countries as well (Germany, Italy and Ireland). Note that the described case studies have not directly influenced this thesis, as it neither performs interviews nor uses firm-level data, but are rather touched upon given their role in shaping the EU ETS literature in the next few paragraphs.

Another strain of EU ETS provides, in contrast to case studies, evidence on larger sample data and are thereby often referred to as "large sample studies" (Martin et al., 2016). In general, these large sample studies found innovation effects to a higher positive degree than earlier EU ETS case studies (except for Löfgren et al. (2014)) (Anderson et al., 2011; Borghesi et al., 2015; Fontini & Pavan, 2014; Hoffmann, 2007; Martin et al., 2012; Pontoglio, 2008; Rogge & Hoffmann, 2010; Rogge et al., 2011; Schmidt et al., 2012). This matches what Calel (2018) concluded for his overall findings in the EU ETS research. Large sample studies demonstrated that this evidence holds for the clean innovation in process and products (Martin et al., 2012), 25 different manufacturing industries (Borghesi et al., 2015), and the paper and pulp industry (Fontini & Pavan, 2014). In contrast to these three studies, Löfgren et al. (2014) detected no effects of technological adoption in both the Swedish energy sector and energy-intensive manufacturing between 2002 and 2008. Most of the large sample EU ETS literature investigated phase I and II of the scheme (Borghesi et al., 2015; Fontini & Pavan, 2014; Löfgren et al., 2014; Martin et al., 2012). This evidence was further showed to hold across different countries and time frames for three out of the four large sample studies with Löfgren et al. (2014) being the exception. Martin et al. (2012) focused on six countries (Belgium, France, Germany, Hungary, Poland and the UK), while both Borghesi et al. (2015) and Fontini and Pavan (2014) looked at Italy. Furthermore, two of these larger sample studies tackled stringency as stringency in the EU ETS increases over time (Borghesi et al., 2015; Martin et al., 2012). Martin et al. (2012) revealed that firms anticipating fewer free permits in phase III had higher innovation rates and freely allocated permits led to lower rates of clean innovations. The opposite was found by Borghesi et al. (2015) - sectors with more stringent allocation were less innovative. Possible explanations for varying stringency results in these two studies could be the use of different countries, sectors and time frames. One similarity between Martin et al. (2012) and Borghesi et al. (2015) is that both concluded that EU ETS-regulated sectors were more likely to innovate. As the results were mixed when considering stringency and innovation, no definite conclusion can be made.

Miller (2014) contributed to the EU ETS research by considering the indirect effects of the EU ETS. Indirect policy effects were defined as "… when a regulated firm responds to a policy through innovation or other means, that firm`s action may change innovation incentives for other regulated and even unregulated firms …" (Miller, 2014, p. 3). The author concentrated on two indirect effects, knowledge spillovers and pass-through of regulation-imposed costs into output prices, for Germany and France. By studying 1992 to 2010, Miller stated that EU ETS-regulated firms on average undervalue the innovation effect from EU ETS by 71 percent. According to Miller, this is a consequence of firms only examining direct innovation effects. Translating that concern to this thesis, which does not control for indirect innovation effects, the expectation would be that the findings in this thesis on innovation effects are lower than they actually are and thereby are downward biased.

A different strain of EU ETS literature explored the relationship between the EU ETS and the innovation effect from EU ETS on low-carbon technologies[12] (Bel & Joseph, 2018; Calel, 2018; Calel & Dechezleprêtre, 2016). Both Calel (2018) and Calel and Dechezleprêtre (2016) proved that EU ETS increased patenting of low-carbon technologies in EU ETS-regulated firms. This conclusion holds for the two studies, despite different time series and scope. Calel and Dechezleprêtre (2016) studied 23 countries between 1979 to 2009, while Calel (2018) observed British firms between 2000 to 2012. Following these two studies, Bel and Joseph (2018) also used low-carbon technologies but instead focused on the energy sector. The authors looked at a shorter time frame by considering 2005 to 2012 and applied data from 12 EU ETS-regulated countries. They demonstrated that a stringent EU ETS encourages innovation to a higher degree than the opposite, as illustrated in Martin et al. (2012). Bel and Joseph (2018) further added to existing research by pointing to that an oversupply of permits negatively impacted technological change. This thesis uses similar R&D variables as Bel and Joseph (2018), which will be discussed in section 5.2. In contrast to the three studies referred to in this paragraph, I focus on EU ETS-regulated sectors known for being emission- and energy-intensive (EC, 2015).

Outside the EU ETS sphere of literature, Fabrizi et al. (2018) developed this topic further by emphasising the role of research networks and regulation policies on environmental innovation. By analysing 23 European countries between 2003 and 2012, the authors revealed a positive relationship between environmental innovation and market-based regulation[13] as well as

[12] Note that Bel and Joseph (2018) refer to this as Climate Change Mitigation Technologies (CCMTs), while Calel (2018) and Calel and Dechezleprêtre (2016) used the term "low-carbon technologies" in their papers. These three studies are placed under the same low-carbon technologies umbrella in this thesis, as all of them use the Y02-tagging scheme from the EPO.

[13] Market-based regulations strive for stakeholders such as firms "... to undertake pollution control efforts that are in their own interests and that collectively meet policy goals" (Jaffe et al., 2002, p. 50). One example of this is cap-and-trade (Calel, 2018). The opposite of a market-based regulation is command-and-control such as uniform standards for pollution (Jaffe et al., 2002).

participation in research networks. Another contribution is Hottenrott and Rexhaüser (2015) whose study looked at regulation-induced environmental innovation from 2006 to 2008 for German firm-level survey data. Hottenrott and Rexhaüser detected no evidence of crowding out of non-green R&D in firms with subsidy-induced environmental innovations. Their findings also showed crowding out of in-house R&D, for instance, regarding firms with financial constraints. Hence, their study found mixed effects for crowding out. In contrast to the other two studies in this paragraph, Dechezleprêtre et al. (2015) used data for automobile emission standards between 1992 to 2007 in 72 countries and connected this with the importance of regulatory distance between countries for patent inflows. The regulatory distance was defined as "… the level of regulation relative to potential source countries ..." (p. 245), where source country is a synonym for inventor country. Dechezleprêtre et al. observed that countries with similar regulation have more patent inflows. A concern for patent spillover effects is later raised in this thesis, which is solved by dropping such data. As innovation literature is a broad topic, the articles in this paragraph were chosen to cover areas where previous chosen literature lacked and do not represent the myriad of published research.

This thesis contributes to the literature by, in addition to studying the cement and manufacturing of the iron and steel sectors, including the aviation sector as a placebo check. Furthermore, most EU ETS literature has so far used data before 2013 (when phase III started) in comparison to the patent application data applied in this thesis, which studies the period from 2000 and 2016 (thereby capturing part of phase III). Hence, another contribution of this thesis is that it offers a more long-term perspective. This is crucial given that innovation processes often span several years and thereby some innovation effects might only be visible when using longer time series (Bernard, 2006; OECD, 2009; Pontoglio, 2008).

5. Data

5.1 Data Collection

Data from OECD in this thesis is used for the following variables: patent applications (as defined by the priority date) for EU ETS-regulated sectors, gross domestic investments (GERD), business enterprise investments (BERD), and GDP growth (OECD, 2021a; OECD, 2021b; OECD, 2021c). For non-EU ETS regulated patent applications, data was compiled from national patent offices by employing the website Espacenet that provides patent documents from all over the world (Espacenet, 2021). Additionally, GDP growth data from Taiwan came from the Chinese Statistical Association (Taiwan) (National Statistics, n.d.).

Patent data for the EU ETS-countries has a yearly structure, while the data for the non-EU ETS countries are given by its exact date. To achieve the same structure for both data sets, a yearly structure was implemented for Espacenet data. In this thesis, the years from 2000 to 2016 are studied. This means that this thesis investigates the policy effect from the first three phases of the EU ETS on patent applications (EC, n.d.a.; EC, n.d.c). While the two first phases are fully captured (2005-2007; 2008-2012), only the initial years of phase III are included in (2013-2016). The main reason for this is the publishing delays of patent application data, which differs between the OECD and Espacenet data (Espacenet, 2021; OECD, 2021a).[14] In both cases, it was hard to find data after 2016. Therefore, 2016 was used as the end year to make sure that no patent applications were overlooked. Besides that, this thesis uses pre-trends for the years 2000 to 2004 on the two sectors (cement and the manufacturing of iron and steel sectors) as the EU ETS was implemented in 2005. The aviation sector, which is later added as a placebo check, uses a different set of pre-trends (2005-2011) to reflect that it became part of EU ETS in 2012.

A longer time frame in this thesis could have been applied if one used the date of grant rather than the priority date. Using a priority date makes it possible to see whether more innovation occurred after 2005, as patent applications by priority date catches innovation closest to the date when it first occurred (OECD, 2009). According to OECD (2009), patent data for the date of a grant can have a time lag of up to 5 years before getting approved (known as *calendar effect*) and therefore warned against using the date of grant. For those two reasons, this thesis opts for the priority date structure when obtaining data for patent applications.[15]

Following the recommendations from OECD (2009), the "inventor(s)´s country(ies) of residence" is used in this thesis to define patents by country rather than the "applicant(s)´s country(ies) of residence".[16] Besides that, with more co-operation among researchers across

[14] The data availability sorted by IPC codes stretches far longer beyond 2016 for Espacenet than OECD (Espacenet, 2021; OECD, 2021a). When it comes to defining total patents as defined by patent application (defined by priority date), OECD data stretches to 2018 (OECD, 2021a). As this thesis defines patent applications by the four-digit IPC code, where there was a lack of data after 2016, the end year was chosen as 2016.
[15] OECD defined the patent application data according to "priority date", while Espacenet gives it according to "earliest priority date". This thesis assumes that these definitions are equal and thereby it is possible to compare the two different data sources.
[16] One can refine patent searches on language through Espacenet. This thesis refined its patents on the three languages: English, German and French (the default setting). Despite that, there was a lack of available data for several countries including Japan and Australia for the chosen EU ETS-regulated sectors.

countries during the last few decades, patent documents often contain inventors from several countries (OECD, 2009). This can lead to double counting of patents, due to the proportion of how the patent is divided up between, for instance, different inventor countries are not accounted for. To combat this issue, fractional counts are often used. The OECD database provides patent fractional counts in contrast to Espacenet. To achieve such statistics from Espacenet data, fractional counts were manually calculated based on information from the Espacenet.[17] For example, if a patent is registered in Russia with two inventors of Russian nationality and the third one Ukrainian, this was counted as a 2/3 Russian patent. This was done to overcome possible discrepancies in calculating patent applications from two different sources. If I did not use double counting or fractional counts, total patent counts in each sector in each studied country would have been higher as both methods separately impacted the patent counts on average by 2 to 5 percent. For this reason, I argue that the two methods removed an upward bias in my data which could have led to incorrect estimates.

Given that lack of data exists for certain R&D variables, this affected which countries could be used as non-EU ETS and EU ETS-regulated countries in the coming analysis. To avoid such omittance, this thesis applies interpolation (Chipman & Lapham, 1995). Interpolation means that the missing observation gets a new value, which comes from taking the mean of the previous observation and the observation that follows the missing observation. Thus, interpolation is performed where one observation is missing. In this thesis, interpolation is used for Sweden for the years 2000 and 2002 for all R&D variables (business enterprise and gross domestics investments).

5.2 Motivation of Data Variables

The following section will describe the motivation behind the variables in this thesis. Every variable has a yearly structure. All R&D variables are measured as a percentage of GDP.

Commonly, intramural R&D expenditures describe R&D variables such as business enterprise and gross domestic investments on R&D that are included in this thesis (OECD, 2015). Intramural R&D expenditures capture all current expenditures (for example, labour costs) plus gross fixed capital expenditures (such as buildings and land) for R&D performed in a country

[17] Manually in this context means that overall registered patent application information was downloaded from Espacenet (2021). Then I converted it to fractional counts by correcting for each patent count with several inventor countries without using programming. Then the data was compiled together from over 100 Excel files containing about 45 000 patent observations.

(as in the case of this thesis) or a region. The opposite is extramural R&D expenditures, which occurs when R&D is performed outside a certain country or a region. Note that this thesis employs an intramural structure on the country level for the two R&D variables shown below.

- *BERD (Business Enterprise Investments)*[18]*:* This variable is a sub-category to gross domestic investments (OECD, 2015). Business enterprise investments depict the amount of intramural R&D expenditures that domestically occurs in the business enterprise sector. Bel and Joseph (2018) included this variable in their patent analysis for EU ETS. For this reason, this thesis applies this variable to investigate a plausible connection between R&D in the business enterprise sector and patent applications. The idea is that higher levels of business enterprise investments mean that the firms in EU ETS-regulated sectors perform more innovations than non-EU ETS regulated sectors. This will in turn lead to the number of patent applications augmenting over time.

- *GDP growth*: It stands for the growth in GDP in percent. The intuition is that a rise in GDP will cause a larger number of innovations and through that more patent applications will occur. Following that Bel and Joseph (2018) used GDP growth, this thesis will also utilise this GDP growth variable. The connection between GDP growth and innovation was also highlighted in earlier literature such as Griliches (1984). In this thesis, the expenditure approach is applied for calculating GDP growth.

- *GERD (Gross Domestic Investments on R&D):* This variable is a sum of gross domestic investments in R&D from five different sectors in country X (OECD, 2015). These sectors are business enterprise, government, higher education, private non-profit, and the rest of the world. It is commonly used as the main aggregated statistic to capture the gross domestic investments in R&D in a specific country. Previous literature did not include this variable and thus is argued to be a contribution from this thesis. The intuition is that increased amounts of gross domestic investments areas will lead to more innovation. As time passes, this increase in investments results in more innovation as visible through the number of patent applications.

[18] Note that this thesis applies different names for R&D variables than those used in OECD (2015). Business enterprise investments are commonly known as business enterprise R&D expenditure (BERD). For gross domestic investments, the term gross domestic R&D expenditures (GERD) are applied.

- *Patents applications by priority date*: Recall that the Porter Hypothesis claimed that more stringent environmental regulation should lead to a spur of innovation (Porter, 1991). The intuition is thus that there will be a positive change in patents by priority date in the EU ETS-regulated sectors due to EU ETS.

Previous literature showed that innovation is affected similarly by the implementation of the EU ETS, while the magnitude of the innovation effect depends on which EU ETS-regulated sectors is studied (for example Borghesi et al., 2015; Rogge et al., 2011). However, this thesis studies different sectors than those used in earlier studies and therefore results might differ. For those two reasons, the expectation with higher patent applications rates (which follows the Porter Hypothesis) is only to be interpreted as the general direction of what patterns can be expected in this thesis (Porter, 1991).

In contrast to Bel and Joseph (2018) that included government investments (usually called GOVERD, but named GORD in their paper)[19], this thesis includes gross domestic investments. This is done due to gross domestic investments capture overall R&D investments in each country and is as an aggregated measure larger than government investments. Hence, it could act as an indicator of R&D investments and how this relates to patent applications on a broader level. Business enterprise investments were also added, due to its size being the largest of the five gross domestic investments components and thus likely has a higher impact on patent applications than the four others. The exclusion of the four other components is argued to not negatively affect the subsequent analysis, given its smaller magnitudes.

As stated before, business enterprise investments are a component of gross domestic investments. This means that there is a concern of a high correlation between these two variables across all studied countries, which is shown in appendix 2. Therefore, it could be problematic to include business enterprise and gross domestic investments in the same regression models. To control for such an obstacle, this thesis separates the variables into two separate model specifications. One of the specifications only includes gross domestic investments as an R&D variable, while the other one solely uses business enterprise investments. For more details on this, refer to section 6.3.

[19] Note that OECD (2015) calls government investments "governmental R&D expenditure (GOVERD)", but a different name was adopted in this thesis to adhere to the same definition for all these variables. Recall that they belong to the same family.

5.3 Motivation of Patents Classification System

Before motivating the final choice of a classification system in this thesis, a few of the possible routes will be presented to argue why the International Patent Classification (IPC) system was used in this thesis. Tanner et al. (2019) stated that there exist multiple ways of defining green (or environmental) innovation.[20] Literature has so far applied several different classification methods to identify patents (for example Brunnermeier & Cohen, 2003; Calel & Dechezleprêtre, 2016).

Brunnermeier and Cohen (2003) identified the number of successful granted patent applications based on the Standard Industrial Classification (SIC) system. This system was not used in this thesis as it is rare in EU ETS studies and as Espacenet do not provide such information. Calel and Dechezleprêtre (2016), instead, opted for low-carbon patent classification through the Cooperative Patent Classification (CPC) from EPO (known as, "Y02" class) (Calel, 2018). As this data is mostly available for European data, it would exclude the possibility of including non-EU ETS regulated countries as a control group and thereby this classification was not chosen. Another method to identify patent applications, through the same OECD patent database as applied in this thesis, was the "selected environmental-related technologies" (ENV-TECH) (OECD, 2016; Tanner et al., 2019). It is possible to define under-categories for ENV-TECH but not for other non-ENV TECH variables. For example, the under-categories include IPC-codes from several IPC-codes where not all of them overlaps with EU ETS-regulated sectors (EC, 2015; OECD, 2016). Hence, this thesis picked another route than the options discussed in this paragraph by choosing the IPC system.

There are several reasons for using the IPC system in this thesis. One main reason is that IPC gives a detailed view of what is included in each subsection (WIPO, 2016). Through this, this thesis could more easily identify which IPC codes could be relevant to include in order to examine the role between patent applications in the chosen EU ETS-regulated sectors and the EU ETS. Also, it is one of the most used classification systems on an international level and thereby makes it easier to find statistics from a vast number of countries.[21]

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[20] Tanner et al. (2019) touched upon a few different classification systems that this thesis does not discuss. The main reason for this is that these systems were not used in the relevant literature for this thesis. Moreover, the discussion of what is the best patent classification system is quite complex and lies outside the scope of this thesis.

[21] Note that Espacenet (2021) only provides classification through the CPC or IPC system. The lack of other classifications that overlapped between non- and EU ETS-regulated countries also impacted why IPC became the final choice.

5.4 Data Limitations

In this section, limitations with the data are discussed.

OECD (2009) recommended only to use data from a single patent office and avoid comparing trends across data from different patent offices. The main reason for this is that countries have different patent legislation and practices, which means that such analysis can cause faulty conclusions. As noted earlier in chapter 4, EU ETS research has, despite this argument from the OECD (2009), performed analyses on the innovation effect with data from several EU Member States at once (for example Bel & Joseph, 2018; Calel and Dechezleprêtre, 2016; Martin et al., 2012). In a similar vein, this thesis uses both patent applications filed by EPO and national offices. Those filed at EPO correspond to the EU ETS-regulated countries, while national offices are used for non-EU ETS regulated countries. Furthermore, this thesis assumes that there are no other systematic differences that would endanger estimating the causal treatment effect of patent application due to the EU ETS. This strategy was deemed necessary to avoid accounting for the possible bias that patent applications from non-EU ETS regulation countries to EPO could have been affected by the implementation of the EU ETS as well. However, it is not possible for certainty to attest that this is the case. As systematic differences might exist across the chosen countries and sectors, I applied the usage of fixed effects and this is further shown in section 6.3.

One factor except for innovation that impacts how well firms can adapt to stricter regulation such as the EU ETS is *fuel switching* (Bel & Joseph, 2018; Calel & Dechezleprêtre, 2016). The EU ETS implementation may incentivise firms to switch fuels, instead of applying for patents as part of their abatement strategy. As it is difficult to separate the fuel switching effect from the EU ETS effect on patent applications, this thesis does not account for such effects.

Although patent applications are commonly used as an indicator of "successful research", it comes with its caveats (OECD, 2009). For example, OECD (2009) pointed out that "… patents do not reflect all of the research and innovative efforts behind an invention" (OECD, 2009, p. 26). Additional explanations at the firm-level may be overlooked as this thesis uses country-level data on patent applications. There could, for example, be behavioural mechanisms and/or more specific firm-related financial incentives as to why certain firms choose to innovate or not. However, these will not be discussed further as it is outside the scope of this thesis.

Another obstacle is that the processing time for examining patents at the EPO has increased over the years (OECD, 2009). This increase creates several statistical issues. For example, it has become harder to connect statistics on patent applications and patents grants as well as to decipher time trends. Statistics for patent applications based on the priority date, which is used in this thesis, tends to be published 18 months after the priority date. To monitor time gaps between the priority date and grant date, patent outcomes can be tracked by using raw data from, for instance, the PATSTAT database from EPO (EPO, n.d.f). Note that any tracking of patents is not done in this thesis, as the applied OECD database does not provide such data (OECD, 2021a). Thus, this thesis cannot check if time gaps between priority date and grant date vary between the ten studied countries. This also means that it is not possible to look into time trends for patent applications within each country or sector in this thesis.

Furthermore, OECD (2009) stated that certain industries are more prone to apply for patents for their innovations than others. This is often referred to as a *patent flooding strategy*. When picking which EU ETS-regulated sectors to study (see section 6.3), it was clear that there were more patent applications in some sectors than others (Espacenet, 2021; OECD, 2021a). Therefore, this thesis chose to avoid investigating certain EU ETS-regulated sectors, such as the organic chemistry sector that was mentioned in OECD (2009) as having few patent applications. More precisely, this thesis does not account for why some sectors are likelier to apply for patents than others and how this might relate to sectoral circumstances.

Concerning other sector level differences, the length of research processes also varies between the sectors (Bernard, 2006). This length could explain why certain sectors see more variation in the number of patent applications than others and thereby could act as an additional explanation for patent application practices. Such a phenomenon cannot be studied in this thesis, as this information is not found in the two chosen databases for patent statistics (OECD and Espacenet) (Espacenet, 2021; OECD, 2021a).

The number of patent applications is affected as well by the costs regarding the patent application process. OECD (2009) showed that this depended on at which patent office the patent application is filed. Costs are the highest for a firm from an EPO Member State out of the three main patent offices. A firm from an EPO member state has €24 100 in average costs for getting a Euro-direct patent that is both granted and validated. This is a contrast to the USPTO grant where a US firm pays €10 250 on average and for a JPO grant where a Japanese firm pays €5 460 on average. Because of such high costs for EPO patents, the number of patent applications over time seen in this thesis may not represent patent applications that are restricted by e.g. limited funds. In the worst case, this could create distortions in competitiveness for patent applications. This is a drawback of this thesis that cannot be solved by using either of the applied databases, as it also reflects how the patent registration system works.

Moreover, patent applications that are only registered at the national level for EU ETS-regulated sectors in the chosen EU Member States are not included in this thesis. Thus, there is a risk that such patent applications may be overlooked if these were not later filed through EPO. To avoid these obstacles, OECD (2009) stated that a complete picture of patent applications on a national level could only be obtained through a merging of EPO, national and PCT (Patent Cooperation Treaty) data. However, this thesis did not opt for such a data method. The two main reasons for this are the hardship of obtaining the data sets needed for such analysis and compiling several patent data sources for the same country increases the risk of double counting.

Apart from the limitations above, two extensions on the empirical analysis in this thesis were not possible due to a lack of such data. One extension was to check the connection between patent applications and research networks between studied countries and sectors, which was not possible as this information is not provided in OECD data (OECD, 2021a). Another robustness check based on countries joining the EU ETS after 2005 was considered but abandoned due to missing data in the studied sectors from the OECD patent database.

Regarding R&D issues, all innovation activity is not reflected in R&D measures (Griliches, 1990). This fact should be kept in mind regarding the results for the applied R&D measures in this thesis. Griliches (1990) argued that firms of varying sizes place different amounts of their expenditures on R&D and their firm size also plays an important role in how many patents they end up obtaining. Any relation between firm-level variables, such as firm size, and R&D variables is not covered in this thesis since the analysis is done at the country-level rather than the firm-level. Therefore, it is not possible to see whether differences in such variables between non-EU ETS and EU ETS-regulated sectors could further explain patent application trends.

As for different industries being more prone to apply for patents, the relationship between R&D and the number of patents also deviate depending on the industry (Griliches, 1990). For example, certain industries might not invest large sums in R&D but still apply and are granted a patent every once in a while. At the same time, Griliches argued that even industries spending more on R&D (in addition to received government research support) tended to patent less than expected based on the size of their R&D investments. Hence, accounting for more specific industrial R&D variables could also be of interest in this thesis. However, previous EU ETS-research such as Bel and Joseph (2018) applied more aggregated measures for R&D variables. For this reason, this thesis opting for these more aggregated measures as well.

6. Methodology

6.1 Difference-in-differences

This thesis applies the difference-in-differences (DiD) method to study how the implementation of the EU ETS affected patent applications for EU ETS-regulated countries between 2000 to 2016 (Brown, 2018; Lee, 2016). A DiD study uses both a control and a treatment group to measure the impact of the policy regulation. The treatment group in this thesis consists of EU ETS-regulated sectors from the EU Member States affected by the EU ETS, while the control group contains the same sectors but in non-EU ETS regulated countries and are therefore not directly affected by the implementation of the EU ETS.

A DiD strategy uses both the trends before (ex-ante) and after (ex-post) the policy was implemented for each of the two groups. The pre-period is represented by the years 2000 to 2004 and after implementation is 2005 to 2016.[22] One key requirement for the DiD method to work is that absent treatment (with no EU ETS), the control and treated groups have the same outcome as seen by the number of patent applications (Fredriksson & Magalhães de Oliveira, 2019; Lee, 2016). As it is not plausible to use a counterfactual scenario to test for such trends, the *parallel trend assumption* is used. This assumption presumes that the treatment and control groups behaved similarly before the implementation of the EU ETS in 2005. If the trends of the two groups are not parallel to each other, it will not be possible to perform a DiD analysis based on those groups. The results for testing parallel trends are provided in appendices 4 and 6. Furthermore, the DiD strategy assumes that there exist no spillovers between the chosen treatment and control group (Fredriksson & Magalhães de Oliveira, 2019). This is known as the *stable unit treatment value assumption (SUTVA).* The DiD method further assumes that the control group are not influenced by the policy change that, in this thesis, is the implementation of the EU ETS. In this thesis, this assumption for the control groups is expected to hold as the control group consists of patent applications in countries not exposed to the EU ETS.

[22] Recall that the data for the pre-trends for the aviation pre-trends are from 2005 to 2011.

6.2 Motivation of the Studied Sectors

This section will highlight which sectors act as treatment groups in the difference-in-differences study and motivate why. Further note that both chosen sectors were regulated by the EU ETS since phase I (2005-2007). As of 2006, the cement industry stood for 9 percent of total EUAs allocations while the iron and steel industry had 8 percent (Alberola et al., 2008).[23] Both sectors have also been subjected to free allocation as of phase III due to carbon leakage concerns (German Emissions Trading Authority, 2014; Stenqvist & Åhman, 2016). For exact definitions from the IPC codes on the two chosen sectors, see appendix 3. Motivation for the aviation sector (the placebo check) and its corresponding IPC codes are shown in appendix 5.

6.2.1 The Cement Sector

Looking at yearly turnover from 2015, the cement manufacturing industry in the EU had €15.2 billion and the lime industry €4.2 billion (EC, 2018). The EU-28 production volume was 163 million tons for cement and about 23.9 million tons for lime products (2016 census). European producers correspond to one-fourth of the global trade. Total jobs in the EU-28 cement and concrete industry were roughly 384 000 (2012 census). This stands out as a contrast to the EU-28 lime industry that had 15 000 jobs (2015 census). For the two industries, the largest European producers are Belgium, France, Germany, Poland and Spain. The cement industry alone was the source of about 8 percent of the world´s total CO_2 emissions in 2016 (Rogers, 2018). On a global level, cement production is expected to increase by 25 percent before 2030. Both these facts raise the concern of the size of the environmental impact from cement in the future. The lime industry emissions in 2012 were 0.6 percent out of the total European greenhouse gas emissions (Stork et al., 2014). Although the lime emissions are low on an aggregated level (both globally and regional), it plays a crucial role as lime emissions can affect air pollution on a local level (Kuenen, 2009). Thus, from an economic and environmental standpoint, innovation as seen through patent applications regarding the cement and lime industries become a relevant topic to explore further.

Following the size of European production levels and data availability, this thesis will examine the connection between patents applications in the cement-related industries (from here on referred to as the cement industry) and the EU ETS for Belgium, France, Germany, Italy, Spain

[23] If counting according to C04B classification, the industry corresponds to 11 percent of allocations as of 2006 (adding 1 percent for glass and 1 percent for ceramics respectively to the 9 percent for cement) (Alberola et al., 2008; WIPO, 2016:01b).

and Sweden. Poland is not included in the analysis as it joined both EU and EPO in 2004, one year before the implementation of EU ETS, which could affect the number of patent applications (EC, n.d.d; EPO, n.d.b). The main reason for picking these countries, except for Sweden, is that they are the largest producers amongst the EU Member States and were members of EPO before 2005. As the EU consists of several smaller Member States, it could be of interest to include how these smaller countries are affected in their patent applications to get a more nuanced picture of the innovation effect. One concern is that only using larger Member States would have led to a distorted picture, since larger countries often innovate on a larger scale and thereby have more patent applications (Espacenet, 2021; OECD, 2021a). Note that Sweden could act as an outlier for patent applications in EU ETS-regulated sectors, because it is commonly viewed as a fast adopter of environmentally friendly technologies and other sustainable practices (Håkansson, 2015; Stenqvist & Åhman, 2016). This possibility is not controlled further in this thesis, given that such analysis on Swedish country-level against a non-EU ETS regulated country would then use a small sample size (below 100 observations).

6.2.2. The Manufacturing of Iron and Steel Sector

The European steel industry has an annual turnover of about €170 billion (EUROFER, 2016). Within Europe, around 170 million tonnes of steel are produced yearly. Europe is the second-largest steel producer globally (EC, 2016). It directly employs 328 000 individuals (2015 census). Total jobs in the European steel industry were roughly 2.6 million in 2019 (EUROFER, 2020). This included induced, indirect and direct jobs. The five largest EU countries in crude steel production in order of size is Germany, Italy, France, Spain and Poland (2019 census). For iron ore and concentrates, the largest European export quantity in 2018 was from Sweden, the Netherlands, Finland, Spain, France and Germany (EUROSTAT, 2020b).[24] Other countries with over 15 million tonnes in export quantity in 2018 were Belgium and Poland. From an environmental perspective, the iron and steel sector emits about 4 to 7 percent of the CO2 emissions in EU-27 (Pardo et al., 2012). Emissions on a global level from this sector amounted to about 7 percent of the total greenhouse gas emissions (SSAB, n.d.). Altogether, this proves that interest in decreasing emissions in this industry over time is likely substantial (which the EU ETS also contributes to) and thereby could act as a driver for further innovation.

[24] This data is compiled using EUROSTAT as no appropriate source was found. Code 7101000 was used and corresponds to "iron ores and concentrates, excluding roasted iron pyrites" (EUROSTAT, 2020b).

The selection of EU ETS-regulated countries to study for the steel and iron sector adopts the same principle as for the cement sector. Therefore, the choice primarily depends, except for data availability, on the size of steel and iron production for EU and EPO Member States. The regulated countries chosen are as follows: Belgium, France, Germany, Italy, Spain and Sweden (EUROFER, 2020; EUROSTAT, 2020b). Although Belgium is not in the top five in the production of iron ore and concentrates, it is in sixth place for steel production in Europe. Therefore, patent applications for the manufacturing of iron and steel from Belgium were included in the thesis. Using data from the Netherlands and Finland was decided against, given that their share of production largely differed from Sweden (EUROSTAT, 2020b). Note that the six chosen countries for the treatment group were part of EPO and the EU before 2000, following earlier arguments that adopting to EPO system and adapting fully to the EU ETS regulation can take time (EC, n.d.c; EPO, n.d.b.).

6.2.3 Choice of the Control Group

This thesis picked its choice of non-EU ETS regulated countries so they have similar traits as the EU ETS-regulated countries (treatment group). Such traits were patent applications, GDP growth and R&D variables. Another basis for the selection of the control group was that these non-EU ETS regulated countries were neither part of the EU nor EPO between 2000 and 2016. The choice is further based on the countries not partaking in the EU ETS. Note that a similar identification strategy was used by Franco and Marin (2017), where one of their two instruments applied patent data from other countries but using the same sector as in the regulated country. In contrast to this thesis, Franco and Marin (2017) did not explicitly focus on the relationship between EU ETS and patent applications. However, their study shows that the identification strategy in this thesis is not uncharted territory and that it works in other settings as testing Porter Hypothesis on a broader level. Furthermore, the final choice of control groups reflects the data available on non-EU ETS regulated countries through Espacenet and data on the independent variables from OECD.

By regarding the traits described in the previous paragraph, I formed the control group based on the following four countries: Canada, Mexico, Russia, and Taiwan. Albeit still different from most European countries, Mexico was chosen to match patents trends in countries with lower population and fewer patent applications in the hope to reflect such patent behaviour. As several decades have passed since the Taiwan economy underwent periods of rapid growth, the growth has slowed down and thereby led to Taiwan was picked as a part of the control group

(Britannica, 2020; National Statistics, n.d.). Russia was included with a similar motivation to Taiwan, that despite its opening up in the early 1990s, had similar investments and GDP growth as other chosen non-EU ETS regulated countries (OECD, 2021b; OECD, 2021c). Canada was chosen with the assumption that its overall economic situation was similar to that of the EU. Besides that, during the late 2010s, Canada adopted a nationwide environmental regulation called the Output-Based Pricing System (Government of Canada, 2021). This regulation included both a federal fuel charge and a regulatory trading system for industry. Before the Output-Based Pricing System, the two Canadian provinces of Ontario and Québec had their own sub-national ETS systems (ICAP, 2018). This means that the implementation of the Output-Based Pricing System and other ETS in Canada could have led to incorrectly estimation of the innovation effect in this thesis. I argue that the Ontario system does not impact my thesis as its first compliance period started in 2017. As the first compliance period for the Québec system started in 2013, it means that this scheme could have distorted the estimations of the EU ETS-policy effect. To deal with this, I assume that the effects of the Québec system on patent applications in the chosen sectors were minimal.

Moreover, as the IPC system consists of several hundred sub-sections, the data availability in all studied sectors in this thesis is not guaranteed (for exact codes, see appendices 3 and 5). There might be countries with lower patent applications in one of the chosen sectors but not in the other. Data availability was thus crucial in this thesis for the final choice of the control group, where the ideal solution was to use the same countries for every studied sector. The scarcity of data on patent applications resulted in countries such as Australia, Brazil and South Africa was disregarded.[25] Ideally, more countries could have been included in the control group to increase the sample size and thereby having a more representable sample of patent applications in non-EU ETS and EU ETS-regulated countries in the chosen sectors. Potential countries for the control group were also excluded if they were part of EPO and/nor had a pending EU application between 2000 to 2016. For example, Turkey was excluded as it had part of EPO since 2000 and had a pending EU application during the studied period (EPO, n.d.b.; EC, n.d.i). Such an argument extends to using Ukrainian data as well. This thesis further avoided using countries that experienced rapid growth between 2000 to 2016 period such as China. This decision was based on the concern to compare data across countries in different

[25] One plan also included using data from India and Japan. This was not possible due to i) missing data in the later years of the studied period on India (in particular, 2014-2016) and ii) a lack of translated patent applications for Japan from Espacenet.

development stages. Except that, I refrained from including countries that had an ETS or similar regulation before 2005 and/or during the studied period (with Canada as an exception).

Apart from those limitations, an initial plan was to include South Korean data in the control group. This was later abandoned as patent applications across South Korean sectors had higher magnitudes than other studied sectors. In the last couple of years, the number of patent applications filed by South Korean companies at EPO has increased substantially (Jung, 2021). For example, the South Korean patent applications through EPO grew by 9.2 percent between 2019 and 2020. This suggests that ongoing innovation in South Korea is transferred outside its borders to other regions (knowledge spillovers) and this rate will likely rise over time. For instance, this can occur in the EU ETS-regulated area and thereby affect patent applications filed through EPO (treatment group in this thesis). Additionally, South Korea stands out by being in 11^{th} place for the 2019 Global Innovation Index among the 129 countries ranked and has a high R&D intensity (Dayton, 2020). Therefore, the assumption is made that South Korean data differs from the other chosen countries in the control and treatment groups. Thus, South Korean data is not included in the control group.

6.3 The Model Specifications

My aim of this thesis is to examine whether patent applications in EU ETS-regulated sectors were affected by the implementation of EU ETS. The effect of patent applications due to the EU ETS on a pooled treatment group from the six following Member States will be investigated: Belgium, France, Germany, Italy, Spain, and Sweden. The pooled control group consists of Canada, Mexico, Russia and Taiwan. In this section, both the equations regarding parallel trends assumptions and the baseline models´ are presented.

6.3.1 Testing for the Parallel Trends Assumption

To verify the parallel trends assumption, this has to be tested twice as the R&D investments variables show a high correlation between them (appendix 2). The control group and treatment group will be the same in both cases.

The two hypotheses are:

H_0: Interaction terms for dummy years is significant

H_a: Interaction terms for dummy years is not significant

If the alternative hypothesis fails to be rejected, the parallel trend assumption holds. To check this assumption, the following regressions will be performed. Each interaction term comes from the multiplication of a dummy for each pre-year with whether the sector is regulated or not (i.e. part of the treated group). In total, there are five pre-trends (before) dummies for the years 2000 to 2004. The first equation controls for parallel trends for the gross domestic investments (GERD) model and the second for the business enterprise investments (BERD) model.

$$1)\ y_{ict} = a_1 + a_2 inter2000 + a_3 inter2001 + a_4 inter2002 + a_5 inter2003 + a_6 inter2004 + a_7 Reg + a_8 Post_i + a_9 Reg\#Post_i + \beta_1 GDP_{growth_{c,t-1}} + \beta_2 GERD_{c,t-1} + \varepsilon_{ict}$$

$$2)\ y_{ict} = a_1 + a_2 inter2000 + a_3 inter2001 + a_4 inter2002 + a_5 inter2003 + a_6 inter2004 + a_7 Reg + a_8 Post_i + a_9 Reg\#Post_i + \beta_1 GDP_{growth_{c,t-1}} + \beta_2 BERD_{c,t-1} + \varepsilon_{ict}$$

where:

- y_{ict} = patents applications (by priority date)
    - where i is an index for EU ETS-regulated sector (i.e. corresponding to chosen IPC codes), c for country and t for time
- Reg = dummy variable coded as =1 if regulated and =0 if unregulated
- $Post_i$ = dummy variable coded as =1 if after 2005 and =0 if before
    - The exception is the aviation sector that is coded =0 if before 2011 and =1 after
- $Reg\#Post_i$ = interaction term between Reg and $Post_i$, which gives the treatment effect of EU ETS on innovation
- $GDP_{growth_{c,t-1}}$ = GDP growth measured on yearly basis in percentage and lagged with one year
- $GERD_{c,t-1}$ = Gross domestic investments on R&D as a percentage of GDP and lagged with one year
- $BERD_{c,t-1}$ = Business enterprise investments on R&D as a percentage of GDP and lagged with one year
- ε_{ict} = error term

Should the outcome of this analysis prove that parallel trends hold (i.e. that the interaction terms for dummy years are insignificant), then DiD regressions regarding patent applications will be performed for the two treated sectors.

6.3.2 Testing for Treatment Effect of EU ETS on Patent Applications

The null hypothesis assumes that there is no difference in patent applications between EU ETS-regulated countries and non-EU ETS regulated countries. Since there is a possibility that EU ETS-regulated sectors have an incentive to innovate more and thus file more patent applications due to the EU ETS, the alternative hypothesis assumes that the number of patent applications will differ post 2005. Recall that the data set captures the years 2000 to 2016.

Hence, the two hypotheses are:

H_0: Reg#$Post_i$ is not significant

H_a: Reg#$Post_i$ is significant

This thesis uses two different baseline models as seen below. The main reason for this is that gross domestic investments (GERD) are an aggregated R&D expenditure measure from five different sources: business enterprise (BERD), governmental, higher education, private non-profit, and the rest of the world (OECD, 2015). Thus, a high correlation between gross domestic and business enterprise investments could be expected (appendix 2). To solve this issue, two different baseline model specifications will be applied where one uses gross domestic investments and the other business enterprise investments.

The two baseline model specifications with gross domestic investments (GERD) (equation 3) and with business enterprise investments (BERD) (equation 4) are as follows:

$$3)\ y_{ict} = a_1 + a_2 Reg + a_3 Post_i + a_4 Reg\#Post_i + \beta_1 GDP_{growth_{c,t-1}} + \beta_2 GERD_{c,t-1} + \varepsilon_{ict}$$

$$4)\ y_{ict} = a_1 + a_2 Reg + a_3 Post_i + a_4 Reg\#Post_i + \beta_1 GDP\_growth_{c,t-1} + \beta_2 BERD_{c,t-1} + \varepsilon_{ict}$$

There is a risk of clustering in the data for country and sector if one would use the two baseline models above. For example, abstaining from checking for clustering can lead to incorrect standard errors (Bertrand et al., 2004). Additionally, there might exist constant differences over time, which are unrelated to the EU ETS, on the country and sector level. To control for such problems, this thesis extends the two baseline models by applying fixed effects and controlling for clustering. One of the fixed effects describes country fixed effects ($country_c$), while the other is sector fixed effects ($sector_i$). The first extension of the model only uses sector fixed effects.

This differs from the second extension model that accounts for both clusters in country and sector. In total, this means that six different regressions will be performed where four uses fixed effects. Both investments specifications have their own three regressions performed.

Given that it often takes time from investment decisions and funding of R&D activities to when innovation and the patent application process starts, lags are implemented in the models (Bel & Joseph, 2018; Borghesi et al., 2015; OECD, 2009). Following Bel and Joseph (2018), I apply one year lag of GDP growth and the R&D-related variable business enterprise investments (BERD). I also use the same lag for gross domestic investments (GERD), as it should adhere to similar lagged effects on patent applications as business enterprise investments.

The coefficient of interest is the interaction term $Reg\#Post_i$, which is the product of the observed patent applications (i.e. sorted by IPC codes per sector) are EU ETS-regulated or not multiplied with whether the year of observation is after 2005 or not. More precisely, it is this term that will reveal whether the number of patent applications in EU ETS-regulated sectors changed due to the EU ETS or not and in what way (less/more/same patent application rate).

6.4 Concerns

This section will raise a few concerns that need to be addressed as these can impact the results presented in chapter 7.

Ideally, a DiD strategy is based on random treatment (Fredriksson & Magalhães de Oliveira, 2019). However, this is not the case with the EU ETS, as it sets out to lower emissions in the manufacturing industries that are deemed as the most emission- and energy-intensive (EC, n.d.a.; EC, 2015). Löfgren et al. (2014) also raised this concern by pointing out that the implementation of the EU ETS was known well in advance, which could result in incorrect estimates of the treatment effect. This thesis does not control for such anticipation effects.

Another obstacle is that this thesis assumes that a whole IPC code can be regarded as an EU-ETS regulated industry. In reality, smaller plants with lower production volumes and fewer emissions are often not regulated (Calel & Dechezleprêtre, 2016; EC, 2015). Hence, there could exist a difference in the incentive to innovate between smaller and large plants depending on the EU ETS-regulatory criteria. Martin et al. (2012) tested such criteria by using a regression discontinuity design and found that freely allocated permits led to lower innovation rates for clean innovation in processes and products. Controlling for such innovation effects could be done by having firm-level data. As such data was not available in the OECD patent database, this thesis does not control for such effects or split up patent applications by IPC codes even further than four-digits to look at more sub-sector innovation effects.

The data used in this thesis for patent applications stretch between 2000 to 2016. It is possible that the estimated innovation effects from the EU ETS changed due to the increased stringency from 2013 (EC, 2015). I refrained from checking whether such higher stringency from 2013 impacted the estimated innovation effects in this thesis. The main argument for this is the lack of data available, where it takes roughly two years before patent applications are published and such data was already scarce for non-EU ETS regulated countries in 2016 (OECD, 2009; OECD, 2021a). Since innovation processes often take a long time, it can also be argued that a longer time series after 2013 would be more optimal to control for EU ETS-related stringency impact on patent applications (Bernard, 2006).

There exist other identification methods besides the one applied in this thesis. For example, one can identify patent applications from control groups by using data on non-EU ETS regulated countries registered through the EPO. More precisely, the OECD database provides EPO-patent application statistics for non-EU ETS regulated countries in addition to the EU ETS-regulated countries patent application data (i.e. treatment group in this thesis). However, there is a concern that the number of patent applications might be affected by the implementation of EU ETS, higher filings cost at EPO, more patent applications on a global level, and other reasons (OECD, 2009; Martin et al., 2016). With those facts in mind, this thesis instead uses national patent statistics for non-EU ETS regulated countries.

Furthermore, the outcome of each patent application is traceable through Espacenet but not the OECD patent database (Espacenet, 2021; OECD, 2021a). The outcome of time that lapses between the grant and filing patent data for the EU ETS-regulated countries is thus not explored in this thesis. Therefore, this thesis does not investigate any dropping out effect (i.e. attrition bias) for the ten countries and whether this could have a link to the EU ETS or any other factors.

6.5 Descriptive Statistics

This section will present results from two-tailed t-tests and descriptive statistics for the variables used in this thesis. A two-sided t-test is performed to check whether there are any substantial differences between the EU ETS-regulated and non-EU ETS regulated data (Cortinhas & Black, 2012). The null hypothesis is that there are no differences between these two distributions in any of the variables included in the baseline models (excluding the dummy variables). Each variable is tested in separate t-tests. If the p-value found is larger than the alpha, the null hypothesis fails to reject.

Table 1. Performing two-tailed t-test between EU ETS-regulated and non-EU ETS regulated sectors

Variable name	Mean not treated	Mean treated	Mean difference
Cement Patent app.	111.69	30.70	80.99***
Steel & Iron Patent app.	44.35	11.07	33.28***
Aviation Patent app.	84.86	46.25	38.61***
Gross domestic investments	1.46	2.08	-.62***
Business enterprise investments	0.90	1.37	-.47***
GDP growth	3.27	1.54	1.73***

Not treated describes the data for non-EU ETS regulated sectors. Treated stands for data for EU ETS-regulated sectors. Each sector variable uses cursive as I will not test such data on sector level in the result chapter.
*** *p*<.01, ** *p*<.05, * *p*<.1

As shown in table 1, the p-values for every sector of patents (dependent variable) and all independent variables are below 1 percent. This means that the null hypothesis that the two distributions are equal is rejected at the 1 percent significance level.

What is interesting for the topic in this thesis is the difference in patent applications between non-EU ETS and EU ETS-regulated sectors. Table 1 shows that patent applications on average across the three sectors are higher for non-EU ETS (not treated) sectors than EU ETS-regulated (treated) sectors. Such a mean difference is largest in the cement sector and smallest in the manufacturing of iron and steel sector. This indicates that there might exist differences on a sector level for patent applications. One possible reason for this is that EU ETS was implemented in 2005. The coming chapter 7 will explore whether patent applications in EU ETS-regulated sectors have changed due to the implementation of the EU ETS.

Looking at R&D variables in table 1, it is evident that both gross domestic and business enterprise investments are on average higher in EU ETS-regulated countries than in non-EU

ETS regulated countries. The average GDP growth is larger in non-EU ETS regulated countries than in EU ETS-regulated countries. It might reflect the impacts of the 2007/2008 financial crisis on the EU and the Sovereign Debt Crisis that only affected the EU. However, I do not further check for how the financial crisis or other financial crises during these years impacted the number of patent applications.

Table 2. Descriptive statistics

Variable name	Treated or not treated	Mean	Std	Min	Max	N
Cement Patent app.	Treated	30.70	34.76	2.18	124.14	102
	Not treated	111.69	173.83	1	664.50	68
Steel & Iron Patent app.	Treated	11.07	14.33	0	55.66	102
	Not treated	44.35	64.69	0	236.09	68
Aviation Patent app.	Treated	46.25	57.37	.59	179.08	102
	Not treated	84.86	124.97	0	419.96	68
Gross domestic investments	Treated	2.08	.81	.84	3.87	102
	Not treated	1.46	.84	.31	3.00	68
Business enterprise investments	Treated	1.37	.67	.44	3.00	102
	Not treated	.90	.63	.08	2.33	68
GDP growth	Treated	1.54	2.22	-5.69	5.95	102
	Not treated	3.27	3.18	-7.82	10.25	68

Table 2 follows the same structure as table 1 but provides additional information on descriptive statistics. The chosen descriptive statistics are mean, std (standard deviation), min, max and N (sample size).

Table 2 illustrates the descriptive statistics divided by non-EU ETS and EU ETS-regulated sectors. It shows that when using two sectors, the total number of observations is 340. From these observations, 204 is for EU ETS-regulated sectors (treatment group) and 136 for non-EU ETS regulated sectors. When including all three sectors by adding aviation data to the existing data set, in total 510 observations are used. Out of these observations, 306 belong to the treatment group and 204 to the control group. In both versions with two and three sectors, 60 percent of the data is represented by the treatment and 40 percent by the control group.

The lowest patent applications on average occur in the manufacturing of iron and steel sector for both the non-EU ETS (44.35) and EU ETS-regulated sectors (11.07), which is visible in table 2. While the highest patent applications on average across the non-EU ETS regulated sectors are found in the cement sector (111.69). For the EU ETS-regulated sectors, the highest average of patent applications across sectors is in the aviation sector. Moreover, the previous findings in table 1 on GDP growth, gross domestic and business enterprise investments is also demonstrated in table 2. It is striking that while GDP growth in non-EU ETS regulated countries has the widest percentage range out of the treatment and control groups, its average rate of GDP growth is higher than EU ETS-regulated countries. Additionally, it is clear that the average for gross domestic and business enterprise investments are higher for EU ETS-regulated countries.

7. Results and robustness check

This chapter will present the results from the regression models that were performed to examine the connection between innovation as proxied by patent applications (by priority date) and the EU ETS. Section 7.1 consists of the regression results for the two sectors cement and manufacturing of iron and steel. To perform a robustness check, data regarding the aviation sector is added in section 7.2 (in total using three sectors) and regressions are redone. In section 7.3, a summary of the results in section 7.1 and 7.2 is given.

7.1 Results for two sectors

Before performing the regressions for the six model specifications, I verify that the parallel trend assumption holds. Appendix 4 demonstrates that the parallel trend assumption holds for the cement and manufacturing of iron and steel sectors. The paragraphs below explore the outcomes from the regressions on the six model specifications. In the specifications (1)-(6) in table 3, the did variable captures the treatment effects from the two sectors that are EU ETS-regulated starting in 2005. Hence, did is the coefficient of interest. My outcome variable is patent applications (defined by priority date).

Table 3. Regression output using 2 sectors (cement and manufacturing of iron and steel)

	gross domestic investments			business enterprise investments		
Specifications	(1)	(2)	(3)	(4)	(5)	(6)
post	60.46	60.46	55.00	59.65	59.65	55.30
	(33.03)	(33.08)	(38.97)	(32.72)	(32.77)	(38.60)
regulated	-12.14***	-12.14***	-4.62	-14.90**	-14.90**	-5.27
	(.02)	(.02)	(20.83)	(.90)	(.90)	(22.18)
did	-51.07	-51.07	-51.04	-50.93	-50.93	-51.46
	(28.17)	(28.21)	(38.66)	(28.28)	(28.32)	(39.59)
gross domestic investments	-6.04	-6.04	-2.31			
	(5.12)	(5.13)	(20.80)			
GDP growth	3.02	3.02	-1.48	2.91	2.91	-1.49
	(.58)	(.58)	(1.54)	(.57)	(.57)	(1.43)
business enterprise investments				-2.70	-2.70	-5.83
				(4.66)	(4.67)	(24.85)
_cons	34.30	53.66**	33.76	28.84	48.20*	38.05
	(16.18)	(3.32)	(38.23)	(13.16)	(6.35)	(29.29)
Observations	340	340	340	340	340	340
R-squared	.1326	.1767	.6920	.1301	.1742	.6920
Robust cluster sector	YES			YES		
FE cluster sector		YES	YES		YES	YES
FE cluster country			YES			YES

In table 3, the results from the regressions with the two sectors are shown. Specifications 1 to 3 in table 3 correspond to the models using gross domestic investments (GERD) while specifications 4 to 6 for models using business enterprise investments (BERD). Specifications 1 and 4 represent the results from performing a robust regression and considering clusters in sectors (2 clusters). In the four other specifications, fixed effects with cluster option are applied. Fixed effects account for differences in characteristics of country and sectors that remain constant over time. Specifications 2 and 5 control for both clusters and fixed effects on a sector level (2 clusters). This notion is later extended to both country and sectors clusters in specifications 3 and 6, which adjust for 20 clusters (2 x 10 countries) and use fixed effects for both country and sector level.

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

Observing the did variable in the three first specifications in table 3, the coefficients are not significant in any of the specifications. This means that the did results in the specifications (1)-(3) are not robust. Thus, no relationship can be found between the implementation of the EU ETS in 2005 and the number of patent applications on average in the cement and manufacturing of iron and steel sectors. The same conclusion as for did extends the specifications (1)-(3) for the post variable, which denotes the number of patent applications on average in the two sectors in non-EU ETS regulated countries after 2005. Neither of the coefficients on gross domestic investments and GDP growth is significant in the specifications (1)-(3).

In the specifications (4)-(6) in table 3, every coefficient for the did variable are insignificant. Ideally, the coefficients for the did variable has the same significance level across all specifications (4)-(6). This is especially important for the specifications with fixed effects (5)-(6), given that these accounts for both unobserved heterogeneity and clusters in chosen countries and sectors. Therefore, I conclude that the results regarding the effect on the number of patent applications in EU ETS-regulated countries from the EU ETS are not robust. As with the specifications (1)-(3) in table 3, the coefficients for the post variable are insignificant in the specifications (4)-(6) in the same table. Hence, the results for the post variable are not robust as well. Moreover, the coefficients of business enterprise investments and GDP growth is insignificant in the specifications (4)-(6).

The research question in this thesis aimed to investigate the link between patent applications in EU ETS-regulated sectors and the EU ETS. From the findings in specifications (1)-(6) in table 3, I conclude that no relationship can be determined to hold between the implementation of the EU ETS in neither non-EU ETS nor EU ETS-regulated sectors. This also means that no connection from these results to the Porter Hypothesis can be made (Porter, 1991).

7.2 Results for three sectors

To ensure that the regressions models used previously are capturing the innovation effects of the implementation of the EU ETS, one common method to test robustness is to apply placebo checks (Fredriksson & Magalhães de Oliveira, 2019). One way of performing placebo checks to use periods where the intervention was not in place or underwent some substantial change. In the EU ETS, the aviation sector joined first in 2012 – seven years after the EU ETS started in 2005 (EC, 2015). Given that the aviation sector joined later, it can be used for a placebo check. Therefore, I apply patent application data (defined by priority date) for the aviation sector to perform such analysis. For an exact definition of what IPC codes entail to the aviation sector in this thesis, refer to appendix 5.

The regressions for checking the parallel trend assumption are redone with three sectors and presented in appendix 6. As parallel trend assumption holds for both business enterprise and gross domestic investments models, I proceed with reperforming the six regressions that I have made in the previous section. Note that in comparison to previous table 3, table 4 contains two different coefficients of interest: did and did_avi. Did reflects that the treatment effect from both cement and manufacturing of iron and steel sectors, which were EU ETS-regulated from 2005. Given that aviation is EU ETS-regulated from 2012, did_avi considers the treatment effect from the EU ETS solely for the aviation sector. The outcome variable in table 4 is the same as in table 3, patent applications by priority date.

Table 4. Regression outputs using 3 sectors (cement, manufacturing of iron and steel, and aviation from 2012)

	gross domestic investments			business enterprise investments		
Specifications	(1)	(2)	(3)	(4)	(5)	(6)
regulated	-47.47*	-50.26*	-25.02	-49.29*	-52.09*	-33.24**
	(15.925)	(12.13)	(15.50)	(16.48)	(12.67)	(16.05)
did	-5.46	2.07	-3.98	-5.84	1.66	-2.51
	(11.68)	(6.41)	(7.52)	(11.47)	(6.42)	(7.54)
did_avi	35.27*	29.13*	20.78*	34.58*	28.46*	23.36*
	(9.98)	(7.62)	(12.06)	(9.85)	(7.29)	(12.53)
gross domestic investments	-3.57	-3.62	21.64**			
	(2.64)	(2.58)	(8.22)			
GDP growth	1.26	1.33	-2.56	1.17	1.24	-2.82
	(.82)	(.81)	(1.66)	(.80)	(.79)	(1.68)
business enterprise investments				-.63	-.65	11.56
				(2.11)	(2.09)	(12.96)
_cons	81.39*	90.35**	-1.48	77.04*	85.92***	33.96
	(23.14)	(10.19)	(24.51)	(21.65)	(8.38)	(28.30)
Observations	510	510	510	510	510	510

R-squared	.0840	.1165	.6979	.0830	.1155	.6979
Robust cluster sector	YES			YES		
FE cluster sector		YES	YES		YES	YES
FE cluster country			YES			YES
The first three specifications in table 4 consist of regression outputs on the gross domestic investments (GERD) models and the fourth to six on the business enterprise investments (BERD) models. Specifications 1 and 4 controls three sector clusters with a robustness option. Moving on to specifications 2 and 5, these use fixed effects that account for unobserved heterogeneity in sectors with a cluster option that checks for clusters in the data on the sector level (three clusters). Specifications 3 and 6 in table 4 stands for the output using a cluster controlling option with fixed effects on two levels, country and sector. This means that specifications 3 and 6 controls for differences that remains constant on both country and sector level over the studied time frame as well as for the 30 clusters (10 countries x 3 sectors). *Standard errors are in parentheses* **** p<.01, ** p<.05, * p<.1*						

Table 4 indicates that none of the specifications (1)-(3) is significant for the did variable. This is exactly what was found previously in table 3 for the specifications (1)-(3). Thus, I conclude that no relationship can be established in table 4 regarding how the number of patent applications in the cement and manufacturing of iron and steel in EU ETS-regulated countries was impacted by the EU ETS being implemented in 2005. I can also see that the coefficients for the did_avi variable in the specifications (1)-(3) in table 4 is positive and significant at a 10 percent level. This means that the aviation sector in EU ETS-regulated countries filed more patent applications on average after the implementation of EU ETS in the aviation sector in 2012. The magnitude of the coefficients for did_avi gets closer to zero when adding on the fixed effects to control for unobserved heterogeneity in sector and clusters. Given the significance level do not drop for did_avi across the specifications (1)-(3), I interpret this as my findings are robust. However, since I have evidence for one sector and not for the two others, I conclude that my overall evidence for the policy effect from the EU ETS in the specifications (1)-(3) is non-existent. Moreover, the coefficients for gross domestic investments are only significant in the specification (1) across the specifications (1)-(3) in table 4. Such a finding differs from table 3, where none of the coefficients for gross domestic investments was significant. The coefficient in the specification (1) in table 4 is significant at a 5 percent level and a magnitude of 21.64. I interpret this as when gross domestic investments increase by one percent the number of patent applications rises by 21.64 percent. However, this evidence is not consistent across the specifications (1)-(3). This causes me to conclude that no relationship can be detected between the gross domestic investments and patent applications in all the three EU ETS-regulated sectors. The coefficients for GDP growth were insignificant across the specifications (1)-(3) in table 4, which was previously demonstrated in table 3.

Looking at the specifications (4)-(6), neither of the coefficients for the did variable is significant. Therefore, I conclude that no relationship can be found between the EU ETS being implemented in 2005 and the number of patent applications in the cement and manufacturing of iron and steel sector in EU ETS-regulated countries. This is the same conclusion I made earlier in table 3 for the did variable in the specifications (4)-(6). The coefficients for did_avi is significant at 10 percent level in all the specifications (4)-(6) in table 4. I interpret this as the number of patent applications in the aviation sector are on average higher in EU ETS-regulated countries after the aviation sector becoming EU ETS-regulated in 2012. As the significance levels do not change for did_avi across the specifications (4)-(6), this means that the findings are robust. I further note that once I add on the fixed effects that the magnitude of the coefficients for did_avi becomes closer to zero (specifications (4)-(6)), which was also the case in the specification (1)-(3) in table 4. The low significance levels for did_avi and the fact that I only find evidence for one of two treatment variables causes me to conclude that no relationship across studied EU ETS-regulated sectors and patent applications can be established. Furthermore, none of the coefficients for the business enterprise investments and GDP growth was significant in the specifications (4)-(6) in table 4. This is the same as what was found in table 3.

This thesis aimed to investigate whether the EU ETS has impacted patent applications in EU ETS-regulated sectors. In conclusion, the results for the did_avi and did variables in table 4 differed across the specifications (1)-(6). This together with low significance levels for did_avi leads me to interpret the results as no relationship exist between the EU ETS and the number of patent applications for either the EU ETS-regulated aviation sector or the cement and manufacturing of iron and steel sectors. Except for that, the large presence of insignificant results across specifications (1)-(6) as well as mixing results for did and did_avi in table 4 means no connection between the treatment effect for the two sectors (the did variable) to the Porter Hypothesis (Porter, 1991).

7.3 Summary of the Results

This thesis employed two different versions to test its six models` specifications. These two versions were as follows:

i) cement sector and manufacturing of iron and steel sector (2 sectors)

ii) cement sector, manufacturing of iron and steel sector, and aviation sector (3 sectors)

It is evident that conflicting results were found regarding the two different treatment effects on patent applications in EU ETS-regulated sectors from the EU ETS. For the treatment effect on the cement and manufacturing of iron and steel sectors, no relationship could be found with either (i) two or (ii) three sectors. This is because its treatment effect "did" was insignificant across all the specifications in both table 3 and 4. However, when only regarding the treatment effect of the aviation sector "did_avi", the results pointed to a positive innovation effect in table 4 but with low significance levels (the specifications (1)-(6)). Ideally, the results for the two treatment effects would point to the same finding unlike what table 3 and 4 showed. Therefore, I conclude that no relationship could be found between the number of patent applications in the studied EU ETS-regulated sectors and the EU ETS.

As earlier pointed out, the Porter Hypothesis says that a spur of innovation occurs in regulated countries after the implementation of stringent environmental regulation such as the EU ETS (Porter, 1991). Because the results were mixed for both the treatment effect for the two sectors regulated from 2005 (cement and manufacturing of iron and steel) and the aviation sector from 2012, I say that this thesis can neither support nor argue against the general Porter Hypothesis.

Before performing the regressions, as discussed before, I dropped South Korea from my initial control group with the motivation that South Korean data differed from the other chosen countries. This was due to that South Korea had higher patent application levels in the three observed sectors than any other of the countries. Thus, I conclude that avoiding using South Korean data removed a bias in the estimated results and led to more trustworthy estimates.

Looking at the results on the coefficients regarding gross domestic and business enterprise investments, I proved that most of these coefficients were insignificant. It is worth noting that the coefficient for gross domestic investments was only significant once in specification 3 in table 4, where it had a positive magnitude. Due to the high presence of insignificance in my result regarding these two R&D variables, I conclude that my findings are not robust and thereby no causal interpretation between the two R&D variables and patent applications should be made. Insignificance across all the specifications was also found for the GDP growth variable in both table 3 and 4. One would imagine that in periods of growth the firms have more money and thereby invest more money in innovation. This would over time manifest itself in terms of more patent applications, which is unlike what the results in this thesis showed. As the findings of the GDP growth variable were insignificant in all specifications in table 3 and 4, no interpretation can be made as the results are not robust.

To sum up, the results in this thesis proved that there is no effect on patent applications across the different treatment effects. The first treatment effect "did" captured cement and manufacturing of iron and steel sectors with (i) two and (ii) three sectors, while the second "did_avi" gave the treatment effect from the aviation sector with a data set containing three sectors. This overall finding is contrary to what has been found in the research so far. Note that there was a high presence of insignificance in the results and hence the results should be interpreted with caution. Therefore, the next chapter will focus on discussing the results shown in chapter 7 to shed some light on why the findings in this thesis may differ.

8. Discussion

8.1 Discussion with focus on Earlier Environmental Regulation Literature

The results in this thesis point to no relationship existing between patent applications and EU ETS for EU ETS-regulated countries, which differs from what earlier research suggests (except for Löfgren et al., 2014) – that there are positive innovation effects (for example Bel & Joseph, 2018; Borghesi et al., 2015; Calel, 2018; Calel & Dechezleprêtre, 2016; Martin et al., 2012). The findings in earlier literature hold across different sectors, patent classification systems, identification strategy, chosen independent variables, sample sizes, time series, and a set of EU ETS-regulated countries. This thesis differs from the earlier research in most of the seven aspects mentioned in the previous sentence.

This thesis used patent application data for three sectors: cement, manufacturing of iron and steel, and aviation. While the cement and manufacturing of iron and steel sectors were included in Borghesi et al. (2015), I could not find any previous literature that looked at the aviation sector. Therefore, incorporating aviation sector data is regarded as a contribution to the research topic from my thesis. Borghesi et al. found that the cement sector[26] had low adoption of environmental innovation. The cement sector interviewees in Borghesi et al. also argued the EU ETS was not stringent enough to create incentives for innovation. As the cement industry was viewed as a special case in Borghesi et al., this may explain my findings of no innovation effects. Since Borghesi et al. did neither include the aviation sector nor discussed the

[26] Borghesi et al. (2015) referred to the cement sector as the ceramics and cement sector. This thesis opted for the "cement sector", but it includes patents from ceramics as well. The same goes for the manufacturing of iron and steel sector in this thesis that Borghesi et al. (2015) called "pig iron or steel". Refer to appendix 3.

manufacturing of iron and steel sector, caution is encouraged when comparing Borgesi et al. to the results from this thesis.

It is important to further highlight the choice of the patent classification system used by researchers, because these systems are the statistical foundation of how patent applications are counted and thereby can affect the estimated innovation effect. Tanner et al. (2019) described that a few researchers created their own classification system, while Calel and Dechezleprêtre (2016) among others used widely available classification systems such as the CPC. In comparison to these studies, this thesis applied the IPC system. This myriad of patent classification systems makes it hard to compare results between different studies. Existing discrepancies in research so far may be partly attributed to differences in classification systems and are not further checked in my thesis. I encourage future research to explore this topic.

In contrast to previous literature, this thesis identified its control group as non-EU ETS regulated sectors by using national data from the non-EU Member States (for example, Bel & Joseph, 2018; Borghesi et al., 2015; Martin et al. 2012). I could not find any prior EU ETS literature that applied this identification strategy. However, as earlier discussed, Franco and Marin (2017) had a similar identification strategy with patent data and regulation to this thesis with the difference that they did not concentrate on the EU ETS.

This thesis further differs from earlier research by using other independent variables. While research such as Bel and Joseph (2018) adopted the business enterprise investments and GDP growth measure, I also included gross domestic investments. I did not find any EU ETS literature using this variable. Another EU ETS study by Martin et al. (2012) used variables such as CO_2 intensity both on the sector and firm level, which I refrained from and thereby could act as another explanation for my different results.

The sample size in this thesis was 340 observations for two sectors and 510 observations for three sectors. This means that the sample size used in this thesis is smaller than large sample studies such as Borghesi et al. (2015) and Martin et al. (2012). It is possible that a larger sample size could have impacted the estimated results in this thesis and made them more similar to what researchers have found to date concerning the EU ETS.

As noted previously, most of the research so far focused on the first two phases of EU ETS (2005-2007; 2008-2012) (for example Bel & Joseph, 2018; Borghesi et al., 2015; Calel & Dechezleprêtre, 2016). This thesis differs from earlier research by using patent application data for 2000 to 2016 and thereby including over 10 years since the implementation of the EU ETS. The application of longer time series in this thesis could also serve as an explanation to my finding of no innovation effects. Since innovation processes often take a long time, the results in this thesis may better represent long term innovation effects due to the EU ETS than previous research does (Bernard, 2006). On the other hand, I cannot argue this for certain as I did not find any earlier research that included phase III or applied data for close to 10 years or more since the EU ETS was implemented in 2005.

In contrast to past studies, this thesis applies patent application data from six EU ETS-regulated countries (Belgium, France, Germany, Italy, Spain, and Sweden). Innovation in Germany was primarily studied in the first years of the EU ETS and showed low to moderate innovation effect (Hoffmann, 2007; Rogge & Hoffmann, 2010; Rogge et al., 2011; Schmidt et al., 2012). A similar finding was found for Italy by Pontoglio (2008), but later published Italian-focused studies found stronger innovation effects (Borghesi et al., 2015; Fontini & Pavan, 2014). From what I have seen, innovation effects due to EU ETS was not studied extensively for Belgium, Spain, and Sweden (except for, Löfgren et al. (2014) who looked into Sweden and Martin et al. (2012) who included Belgium). It is further possible that using a sample with more countries, which was done by Calel and Dechezleprêtre (2016) and Borghesi et al. (2015), would have produced results more similar to earlier research.

Moreover, as this thesis also included R&D expenditure variables, it is crucial to compare such findings in this thesis to earlier research. Bel and Joseph (2018) found a positive and significant relationship between business enterprise investments and low-carbon technologies patents in the energy sector. Given these insignificant coefficients in my results, I cannot do any causal interpretation of my results and thereby avoid drawing a parallel to findings in Bel and Joseph. The GDP growth variable in my results was negative but insignificant across all specifications with two and three sectors. This stands out from the findings by Bel and Joseph, where GDP growth was found to have a positive magnitude but was insignificant. The magnitudes of gross domestic investments were for the most part insignificant in my results. No parallel can be drawn between my results on gross domestic investments and previous research, because no other research was found that included this variable.

Altogether, the points above and the high presence of insignificant coefficients in my results are reasons for caution when interpreting my findings. This argument further extends to extrapolating the results when comparing them to earlier research.

Thus, this section has shown and compared the findings in this thesis with earlier research. To further motivate the data quality of the data used in this thesis and the disparities in the results between this thesis and previous research, the next section will concentrate on why the data in this thesis is thought to be representative of overall patent application trends.

8.2 Further Discussion of the Data Quality on Patent Applications

This section discusses why patent application data in the chosen EU ETS-regulated sectors in this thesis are believed to reflect overall patent application trends in Europe. This is crucial, given that this thesis finds different results than previous research (for example Bel & Joseph, 2018; Calel, 2018, Martin et al., 2012).

One reason for the gap between the control and treatment groups might be that patent applications of Europe are only one-tenth of the world total, while the majority comes from Asia (WIPO, 2018). Following this, the growth rate in the number of patent applications between 2007 to 2017 in Europe was less than in Asia and North America.[27] These two arguments explain why such trends between the two groups in this thesis may differ. However, when studying Taiwanese data applied in the control group, it was similar to the data on other chosen countries and thereby was used in the thesis. The same argument also holds for Canadian and Mexican data.

From the parallel trend figures A1 and A2 in appendices 4 and 6 respectively, patent applications on average looks barely changed for EU ETS-regulated sectors between 2000 to 2016. One reason for this is that patent applications on average in non-EU ETS regulated sectors is higher than in EU ETS-regulated sectors. When I look closer at only EU ETS-regulated sectors, more patent applications on average can be seen from 2000 and onwards in figure 1, 2 and 3. Figure 1 and 2 illustrate the average number of patent applications in two and three sectors respectively from 2000 to 2016, while figure 3 displays the same variable but for the

[27] Europe as a continent had 0.5 percent in growth, while Asia had 8.3 percent and North America 2.6 percent (WIPO, 2018).

aviation sector. This indicates that the EU ETS-regulated sectors increased their patent applications to varying degrees, which was visible for non-EU ETS regulated sectors as well (appendices 4 and 6). As figure 2 shows a higher mean of patent applications than figure 1, I interpret that most of the increase can be attributed to the aviation sector. This fact is further emphasised by figure 3, where average patent applications in the aviation sector for EU ETS-regulated countries increased at a faster pace than the other two sectors.

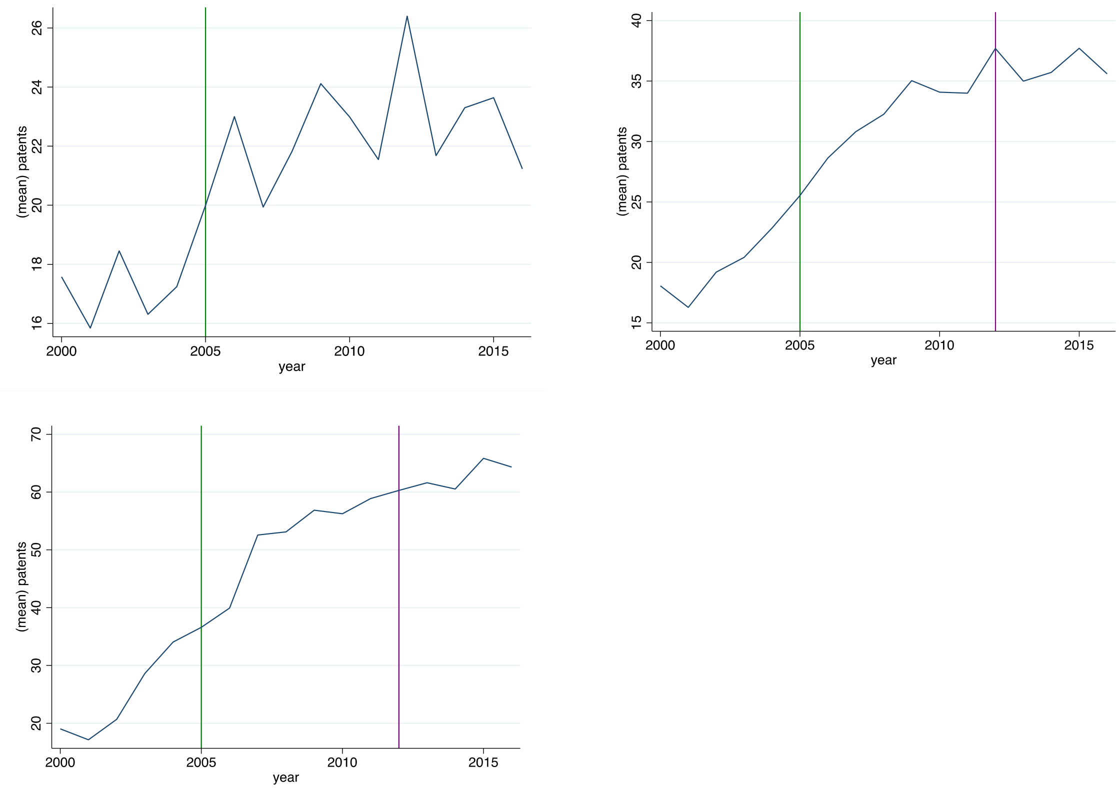

Figure 1, 2 and 3. Patent trends in EU ETS-regulated countries for two sectors (figure 1) up-left, three sectors (figure 2) up-right, with only aviation sector (figure 3) below

To further control for possible sector differences that could explain this gap, I explored patent application trends over time on a worldwide level. The category “materials, metallurgy” acts as a proxy for the manufacturing of iron and steel, while “basic materials chemistry” is used for the cement sector (WIPO, 2018). For the aviation sector, I apply the field “transport”. I compare these three categories with “environmental technology”. The average growth rates in published patent applications in these fields, except for transport, are roughly the same from 2006 to 2016 from a worldwide perspective.[28] As transport does not largely differ in its average growth from the other fields, I interpret this as a sign that the three studied sectors in this thesis are similar

[28] The average growth from 2006 to 2016 in “environmental technology” was field 8.5 percent, “basic materials chemistry” 8.1 percent, “materials, metallurgy” was 8.8 percent, and “transport” 5.9 percent (WIPO, 2018).

to the "environmental technology" sector. This means that my findings should not deviate from previous findings that used environmental technology such as Calel (2018). Moreover, when I look closer at the same four fields for published patent applications by top 10 origins, Germany and France have about the same distribution in two of the four fields between 2014 to 2016 (WIPO, 2018). This suggests that the patent application trends in "materials, metallurgy" and "environmental technology" are similar in these two countries. In "basic materials chemistry" France has a lower rate than Germany, while German data is close to the UK data that is often used in EU ETS-research on innovation (Calel, 2018; Martin et al., 2012). Therefore, I conclude that the data used in my chosen sectors do not differ greatly from findings in previous literature such as Calel and Dechezleprêtre (2016) and thereby should be trustworthy. I also discover that the average of published patent applications is the highest for transport (as a proxy for aviation) out of the four fields in both Germany and France (WIPO, 2018). This results in the expectation that transport has more patent applications than other sectors, which could not be proved empirically in this thesis due to the high presence of insignificant results (see table 3 and 4).

Apart from the differences and similarities to previous EU ETS literature outlined in section 8.1 and the data quality motivation in section 8.2, additional explanations could affect the estimated results and thus need to be taken into account. Such explanations are presented in the next section 8.3.

8.3 Discussion beyond Earlier EU ETS-research

One strength of this thesis is that it controls for clusters and fixed effects in the data. The issue of trusting DiD estimates that disregard clustering was discussed by Bertrand et al. (2004). Fixed effects account for differences on a country and sector level which are constant over time. My results, as mentioned earlier, in two specifications that applied fixed effects for country and sectors and took clusters into account that were largely insignificant. With more significance in the results in this thesis, it would have been possible to draw conclusions for the fixed effects specifications and thereby I refrain from doing so.

It is crucial to acknowledge that there exist multiple explanations, besides the implementation of environmental regulations (such as the EU ETS), as to why patent applications have augmented in the last decades. As previously described, the higher patent applications can be attributed to patenting becoming more popular and thereby results in the statistics showing even more patent applications (especially, when comparing to periods before 2000) (Espacenet, 2021; OECD, 2009; OECD, 2021a). Patent applications were also impacted by the growing trend of environmental innovation (and thereby patent applications in such fields) as well as fuel switching (Bel & Joseph, 2018; Calel & Dechezleprêtre, 2016; OECD, 2009). Brunnermeier and Cohen (2003), apart from the other explanations in this paragraph, stated that industries with international competitiveness had a higher likelihood of environmental innovation occurring. Dechezleprêtre et al. (2015) further added to the discussion by proving that countries with similar regulatory stringency (i.e. regulatory distance) had higher patents inflows in the automobile industries. Although controlling for such aspects were not done in this thesis, it is possible that these aspects impacted the results on patent applications.

In line with the paragraph above, patent applications may be affected by other environmental schemes besides the EU ETS (e.g. environmental taxation) and policies aimed at increasing innovation. This thesis has not accounted for the effects of such policies and how these policies bias the estimated innovation effects from the EU ETS. It is also important to highlight that the chosen EU ETS-regulated sectors could be impacted by the EU ETS in different ways. For example, the EU cement sector has during the last couple of years been dominated by large firms following a trend of merger and acquisitions (EC, 2018). There is thus a possibility that competition effects could distort patent applications in the cement sector, which this thesis does not control for. Besides that, the cement sector was influenced by instances exchange rate policies from countries such as Russia and this can hinder its future export growth. Furthermore, the EU steel industry faced trade barriers, lower demand, higher production costs and raw material costs, as well as unfair trading prices (EC, n.d.j; EC, 2016; Trappman, 2015). Therefore, I argue that future research should include a broader perspective when looking at patent applications in these two sectors.

Moreover, the possible role of knowledge spillovers needs to be addressed. In the previous chapters, I put forward the thesis that there might occur spillovers of patent applications from South Korea to EU ETS-regulated countries and this occurrence is then manifested in the EPO patent application data. Should such a relationship exist, it would mean that the EU ETS affects incoming patent applications in the studied EU ETS-regulated sectors from non-EU ETS regulated countries rather than patent applications within the EU ETS-regulated sectors (treatment group). This thesis abstained from any analysis of knowledge spillovers on South Korean data. The main reason for this is that the OECD does not provide the information needed to track patent applications and determine the rate of knowledge spillovers. Future research should look into the proposed relationship between patent applications and the EU ETS for South Korea but also other countries with a high number of patent applications at EPO such as the US and China (Jung, 2021). Knowledge spillovers are also seldom studied in EU ETS literature, except for with Miller (2014), and thus this angle should be further investigated in future research focusing on EU ETS-regulated countries.

Another strain for future research to explore whether the EU ETS caused crowding out of patent applications in EU ETS-regulated industries. Hottenrott and Rexhaüser (2015) showed mixed evidence of crowding out but did not explicitly study the EU ETS. This stands in contrast to Calel and Dechezleprêtre (2016), which proved that no crowding out existed for non-low carbon technologies within the EU ETS. Note that crowding out of certain innovations was rarely discussed in the literature found when working on this thesis. Apart from that, examining crowding out for the sectors studied in this thesis could perhaps explain the different number of patent applications between EU ETS-regulated and non-EU ETS regulated countries. To sum up, section 8.2 demonstrated that there might exist additional explanations to the findings in this thesis and provided a few examples of what future research could analyse.

9. Conclusion

This thesis has studied how patent applications (as a proxy measure for innovation) in EU ETS-regulated sectors were affected by the EU ETS. Two different versions with EU ETS-regulated sectors were used; i) two sectors (cement and manufacturing of iron and steel); and ii) three sectors (cement, manufacturing of iron and steel, and aviation). To perform such an analysis, I applied the DiD method and patent application data from 2000 to 2016. The control group, which consisted of non-EU ETS regulated countries, was Canada, Mexico, Russia and Taiwan. EU ETS-regulated countries as the treatment group, on the other hand, was represented by Belgium, France, Germany, Italy, Spain and Sweden. My results showed no relationship between the number of patent applications on average in the chosen EU ETS-regulated sectors for EU ETS-regulated countries after 2005. This also led to that no parallel could be drawn between the findings in this thesis and what the Porter Hypothesis states, which is that strict environmental regulation such as EU ETS should lead to more innovation (Porter, 1991). I found the same results for non-EU ETS regulated countries with two sectors. The findings for EU ETS-regulated countries were not consistent across the two different treatment effects, where one was for cement and manufacturing of iron and steel sectors starting in 2005 and the other for aviation from 2012. Therefore, the results in this thesis should be interpreted with caution.

Furthermore, fixed effects were applied in this thesis to control for disparities between countries and sectors that are constant between 2000 to 2016. I also controlled for clustering in my regressions. Such inclusion of fixed effects and clustering controls in the specifications did not improve the low significance levels in my results. Hence, I cannot provide an overall conclusion regarding the relationship between patent applications and the EU ETS. Besides that, mostly insignificant coefficients were also found for business and gross domestic investments. The GDP growth variable had only insignificant results and this means that the results for GDP growth were not robust as well. From this paragraph, it is clear that the results in this thesis were influenced by a high presence of insignificant coefficients and one should thus be careful with giving such results a causal interpretation.

When comparing the results from my thesis to previous literature, it stands out as other research found positive innovation effects due to the EU ETS (for example Bel & Joseph, 2018; Borghesi et al., 2015; Calel, 2018; Calel & Dechezleprêtre, 2016; Martin et al., 2012). To investigate why my findings may deviate, I looked closer into discrepancies between my thesis and the EU ETS research described in my literature framework. I found that my thesis differed in seven main aspects: sectors, patent classification system, identification strategy, chosen independent variables, sample size, time series, and the chosen EU ETS-regulated countries.

One key contribution from this thesis is the incorporation of aviation data. This angle on EU ETS was not found in other EU ETS innovation literature when writing this thesis. For that reason, future research should explore innovation effects in the aviation sector. Another reason for this is that the EU ETS is set to after 31 December 2023 include non-EEA destinations in addition to its current scope (EC, n.d.a). Such a regulatory extension might impact innovation in the aviation sector both on an aggregated (country) level and a disaggregated (firm) level. Therefore, I argue that future research should perform aviation studies on both the country- and firm-level. Such a division also adheres to the structure used in previous research.

In the years to come, EU ETS is set to undergo several changes in terms of higher stringency, market stability reserve and fewer freely allocated permits (EC, n.d.a.; EC, n.d.d.; EC, 2015). Except for these changes, incentives on other climate policy fronts such as the modernization fund and the innovation fund could also impact the EU ETS regulation (EC, n.d.f; EC, n.d.g). Drawing a parallel to this thesis, such mechanisms could influence patent applications in EU ETS-regulated sectors. Hence, this becomes another topic for future research to look into.

To date there have been few studies exploring how patent applications in i) the EU Member States joining in 2004 or afterwards and ii) non-EU Members only joining the scheme but not the EU was affected by the EU ETS in their EU ETS-regulated sectors. A few examples of studies including such "newer" EU ETS-countries are Martin et al. (2012) (includes Hungary and Poland), Jaraite-Kažukauske and Di Maria (2016) on Lithuanian firms, as well as Klemetsen et al. (2020) on Norway. Studying "newer" EU ETS-countries and their patent applications is also crucial, given that this could help ease the transition for countries set to join the EU and/or only its EU ETS in the future. Additionally, the number of patent applications may differ between "newer" and "older" EU ETS-countries (pre-2004). This has not been investigated in the literature so far from what I have seen. Thus, there should be an interest for future research to examine innovation effects due to EU ETS on the "newer" EU ETS-countries as well.

To conclude, it is essential to highlight the issue of data availability for patents as done earlier by researchers such as Calel (2018). The lack of data impacted, for example, the chosen identification strategy and which countries ended up as control and treated groups in this thesis. It is also possible that this scarcity of data can explain why researchers in the past built their own classification systems and also the divergence in research of which patent classification systems are used (Brunnermeier & Cohen, 2003; Calel & Dechezleprêtre, 2016; Tanner et al., 2019). From this background, I argue that data availability for patent statistics needs to improve on an international level (notwithstanding that OECD, PATSTAT and Espacenet patent search acts as important resources today). It is hard to navigate national patent offices, where the extraction method often differs between them. Without improvement in these areas, future research will be negatively affected.

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[29] Note that the title is misspelled and it should be "the", instead of "the". This is not corrected due to the title not being corrected when one searches for it online.

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Appendices

Appendix 1. An Overall illustration of the EU ETS

Table A1. All phases of the EU ETS and its key features

Key features	Phase I (2005-2007)	Phase II (2008-2012)	Phase III (2013-2020)	Phase IV (2021-2030)
Countries participating	EU27	EC27 + Norway, Iceland, Lichtenstein	EC27 + Norway, Iceland, Lichtenstein + Croatia (their aviation from 1.1.2014)	EC27 + Norway, Iceland, Lichtenstein + Croatia
Sectors	- Brick - Cement clinker - Ceramics - Coke ovens - Glass - Iron and steel plants - Lime - Oil refineries - Paper and board - Power stations and other combustion plants ≥20MW - Pulp	- Same as phase I - Aviation (from 2012)	- Same as phase I - Aluminium - Aviation from 1.1.2014 - Petrochemicals	- Same as phase III
Regulated greenhouse gas emissions	- CO_2	- CO_2 - N_2O emissions via opt-in	- CO_2 - N_2O - PFC from aluminium production	- Same as phase III
Cap	2058 million tCO_2	1859 million tCO_2	2084 tCO_2 (decreasing linearly by 38 million tCO_2 yearly)	*** tCO_2 (decreasing linearly by 43 million allowances yearly)

Sources: EC (2015), EC (n.d.a)

Romania and Bulgaria partook from 2007 and onwards. Before then it was 25 Member States participating in the EU ETS.

No information could be found regarding the cap in tCO_2 for phase IV at the stage of writing this thesis and are because of this marked with ***. Note that phase IV is currently in its first months (as it started in early 2021) and all future changes regarding cap, countries participating, and other factors are subject to change (EC, n.d.a). tCO_2 is an abbreviation for 1 tonne of CO_2 (EC, 2015).

Appendix 2. Correlation table

Table A2. Correlation table between business enterprise and gross domestic investments

	Business enterprise investments	Gross domestic investments
Business enterprise investments	1.000	
Gross domestic investments	0.9897	1.000

The correlation between business enterprise and gross domestic investments is particularly high at 0.9897. To control for this, I use two separate models where one applies business enterprise investments and the other gross domestic investments.

Appendix 3. Presentation of IPC codes

The IPC system provides a more detailed insight based on eight broader categories (WIPO, 2016). These broader categories are defined as:

- Human Necessities (A)
- Performing Operations; Transporting (B)
- Chemistry; Metallurgy (C)
- Textiles; Paper (D)
- Fixed Constructions (E)
- Mechanical Engineering; Lighting; Heating; Weapons; Blasting (F)
- Physics (G)
- Electricity (H)

Further specification based on the categories above can be done into 658 more precise categories. A chosen assortment of these more precise categories will be applied to track patent application patterns between 2000 to 2016. The treatment group will correspond to a sector that is regulated by the EU ETS, where the control group stands for a group that is not part of the EU ETS. More details on exact IPC codes for the aviation sector in this thesis is provided in appendix 5, in addition to this appendix 3.

This thesis will apply a four-digit code corresponding to each treatment and control group. Given the structure of IPC, it is feasible to opt for more refined categories as well. As many countries have few patents overall with four-digit codes and thereby they will likely have even fewer if breaking down the categories even further, using more specific codes were not used. By having the four-digit code on the chosen sectors, one can use the compiled statistics that the

OECD database and Espacenet supplies.[30] As mentioned earlier, for non-EU ETS countries data from Espacenet was applied and assigned their own fractional values based on the information provided through the website (such as concerning inventors and earliest priority date).

Both of the chosen sectors, i.e. the lime and cement industry as well as the iron and steel industry, are covered by the "Chemistry; Metallurgy (C)"-part of the IPC classification system (WIPO, 2016:01a). Classification C has three main subsections; chemistry, metallurgy, and combinatorial technology.

The lime and cement industry belongs to the chemistry subsection C04B. The official definition according to the 2016:01 edition is as follows:

- "Lime; magnesia; slag; cement; composition thereof, e.g. mortars, concrete or like building materials; artificial stone; ceramics (devitrified glass-ceramics C03C 10/00); refractories (alloys based on refractory metals C22C); treatment of natural stone" (WIPO, 2016:01b, p. 2).

In contrast to the lime and cement industry, the iron and steel industry belongs to the subsection of metallurgy C21B. Looking closer at data availability and size of patent applications, the manufacturing of iron and steel (C21B) has lower numbers in comparison to that of lime and steel (C04B) ("data source"). This trend for manufacturing of steel and iron holds even for larger countries such as Germany and France. Consequently, I will both study an aggregated measure and three disaggregated measures to investigate patent applications in the manufacturing of steel and iron sector. The prediction is then that the patterns that are found in patent applications for the treatment group will hold both for the aggregated and disaggregated data.

The classification C21 "metallurgy of iron" contains three different subclassifications;

1. Manufacture of iron or steel (C21B)
2. Processing of pig-iron (C21C)
3. Modifying the physical structure of ferrous metals (C21D) (WIPO, 2016:01c).

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[30] Espacenet also provides for a few IPC codes even further specification (eight-digit code or above). This was not used for the same reasons as outlined above, i.e. concerns that there would be too little data to later test on.

To further precise what each subsection includes, the three subsections will be presented with examples in the three following paragraphs. The aggregated measure is the result of adding data for every year from 2000 to 2016 for all of these three subsections together (C21), while the three disaggregated measures correspond to the subsections separated (C21B, C21C and C21D). Note that using subsections for patent number is described by Griliches (1990) as a common principle when working with patent data. Griliches (1990) further discussed that using an aggregated measure is useful to capture patent trends for a whole industry, which was also done in previous EU ETS studies such as Bel and Joseph (2018) as well as Borghesi et al. (2015).[31]

The overall name for C21B is the manufacture of iron or steel. It primarily incorporates:

- "… production of iron or steel from source materials, e.g. the production of pig-iron; apparatus specifically adapted therefor, e.g. blast furnaces, air heaters (furnaces in general.)" (WIPO, 2016:01d, p. 2).

This stands in contrast to C21C which describes the pig-iron related patent applications. More precisely, it stands for:

- "processing of pig iron, e.g. refining, manufacture of wrought-iron or steel; treatment in molten state of ferrous alloys" (WIPO, 2016:01e, p. 2).

Another part of the metallurgy of the iron family is the "modifying the physical structure of ferrous metals" sector (C21D). This C21D classification has a higher data availability than C21B, especially for smaller countries. The category for C21D is defined as:

- "modifying the physical structure of ferrous metals; general devices for heat treatment of ferrous or non-ferrous metals or alloys; making metal malleable by decarburization, tempering, or other treatments" (WIPO, 2016:01f, p. 2).

Note that as part of the result section, the aggregated measure of the steel and iron sector (C21 AGG) will be studied together with the cement sector (C04B).

[31] Bel and Joseph (2018) applied the Y02-classification, which consists of a broad selection of environmental-related patents, and can thus be argued to be an aggregated method for patent data. On the other hand, Borghesi et al. (2015) applies a SIC-code system corresponding to 24 industries, which are then grouped into different aggregated groups where four is EU ETS-sectors and one is non-EU ETS.

Appendix 4. Parallel trends with two sectors

Appendix 4 presents the same parallel trends regressions with two sectors (cement sector and manufacturing of iron and steel sector).

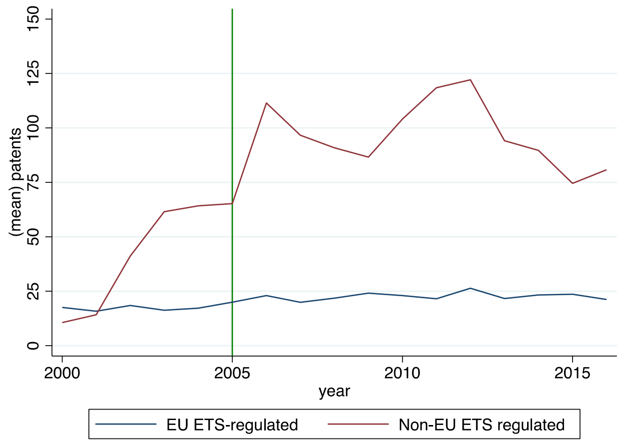

Figure A1. Parallel trends with two sectors

Figure A1 above is a graphical illustration of the parallel trends assumption for the two sectors.

Initially, the patents on average were quite similar but this changed over time. At the same time, the EU ETS-regulated sectors (blue line) remain flat over the period while the non-EU ETS regulated (red) experience larger fluctuations. These two factors make it hard to see whether the parallel trends assumption holds. As it is not immediately clear, I will perform regressions as well.

Table A3. Regression outputs for two sectors (cement sector and manufacturing of iron and steel sector) with pre-trends 2000-2004

	gross domestic investments	business enterprise investments
Specifications	(1)	(2)
post	60.60***	59.79***
	(16.56)	(16.58)
regulated	-18.64	-21.11
	(28.92)	(28.98)
did	-44.31	-44.48
	(31.06)	(31.11)
gross domestic investments	-6.12	
	(5.85)	
GDP growth	3.15*	3.03
	(1.88)	(1.89)
business enterprise investments		-2.79
		(7.39)
inter_2000	4.03	4.16
	(35.60)	(35.65)
inter_2001		

inter_2002	9.47	8.96
	(35.78)	(35.83)
inter_2003	9.47	8.87
	(35.94)	(35.99)
inter_2004	10.86	10.32
	(36.00)	(36.05)
_cons	33.91**	28.45*
	(17.17)	(16.46)
Obs	340	340
R-squared	.1329	.1304

Specification 1 includes gross domestic investments (GERD), where specification 2 includes business enterprise investments (BERD).

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

In table A3, all interaction terms from 2000 to 2004 (except for 2001 that drops out) are significant in the specification 1 and 2. This means that parallel trends hold in both specifications. Therefore, it is possible to perform the regression models for the two sectors. For those results, refer back to section 7.1.

Appendix 5. Definition for the aviation sector

The aviation sector in EU-28 stood for approximately 3.6 percent of its total greenhouse gas emissions in 2016 (EASA, 2019). According to EUROSTAT (2020c), about 408 000 individuals were employed in the sector within the EU (2019 census). This indicates that there exist reasons for the aviation sector, including the EU ETS regulation, to minimise emissions and invest more into innovation in the future.

As with the cement sector (C04B) and manufacturing of iron and steel (C21 AGG), the aviation sector corresponds to its own categories in the IPC system. According to Eugui and Bifani (2014), aviation patents belong to several different IPC classes. This thesis selected the B64 category as it was included in every key word-subgroup that Eugui and Bifani applied for searching for aircraft technologies that could potentially lead to greenhouse gas emission reductions. Moreover, as seen below, the B64 section captures several different aspects of the aviation patent classifications and thus can be argued to be a good representative of the ongoing patent application trends that exist in the aviation sector.

In contrast to the earlier subclass "C", classification B touches upon patent regarding performing operations and transporting (WIPO, 2016:01g). The category B64 corresponds to "aircraft; aviation; cosmonautics" (WIPO, 2016:01h). Following the principle for the manufacturing of iron and steel (C21 AGG), data for patent applications regarding all five B64 categories are merged to create an aggregate measure of the aviation called B64 AGG.

The B64 category consists of five subclassification that are defined as;

1. "Lighter-than-air aircraft" (B64B)
2. "Aeroplanes; helicopters (air-cushion vehicles B60V)" (B64C)
3. Equipment for fitting in or to aircraft; flying suits; parachutes; arrangements or mounting of power plants or propulsion transmissions in aircraft (B64D)
4. Ground or aircraft-carrier-deck installations specifically adapted for use in connection with aircraft; designing, manufacturing, assembling, cleaning, maintaining or repairing aircraft, not otherwise provided for (B64F)
5. Cosmonautics; vehicles or equipment therefor (apparatus for, or methods of, winning materials from extraterrestrial sources E21C 51/00) (B64G) (WIPO, 2016:01i).

Note that this does not mean that all aviation patents are covered by these IPC codes. This thesis has opted to use B64 AGG as a proxy measure for aviation patents.

As done previously, I divide it up to two models given high correlation between gross domestic and business enterprise investments. Equation 5 represents gross domestic investments, while equation 6 business enterprise investments. The equations for testing the parallel trends on the aviation sector are:

$$5)\ y_{ict} = a_1 + a_2 inter2005 + a_3 inter2006 + a_4 inter2007 + a_5 inter2008 + a_6 inter2009 + a_7 inter2010 + a_8 inter2011 + a_{10} Reg + a_{11} Post_i + a_{12} Reg\#Post_i + \beta_1 GDP_{growth_{c,t-1}} + \beta_1 GDP_{growth_{c,t-1}} + \beta_2 BERD_{c,t-1} + \varepsilon_{ict}$$

$$6)\ y_{ict} = a_1 + a_2 inter2005 + a_3 inter2006 + a_4 inter2007 + a_5 inter2008 + a_6 inter2009 + a_7 inter2010 + a_8 inter2011 + a_9 Reg + a_{10} Post_i + a_{11} Reg\#Post_i + \beta_1 GDP_{growth_{c,t-1}} + \beta_1 GDP_{growth_{c,t-1}} + \beta_2 BERD_{c,t-1} + \varepsilon_{ict}$$

They follow the same hypothesis testing as given in section 6.3.2. If the dummy years are insignificant, I can proceed with testing the six model specifications in my regressions.

Appendix 6. Parallel trends with three sectors

Appendix 6 consists of two tables called A4 and A5. This is because the aviation sector was part of EU ETS from 2012, where the other two sectors were part of EU ETS from 2005. I only use aviation data for the regressions performed in table A5 due to the fact that patent application in this sector is believed to differ greatly from such applications in the other two sectors.

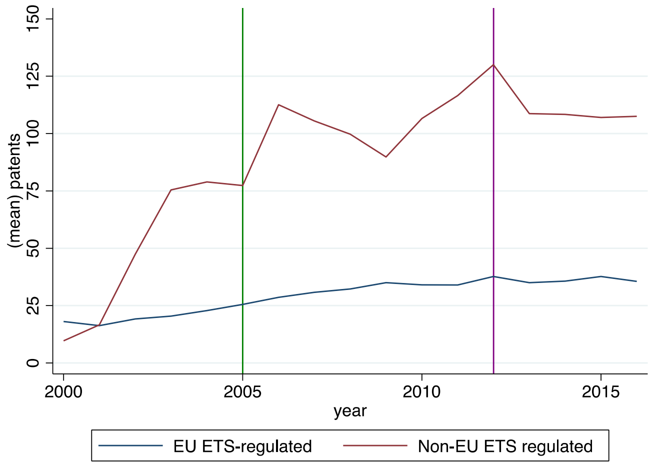

Figure A2. Parallel trends for three sectors where two sectors are regulated from 2005

Figure A2 above is a graphical representation of parallel trends assumption. It uses data from three sectors, where 2 sectors (cement and manufacturing of iron and steel sectors) are regulated from 2005 onwards as represented by the green line. The purple line is included to show when aviation sector became EU ETS-regulated (2012), but those parallel trends are tested in table A5 and its graph are shown in figure A3. It is not clear from figure A2 that the parallel trends assumption might hold.

To further verify the parallel trends assumption, I perform the regressions again but with the new data set which includes three sectors.

Table A4. Regression outputs for three sectors (cement sector, manufacturing of iron sector and aviation sector) with pre-trends 2000 to 2004 for the two regulated sectors (cement sector and manufacturing of iron and steel sector)

	gross domestic investments	business enterprise investments
Specifications	(1)	(2)
post	74.80***	75.53***
	(14.79)	(14.78)
regulated	2.78	.02
	(16.74)	(16.72)
did	-82.41***	-83.25***
	(19.28)	(19.26)
gross domestic	2.52	

investments		
	(5.32)	
GDP growth	3.22*	3.05*
	(1.66)	(1.66)
business domestic investments		8.02
		(6.76)
inter_2000	-25.65	-25.19
	(28.02)	(27.98)
inter_2001	-30.30	-30.02
	(28.17)	(28.13)
inter_2002	-21.30	-21.66
	(27.92)	(27.89)
inter_2003	-21.11	-21.35
	(27.93)	(27.90)
inter_2004	-19.44	-19.49
	(27.94)	(27.91)
_cons	25.28*	22.61
	(15.23)	(14.51)
Obs	476	476
R-squared	.1404	.1426
Specification 1 includes gross domestic investments (GERD), where specification 2 includes business enterprise investments (BERD). *Standard errors are in parentheses* **** p<.01, ** p<.05, * p<.1*		

In table A4, the dummy variables for year 2000 to 2004 is insignificant in both specifications. Following the principle in earlier appendices, this means that parallel trends hold.

Before performing any regressions with three sectors, however, one has to check that the parallel trends hold for the aviation sector as well. The next figure A3 and table A5 represents parallel trends graphical representation and regression outputs for the aviation sector.

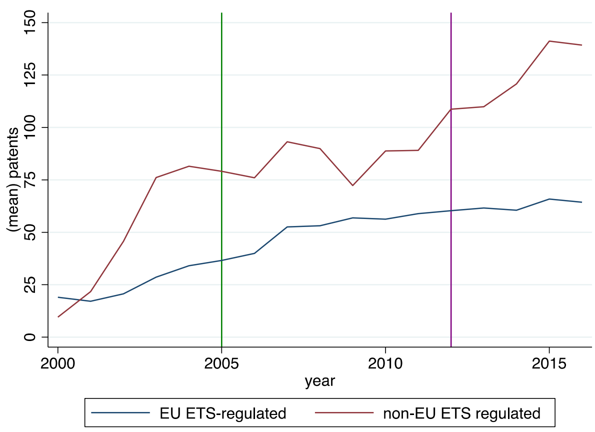

Figure A3. Parallel trends for the aviation sector

In the figure A3 above, the parallel trends for aviation are shown. The pre-trends used are from year 2005 to 2011, where the purple line shows when the aviation becomes EU ETS-regulated in 2012. In comparison to the other figures (A1 and A2), the blue line that represents the treatment group (i.e. EU ETS-regulated countries) increases more sharply where in the other figures it looked flat.

It looks as though the parallel trends assumption holds in figure A3. Next I will perform regressions to check if my parallel trend assumption holds for the aviation sector as well. Note that avi_post denotes =0 if the year is before 2012 and =1 otherwise.

Table A5. Regression outputs for the aviation sector with pre-trends from 2005 to 2011

	gross domestic investments	business enterprise investments
Specifications	(1)	(2)
avi_post	81.63***	82.08***
	(22.75)	(22.74)
regulated	-9.97	-10.91
	(24.48)	(24.52)
did_avi	-36.31	-36.88
	(32.12)	(32.03)
gross domestic investments	.77	
	(8.51)	
GDP growth	2.97	2.87
	(3.07)	(3.08)
business enterprise investments		3.27
		(10.73)
inter_2005	12.09	12.33
	(39.77)	(39.76)
inter_2006	17.61	17.81
	(39.76)	(39.75)
inter_2007	26.57	26.76
	(39.83)	(39.83)
inter_2008	28.02	28.23
	(39.79)	(39.78)
inter_2009	39.85	39.65
	(40.31)	(40.29)
inter_2010	51.60	51.06
	(44.33)	(44.29)
inter_2011	34.08	34.27
	(39.77)	(39.76)
_cons	24.81	23.03
	(24.98)	(23.55)
Obs	170	170
R-squared	.1341	.1345

Specification 1 includes gross domestic investments (GERD), where specification 2 includes business enterprise investments (BERD).

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

When using the aviation sector, the dummy variables for the years 2005 to 2011 are all insignificant. This means that parallel trends assumption holds for the aviation sector.

Because the parallel trends assumption was verified to hold both for the aviation sector (table A5) and three sectors (table A4), regressions can now be performed by using the data for three sectors. As the three sectors are EU ETS-regulated from different points of time, the regression equations need to reflect this notion. The aviation sector joined in 2012 in contrast to the cement and manufacturing of iron and steel that became part of the EU ETS at its start in 2005. Treatment effect for the cement and manufacturing of iron and steel (the two EU ETS-regulated sectors) is captured by Reg#Post$_i$ (called did in table A4), which was the case with earlier equations 3) and 4) as well. For the aviation sector, the treatment effect from the EU ETS on patent applications is captured by Reg#Avi_post$_i$ (denotes as did_avi in table 5).

$$7)\ y_{ict} = a_1 + a_2Reg + a_3Reg\#Post_i + a_4Reg\#Avi\_Post_i + \beta_1GDP_{growth_{c,t-1}} + \beta_2GERD_{c,t-1} + \varepsilon_{ict}$$

$$8)\ y_{ict} = a_1 + a_2Reg + a_3Reg\#Post_i + a_4Reg\#Avi\_Post_i + \beta_1GDP\_growth_{c,t-1} + \beta_2BERD_{c,t-1} + \varepsilon_{ict}$$

I will as I did earlier perform separate specifications that controls for clusters in country and sectors through fixed effects for both equation 7 and 8. This means that four regressions will be performed that uses fixed effects. The regression results for these six specifications are presented in section 7.2.