WP 2024:03

The Role of Environmental Policy and Public Innovation

Subsidies in Promoting Green Patenting in Sweden

Growth analysis

Swedish Agency for Growth Policy Analysis

Dnr: 2022/124
Myndigheten för tillväxtpolitiska utvärderingar och analyser
Studentplan 3, 831 40 Östersund
Telefon: 010 447 44 00
E-post: info@tillvaxtanalys.se
www.tillvaxtanalys.se
För ytterligare information kontakta: Ulrika Stavlöt
Telefon: 010 447 44 43
E-post: ulrika.stavlot@tillvaxtanalys.se

The Role of Environmental Policy and Public Innovation

Subsidies in Promoting Green Patenting in Sweden

Dr Jessica Coria (University of Gothenburg)

Dr Jurate Jaraite (Umeå University, Vilnius University)

May, 2024

Abstract

This report examines the impact of public innovation subsidies and the EU Emission Trading Scheme (EU ETS) on green innovation in Swedish industrial firms. Analyzing green patents from 1985-2018 and firm-level data, our findings indicate that substantial innovation subsidies significantly boost green patenting in the manufacturing sector, while smaller subsidies have little effect. ETS firms produce fewer, narrower, and less cited green patents than non-ETS firms, indicating a focus on compliance over broader innovation. No significant combined effects of subsidies and emissions trading were observed, highlighting the importance of targeted subsidies in promoting green technology.

Keywords: climate policy, emissions trading, innovation, manufacturing, patents, subsidies

JEL codes: D22, H23, H25, Q55, Q58

Preface

Technological change is the main force in improving the trade-off between economic growth and environmental quality in the long run. Unfortunately, the development of new green technologies is constrained by two types of market failures. First, the private sector does not have sufficient incentive to carry out research and development (R&D) because of knowledge spillovers and credit market failures that discourage lenders from providing loans to firms for low-probability high-return investments such as research and development. Second, the demand for environmental innovations is driven by regulations that might be difficult to implement or might not be stringent enough to have a sizeable effect on innovation.

In the presence of joint market failures (environmental and technological), a case may be made for the joint application of two policy instruments, such as environmental taxes and green innovation subsidies. In this report, we investigate the combined effect of direct public innovation subsidies and the European Union Emission Trading Scheme (EU ETS) on industrial firms' green innovation activity in the case of Sweden. The main goal is to determine the overall combined effect of both policies as well as their relative efficiency in promoting green innovation.

Green innovation by Swedish firms is measured through green patenting. Information on green patents over the period 1985-2018 is complemented with firm-level data allowing us to account for relevant variables that could explain firm selection into green innovative activities. Firm-level data is also merged with ETS regulation status retrieved from the European Union Transaction Log and firm-level data on innovation subsidies, which has been collected from the MISS database (developed by the Swedish Agency for Growth and Policy Analysis). This database contains granular information on various direct support provided by various public Swedish agencies to firms. Using all these data and matching methods, the aim is to estimate the causal effect of innovation subsidies and emissions trading on corporate green innovation Although the analysis has access to rich data and aims to take into account as many relevant factors as possible, we cannot know with certainty if the effects we observe are causal. Therefore, results should be interpreted with some caution.

Our analysis indicates that large levels of innovation subsidies contribute significantly to the development of green patenting among firms operating in the manufacturing sector. In contrast, low levels of subsidies do not affect patenting, potentially implying that there exists a minimum level of subsidy support necessary to stimulate meaningful innovation within the manufacturing sector. Below this threshold, the impact of subsidies on patenting activity seems to be negligible. Furthermore, we find that ETS firms have fewer, narrower, and less cited green patents than comparable non-ETS firms. This finding might suggest that innovations by ETS firms may be more specifically tailored towards emissions reduction rather than broader commercialization. Meanwhile, non-ETS firms may pursue broader technologies with greater potential for market success beyond regulatory compliance. Finally, we find no significant combined effects of innovation subsidies and emissions trading, suggesting that – even if environmental policies might play a role in creating a demand for green innovation-targeted, subsidies are crucial in overcoming market failures that prevent the development and patenting of green technologies.

This report was written by associate professor Dr Jessica Coria (University of Gothenburg) and professor Dr Jurate Jaraite (Umeå University, Vilnius University) under the supervision and guidance of the Swedish Agency for Growth Policy Analysis. We are particularly grateful to

Ulrika Stavlöt and Laszlo Sajtos for sharing their views and knowledge about the effects of environmental policies and direct government support on green innovation. We are also grateful to the internal and external reviewers who provided us with insightful comments to improve the analysis in the report.

Content

1. Introduction

Innovation and regulation form the main pillars of the European Union's policy for sustainable development (Fankhauser et al., 2013). Innovation in general and environmentally friendly technologies, in particular, are expected to help the EU develop a resource-efficient, greener, and more competitive economy while delivering high levels of employment, productivity, and social cohesion (Fabrizi et al., 2018). Since environmental policies encourage polluting facilities to undertake abatement activities, it is expected to foster far-reaching changes in production processes and resource use through the development of innovative technology and its adoption. Thus, the effect of environmental policies on the development and spread of new technologies is among the most important determinants of the success or failure of environmental protection efforts.

Studies on the impact of actual environmental regulations on technological development have shown that the technology responses to environmental policy range from the diffusion of existing technology, incremental changes in processes, product reformulation to product substitution, and the development of new processes. However, the most common responses to regulation are the diffusion of existing technology and incremental innovation in processes and products by firms outside the regulated industry (see, e.g., Kemp, 2000; Popp, 2019). The existing studies also show that the stringency of the regulation is an important determinant of the degree of innovation with stringent regulations being necessary for radical technological responses (Eugster, 2021).

Subsidies are also an important element of government policy toward technology (Bloom et al., 2019). Public direct support for green innovation is growing. For instance, under the Paris Climate Agreement, countries committed to double governmental support to renewable energy R&D budgets to over $ 30 billion by 2030 (see, e.g., Popp, 2019). Thus, evaluating the impact of public R&D investments on green innovation is important.

Implicit in the widespread use of government subsidies are the assumptions that (i) R&D has a positive impact on productivity and (ii) the market will fail to provide the socially optimal level of R&D spending due to knowledge spillovers and credit constraints. Knowledge spillovers appear because R&D creates knowledge that cannot be fully appropriated by the firm that paid for the investment, and so other firms also benefit without paying the full cost. In addition, private financers may be reluctant to lend to innovating companies when the investment is concentrated essentially on intangible assets. This situation results in a higher cost of financing concerning ordinary investment and a lower level of private external funding of R&D activities. Knowledge spillovers and funding constraints cause the private return to R&D to lie below the social return, justifying government-supported innovation policy.

In this report, we examine the combined effect of environmental policies and direct R&D subsidies for promoting green innovation. Most studies addressing government R&D simply include public R&D expenditures as one of several variables in more general studies of the drivers of innovation (see, e.g., Dechezleprêtre and Glachant, 2014; Nesta et al., 2014). Such an approach disregards that R&D activity is highly heterogeneous across firms and that firms with larger innovation abilities are more likely to receive R&D support (e.g., Galaasen and Irarrazabal, 2021). In contrast, the information available in the database MISS allows accounting for the effects of selection, by providing firm-level information on whether firms have received R&D support from relevant researcher funding organizations. Indeed, our analysis reveals a notable concentration of innovation subsidies within a select few firms, which receive considerably higher subsidies compared to others over the examined period. This concentration may stem from various factors. Firstly, these firms may possess superior capabilities or resources, such as robust R&D infrastructure or established innovation track records, enhancing their competitiveness in securing subsidies. Secondly, administrative hurdles in accessing subsidy programs may dissuade smaller firms, leading to a further concentration among larger players. Additionally, policymakers may strategically allocate funding to firms perceived to have the highest innovation potential, further consolidating the subsidy concentration. This underscores the importance of understanding subsidy allocation dynamics and their impact on firm-level innovation strategies and outcomes.

The conditions for analyzing our questions are based on register data and available statistical methods. In other words, there are no prerequisites for using so-called experimental or quasi-experimental methods. In this paper, we use 'matching'. The aim of this method is to use information in the data to identify two groups of firms that are identical, i.e. “twins”, in the pre-policy period. The basic premise for the identification of causality is that the available register data allow us to take into account all factors that affect our outcome - innovations. As there may be unobservable factors in the data that could influence innovation, we cannot be certain that the groups we are comparing are similar in all aspects. Although the analysis has access to rich data and aims to take into account as many relevant factors as possible, we cannot know with certainty if the effects we observe are causal. Therefore, results should be interpreted with some caution.

Our analysis reveals that substantial levels of innovation subsidies play a significant role in fostering the advancement of green patenting among firms operating in the manufacturing sector. Conversely, lower subsidy levels do not exert an influence on patenting, suggesting that there exists a minimum threshold of subsidy support required to catalyze meaningful innovation within the manufacturing domain. Below this threshold, the impact of subsidies on patenting activity appears to be negligible. Additionally, we observe that firms participating in the EU ETS tend to have fewer, narrower, and less cited green patents compared to their non-ETS counterparts. This finding implies that innovations by ETS firms may be more narrowly focused on emissions reduction rather than broader commercialization. In contrast, non-ETS firms may pursue broader technologies with greater potential for market success beyond mere regulatory compliance. While environmental policies may play a role in creating a demand for green innovations, our analysis does not reveal significant combined effects of innovation subsidies and emissions trading. This suggests that while environmental policies may stimulate demand, subsidies are crucial in overcoming market failures and incentivizing innovation.

This report is organized as follows. Section 2 presents a short overview of existing studies investigating the effects of environmental policies and direct subsidies to R&D on innovation. Section 3 describes the patent data used in this report, providing an overview of green patenting by Swedish firms over the period 1985-2018. Section 4 provides an overview of environmental policies in place expected to have a significant effect on green innovation in the case of Swedish industrial firms. Section 5 provides an overview of the major green innovation subsidy schemes available through the MISS database. Section 6 provides an empirical analysis of the effects of environmental policies and innovation subsidies on green patenting, disentangling their effects and investigating their complementarity. Finally, Section 7 provides the conclusions, some policy recommendations, and directions for future research in the area of environmental policy and green innovation.

2. Previous research

In this section, we summarize some key findings on the effects of environmental policies and direct subsidies to R&D on green patenting and their combined effect.

2.1 Green Patenting and Environmental Policies

Several comprehensive and critical review studies have summarized the existent literature on innovation responses to environmental policies (see, e.g., Jaffe et al., 2003 and 2005; Popp, 2019; Kemp and Pontoglio, 2011; Lilliestam et al., 2021). As highlighted by these studies, environmental policies have influenced green innovation to varying extents. In what follows, we summarize a few studies analyzing the effects of environmental policies – particularly, climate-related policies – on patenting.

Johnstone et al. (2010) use aggregated country-level patent data on a panel of 25 countries over the period 1978–2003 to analyze the effect of environmental policies on technological innovation in the case of renewable energy. They investigate the effect of a wide variety of policy types, including feed-in tariffs, production quotas, and public research and development expenditures on energy R&D disaggregated by type of renewable energy. Interestingly, they find that there is variation in the effects of instrument type on different types of renewable energy. Broad-based policies, such as tradable energy certificates, are more likely to induce innovation in technologies that are close to competitive with fossil fuels. In contrast, more targeted subsidies, such as feed-in tariffs, are needed to induce innovation on more costly energy technologies, such as solar power.

Aghion et al. (2016) investigate the role of carbon prices in directing technical change. They use patenting data between 1965 and 2005 across 80 patent offices. They exploit the fact that tax-inclusive fuel prices (that they use as a proxy for a carbon tax) evolve differentially over time across countries in their data and that firms are differentially exposed to these price changes because of their heterogeneous market positions in different geographic markets. They find that clean innovation is stimulated by increases in fuel prices whereas dirty innovation is depressed. Furthermore, they find strong evidence for "path dependency" in the sense that firms more exposed to clean (dirty) innovation from other firms are more likely to direct their research energies to clean (dirty) innovation in the future. The fact path dependency holds for clean and dirty innovation highlights the need of acting sooner to shift incentives for climate change innovation.

Concerning the effects of broad policies such as the EU ETS, studies that have investigated its effects on patenting have found sizeable effects on regulated firms. For example, Calel and Dechezleprêtre (2016) made use of a matched difference-in-differences study design to investigate the effects of the EU ETS on low-carbon patenting in the EU. Their results indicate that the EU ETS has had a strong impact on the patenting behavior of EU ETS–regulated firms, which increased their patenting by as much as 10%. They also found that the EU ETS has not affected patenting beyond the set of regulated companies. These results imply that the EU ETS accounts for nearly a 1% increase in European low-carbon patenting compared to a counterfactual scenario. Thus, the EU ETS has a limited impact on overall low-carbon patenting, but a strong and targeted effect on a small set of firms under the regime. Likewise, Calel (2020) compares British ETS-regulated firms to non-regulated firms over the period 2000-2012. His results indicate that the EU ETS has caused low-carbon patenting to increase by 25% compared with the counterfactual. Furthermore, he finds that the EU ETS has, contrary to experience with previous cap-and-trade programs, encouraged innovation of new low-carbon technologies rather than the adoption of existing carbon-reducing technologies.

He argues that previous cap-and-trade programs have generally targeted pollutants and polluters that had technologies available that could achieve the regulator's long-term abatement targets at a reasonable cost. Under such conditions, the only real question facing companies is when to install the existing abatement technologies rather than the development of new technologies. In contrast, the increases in patenting and R&D signal that new low-carbon technologies are being developed, and that greater near-term stringency may be needed to spur the adoption of such technologies.

Finally, previous studies investigating the effects of environmental policies on green innovation in Sweden are less conclusive. For instance, Löfgren et al. (2014) look at the effects of the EU ETS on investments in CO_2-reducing measures in Sweden from 2002 to 2008. By using a difference-in-differences approach, they do not find a significant effect of the EU ETS on the likelihood of investing in carbon mitigation. They note though substantial investments in carbon-reducing equipment, particularly in bioenergy and district heating, but find that these investments would have happened also without the EU ETS, triggered by other policy measures or because they were profitable on their own. Some caveats of such a study are the short-term data set and the fact that they only focused on a one-sided measure of innovation.

2.2 Green Patenting and Direct Government Support

The literature investigating the effects of governmental support on R&D can be categorized into three groups: 1) studies analyzing the additionality of R&D expenditure to determine the degree to which firms' R&D expenditures increase because of government support, 2) studies analyzing the effects of R&D on innovation, i.e., the degree of changes in innovation behavior of firms measured by product and process innovation, increased number of patents, improved organization, and management of the firm, and 3) studies analyzing economic outcomes at a macroeconomic level (i.e., increased productivity and economic growth) that may be induced by government funding of R&D investments in firms (see, e.g., Petri 2018 for a review of the literature about direct government support to innovation).

The bulk of the existing empirical studies has focused on input additionality, testing the crowding-in and crowding-out hypothesis, i.e., whether public investments have a positive or negative effect on private investment flows. Empirical studies on output additionality or those evaluating effects on the macroeconomic level are more limited, although this evidence is highly important for judging the overall effectiveness of government innovation policy (Petri, 2018). Furthermore, government support for R&D can take different forms. Grants, subsidies, and loans are often referred to as direct government support, while tax incentives, especially tax credits are instruments referred to as indirect government support. It is widely accepted that direct support is more appropriate for R&D projects having the largest gap between the social and private rate of return. In these cases, government R&D could be more effective because of the tendency of private firms to invest in projects that yield the highest private rate of return.

Concerning the effects of R&D on innovation, to date, most studies investigating the effectiveness of governmental support to green R&D simply include public R&D expenditures as one potential driver of innovation. In some of those studies, the effect of R&D is statistically insignificant or minor (see Popp, 2019), while in others, it is large and even larger than the effects of environmental policies. For instance, Deleidi et al. (2020) investigate the effects of public investments in private investments in renewable energy. They find that increases in public direct investments have the largest impact on private investments, while environmental subsidies and environmental taxes have smaller positive impacts. Their results speak strongly against the existence of a crowding-out effect of public investment on private investment. They argue that the crowding out/in concept is inapplicable to sectoral studies such as renewable electricity because public investments in markets with failures can help correct these failures and thus mobilize private financial flows.

The previous literature faces the major caveat that government R&D subsidies are not randomly allocated to firms since subsidized firms are selected according to established criteria or firms themselves selected into various subsidy schemes, and this selection process is unobservable on the part of the researcher. Few studies address this selection bias. Some of these studies are Howell (2017) and Bai et al. (2019). Howell (2017) investigates the effects of R&D grants provided by the U.S. Department of Energy on cite-weighted patents by high-tech energy startups facing financing constraints that impede innovation. She makes use of a regression discontinuity design that compares firms immediately around the award cutoff. She finds that an early-stage award approximately doubles the probability that a firm receives subsequent venture capital and has large, positive impacts on patenting and revenue. Moreover, these effects are stronger for more financially constrained firms.

Bai et al. (2019) make use of propensity score matching to investigate the impacts of government R&D subsidies on the green innovation of energy-intensive firms in China. Their results show that government R&D subsidies increase the green innovation of energy-intensive firms, both in terms of their tendency (measured by the count of applications for green patents) and performance (measured by the count of green patents granted). The results are sizeable: applications for green patents in the treated group are 107.3% larger than in the control group, while the number of granted green patents is 54.1% larger in the treated than in the control group. Heterogeneity analyses show that the impact is stronger in state-owned enterprises and in small and medium enterprises.

2.3 Combined Effect of Environmental Policy and Direct Government Support

Theoretical analyses have highlighted the need to combine environmental policies with research subsidies to redirect technical change toward the development of green technologies. For instance, Acemoglu et al. (2012) show that optimal environmental regulation should always use both a carbon tax to control current emissions and research subsidies to influence the direction of research. Even though a carbon tax would by itself discourage research in the dirty sector, using this tax both to reduce current emissions and to influence the path of research would lead to excessive distortions. Instead, optimal policy relies less on a carbon tax and more on direct encouragement for the development of clean technologies. Christiansen and Smith (2015) arrive at a similar result when investigating the case when abatement costs are uncertain or fluctuate over time, i.e., an environmental policy such as a tax instrument is insufficient to achieve an efficient outcome. They show that under conditions of uncertainty, it will always be desirable to supplement an emissions tax with a subsidy for abatement, rather than to rely on the emissions tax alone.

More recently, Ahlvik and van den Bijgaart (2024) highlight the role of environmental policies, such as carbon taxes, to screen innovations. They argue that although innovation subsidies encourage innovations, the subsidies are unlikely to perfectly reward the most promising innovations. A high carbon tax (i.e., higher than the Pigouvian level) can help “screening winners”, incentivizing the development of radical innovations.

Summarizing, previous research reveals nuanced dynamics between environmental policies, direct government support, and their combined effect on green patenting. Environmental policies exhibit varying impacts on green innovation. Carbon pricing has been shown to stimulate clean innovation while dampening dirty innovation. In contrast, the EU ETS demonstrates a targeted influence on some of the regulated firms, notably boosting their low-carbon patenting. The effects of environmental policies on green innovation in Sweden remain, however, inconclusive.

Meanwhile, governmental support for R&D emerges as a promising avenue for fostering innovation, though studies yield mixed results regarding its effectiveness. Direct support mechanisms, such as grants and subsidies, are deemed particularly beneficial for projects characterized by substantial social-private return gaps. However, empirical analyses often neglect selection bias, an aspect that has received scant attention in existing literature.

Finally, theoretical analyses advocate for an integrated approach, combining environmental policies with research subsidies to steer technical change toward green technologies. This synergy between carbon taxes and research subsidies not only guides research toward cleaner solutions but also screens for radical innovations, thus enhancing the overall effectiveness of green innovation initiatives.

3. Green patenting by Swedish firms

As previously described, granted patent counts have been widely used as a measure of innovative output. They not only provide a measure of innovation but also of innovation trends since the changes in patent counts over time also are an indicator of R&D activity (e.g., Popp, 2019). It is important though to note that patent counts are just a proxy for innovation since many innovations are not patented at all (Calel and Dechezleprêtre, 2016).

Concerning green patenting, the recent efforts of the European Patent Office (EPO) to classify sustainable technology patents using the Y02 classes have been particularly useful for research purposes. The Y02 classes provide separate classifications for technologies pertaining to climate change mitigation and adaptation, as well as for smart grids. These classifications allow non-patent experts to search for climate change-related technologies in a more user-friendly fashion (see, e.g., Angelucci et al., 2018).

The Y02 classes are based on automated search statements defined and implemented by internal experts working at the EPO. These search statements are periodically run and the new patent documents relating to Climate Change Mitigation Technologies (CCMTs) are identified and automatically tagged.

The Y02 classes cover the technical fields where climate change mitigation can be identified and the following subclasses: Y0A related to adaptation to climate change; Y0B related to buildings; Y02C related to GHG capture, storage, and disposal; Y0D related to the reduction of own energy use; Y02E related to the production, distribution, and transport of energy; Y02P related to industry and agriculture; Y02T related to transportation; and Y02W related to wastewater treatment and waste management (see Table 3.1 for a description of the technologies included in each subclass). This classification provides the most accurate tagging of climate change mitigation patents available today and is becoming the international standard for clean innovation studies (see, e.g., Calel and Dechezleprêtre, 2016).

The analysis in this report is based on patent data received from the Swedish Intellectual Property Office (PRV). The data contains information about all patents that have been granted for use in Sweden between the years 1985 and 2018 where at least one of the patent classifications corresponds to the Y02 classes. This is to say, we make use of climate adaptation and climate mitigation patents as a proxy measure for new-to-market green innovations. In what follows, we describe the main features of the green patents in the data and its evolution over time, separating between patenting by Swedish firms and other entities.

Table 3.1 Technologies or Applications for Mitigation or Adaptation Against Climate Change Included in the Y02 category.

Classification	Objective	Technologies included
Y02A	Adaptation to Climate Change	Technologies enabling adaptation in coastal zones and river basins. Water conservation, efficient water supply, and efficient water use. Technologies adapting or protecting infrastructure or their operation. Adaptation technologies in agriculture, forestry, livestock or agroalimentary production Technologies enhancing human health protection, e.g., against extreme weather. Technologies having an indirect contribution to adaptation to climate change.
Y02B	Climate Change Mitigation in Buildings	Integration of renewable energy sources in buildings. Energy-efficient lighting technologies. Energy-efficient heating, ventilation, or air conditioning. Technologies aiming at improving the efficiency of home appliances. Energy-efficient technologies in elevators, escalators, and moving walkways. Technologies for an efficient end-user side electric power management and consumption. Architectural or constructional elements improving the thermal performance of buildings. Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation
Y02C	Capture, Storage, Sequestration, or Disposal of Greenhouse Gases	Capture or disposal of greenhouse gases
Y02D	Climate Mitigation in Information and Communication Technologies	Energy efficient computing. Reducing energy consumption in communication networks.
Y02E	Climate Mitigation in Energy Generation, Transmission and Distribution	Energy generation through renewable energy sources. Combustion technologies with mitigation potential. Energy generation of nuclear origin. Technologies for an efficient electrical power generation, transmission, or distribution. Technologies to produce fuel of non-fossil origin. Enabling technologies; Technologies with a potential or indirect contribution to GHG emissions mitigation Other energy conversion or management systems reducing GHG emissions.

Classification	Objective	Technologies included
Y02P	Climate Mitigation in the Production or Processing of Goods	Technologies related to metal processing. Technologies relating to chemical industry. Technologies relating to oil refining and petrochemical industry. Technologies relating to the processing of minerals. Technologies relating to agriculture, livestock, or agroalimentary industries. Technologies in the production process for final industrial or consumer products. Technologies for sector wide applications. Enabling technologies with a potential contribution to GHG emissions mitigation.
Y02T	Climate Mitigation in Transportation	Road transport of goods or passengers. Transportation of goods or passengers via railways. Aeronautics or air transport. Maritime or waterways transport. Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation.
Y02W	Climate Mitigation in Wastewater Treatment and Waste Management	Technologies for wastewater treatment. Technologies for solid waste management. Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation.

Source: European Patent Office. Information about subclasses was retrieved from https://www.epo.org/en/searching-for-patents/helpful-resources/first-time-here/classification/cpc.

3.1 Green Patents: Patent counts and Evolution over time

Table 3.2 presents some descriptive statistics of the number of green patents granted for use in Sweden between the years 1985 and 2018. The patents are divided between those granted to Swedish and non-Swedish entities. As seen from the Table, only 13 % of the 30 412 patents granted were granted to Swedish entities (i.e., 4 007 patents). Moreover, 85% of the patents granted to Swedish entities were granted to Swedish firms.

Table 3.2 also reports the average patent family size and the average number of patent citations. The patent family size corresponds to the set of patents protecting the same invention in various countries, while the citations correspond to the number of times the granted patent is cited in subsequent patents. Finally, each patent can be assigned several patent classes, both within the Y02 classes as well as within other patent classes. Table 3.2 reports the average total number of Y02 classes of the granted patents, the average total number of classes, and the average relative share of Y02 patents to all classes.

Table 3.2 Descriptive Statistics of Counts of Green Patents

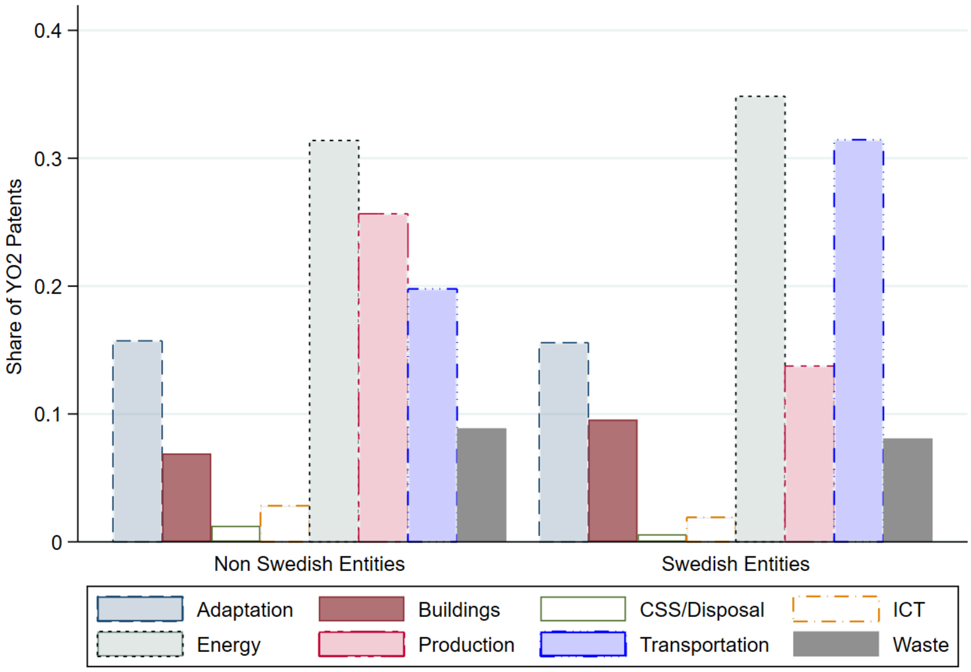
	N	Family size	Citations	No. of Y02 classes	Total classes	Y02 share to total classes
1. All patents	30 412	11.6	24.0	2.1	14.4	21.9%
2. Swedish entities	4 007	6.2	9.1	2.0	13.2	23.6%
Firms	3 389	6.6	9.7	2.1	14.1	22.3%
Individuals	618	4.1	5.8	1.8	7.8	30.9%
3. Non-Swedish entities	26 405	12.5	26.3	2.1	14.6	21.6%
p-value differences (2)-(3)		<0.001	<0.001			<0.001

Notes: The table was compiled by the authors using PRV green patent data.

Some differences to highlight are that patents granted to Swedish entities have a statistically significantly smaller family size and fewer citations. Moreover, the relative share of Y02 classes to the total patent classes is statistically lower for patents granted to non-Swedish entities.

Figure 3. 1 presents the share of Y02 patents belonging to each subclass (see Table 1). From the figure, it is clear that a large share of Y02 patents granted to Swedish entities occurs within the subclasses Y02E (energy generation, transmission, and distribution), and Y02 (transportation). In contrast, the relative incidence of patents belonging to the subclass Y0P (climate mitigation in the production of processing of goods) is larger among non-Swedish entities.

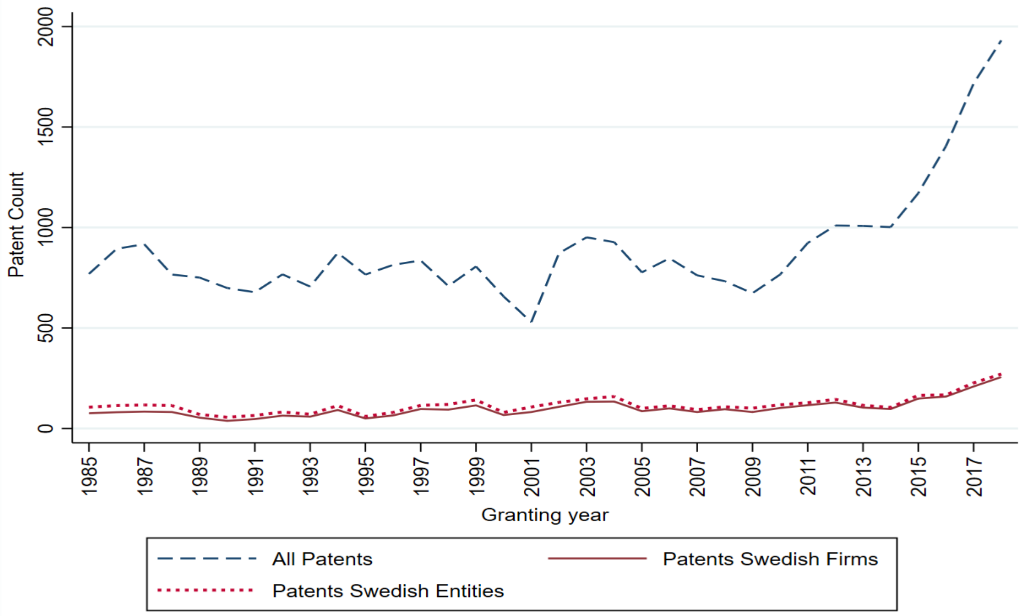
Figure 3.1 Share of Y02 patents belonging to different subclasses



Notes: The figure was compiled by the authors using PRV green patent data.

Concerning the evolution of granted patent counts over time, Figure 3. 2 plots the number of counts per year, displaying the total number of patents, and those by Swedish and non-Swedish entities. The number of patents has increased sharply since 2011, and such a trend seems to be mostly explained by the increased number of patents registered by non-Swedish entities (see also Figure 3.3). In contrast, the number of patents by Swedish entities has remained relatively constant until 2014, a year since which we observe a clear trend towards an increasing number of patents. For instance, the number of patents by Swedish entities increased from 115 patents in 2013 to 271 patents in 2018 (a 236% increase).

Figure 3.2 Trends on the Number of Green Patents Granted



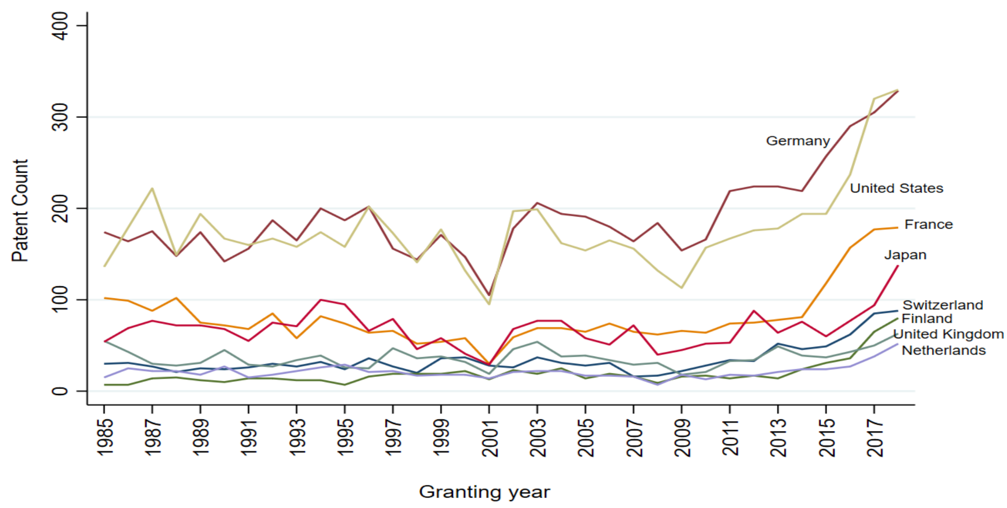
Notes: The figure was compiled by the authors using PRV green patent data.

Figure 3.3 plots the number of patent counts per year for the eight countries with an average number of patents granted that is larger than the average number of patents granted to Swedish entities. The two countries with the largest number of patents registered in Sweden are Germany and the United States, followed by France and Japan, and by Switzerland, Finland, the United Kingdom, and the Netherlands. Interestingly, the number of patents granted to applicants from Germany and the United States has increased sharply since 2010, while the number of patents granted to applicants from France and Japan has also increased sharply since 2014.

According to OECD, in 2015, 21.1% of the world's green innovations are developed by the United States, followed by Korea (21.0%), Japan (15.5%), Germany (12.6%), China (3.9%), France (3.8%), and the United Kingdom (2.4%).[1] From the information in Figure 3.2 is thus not surprising that Sweden is an important market for the technologies developed by some of these countries, as well as for the technologies developed by other European countries such as Switzerland, Finland, and the Netherlands.

[1] https://www.oecd.org/env/indicators-modelling-outlooks/green-patents.htm

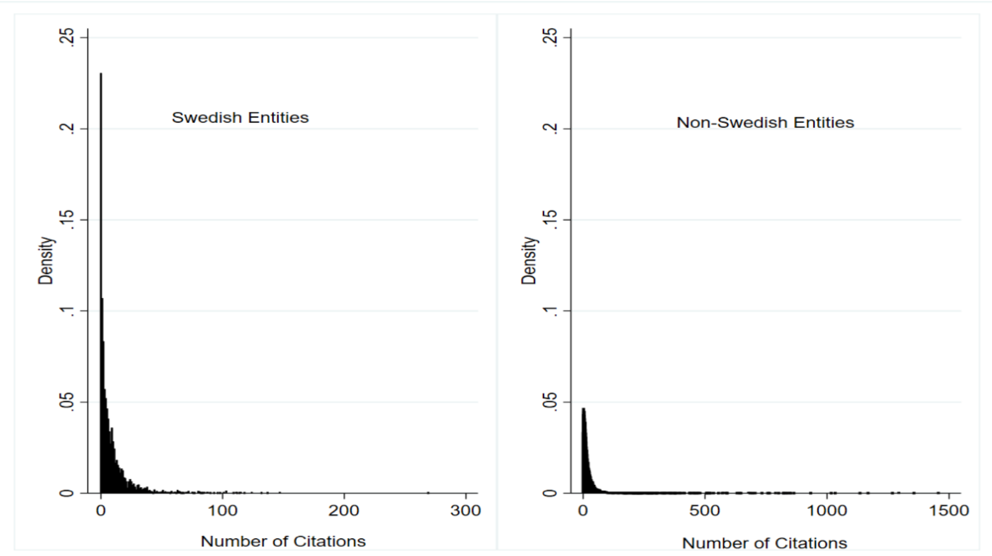
Figure 3.3 Number of Green Patents Granted to Non-Swedish Entities per Country, 1988-2018



Notes: The figure was compiled by the authors using PRV green patent data.

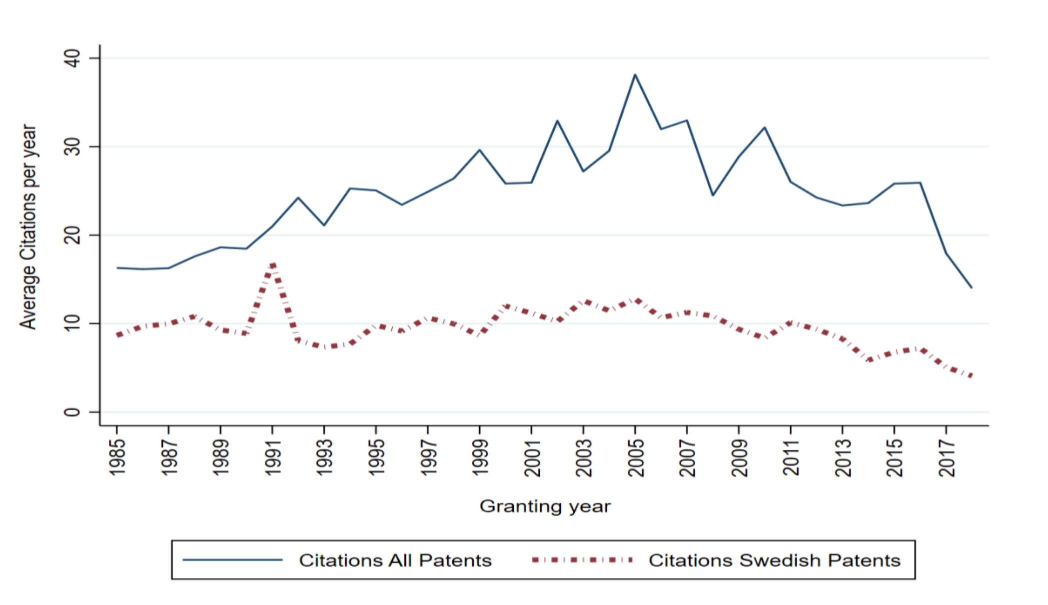
Concerning citations, Figure 3.4 displays the distributions of the number of citations granted to Swedish and non-Swedish entities. More than 23% of the patents granted to Swedish entities have received no citation, while the maximum number of citations corresponds to 269. In contrast, only 3.35% of the patents granted to non-Swedish entities have received no citations and the largest number of citations (excluding two outliers) is 1 456. This is to say, patents granted to non-Swedish entities are much more cited, possibly because these patents are in force in many markets. Finally, Figure 3.5 displays the average count of citations across years. Consistent with Table 3.2, we observe a larger average number of citations to patents granted to non-Swedish entities. We also observe that the number of citations increases over time, but that the increase stops after some years, possibly since new technologies emerge, and these technologies become the state of the art to be cited.

Figure 3.4 Distribution of the Number of Citations of Granted Green Patents



Notes: The figure was compiled by the authors using PRV green patent data.

Figure 3.5 The Average Number of Green Patent Citations, 1985-2018



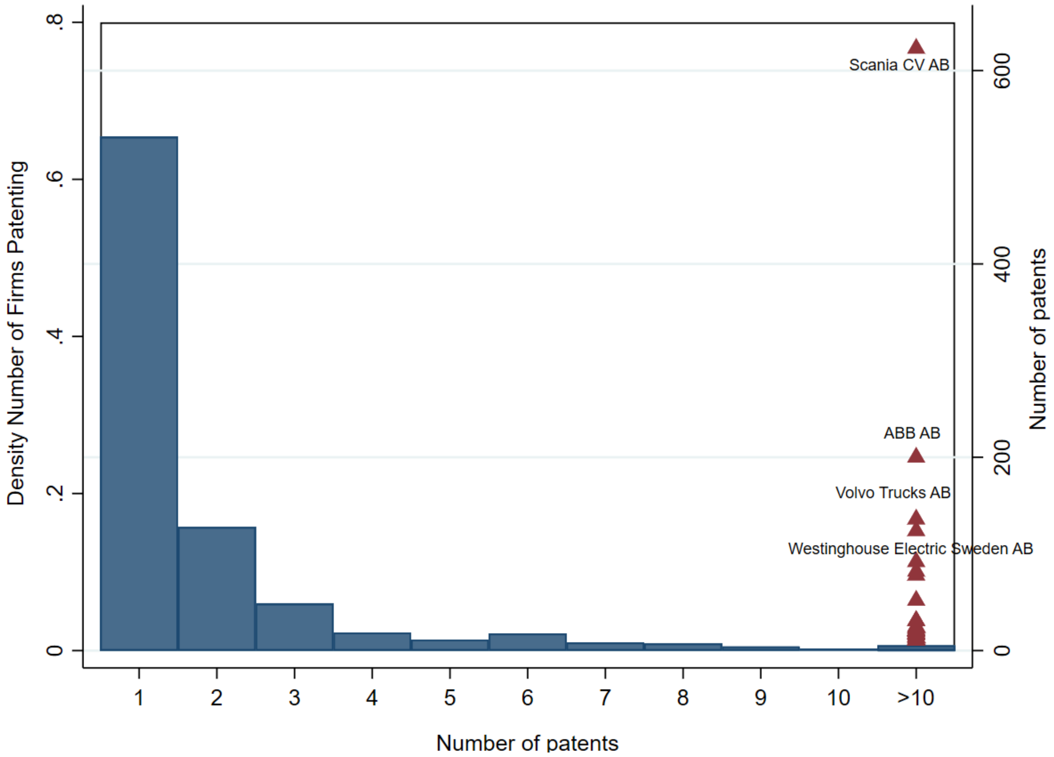
Notes: The figure was compiled by the authors using PRV green patent data.

3.2 Green Patenting by Swedish Firms

The patents filed by Swedish firms were, where possible, matched with a Swedish organization number. A search on firm names was made in the Orbis Europe financial database. The search resulted in 714 matches between firm names and Swedish organization numbers. The remaining patents were matched manually, using the information at hand (firm name, address, year of patent filing). The organization numbers were found using mainly allabolag.se and eniro.se, and other relevant websites. Firms that no longer exist and thus have no organization number, because of that they either were dissolved, sold, or merged with another firm, were difficult to match. Where possible, the patent application was merged with the current iteration of the sold or merged firm as they would potentially be the owner of the patent.

In total, we recover information for 789 Swedish firms. Concerning the distribution of the number of patents per firm, in Figure 3.6 we observe that 516 out of 789 Swedish firms that were granted patents during the period 1985-2018 were granted one patent (i.e., 65%). Moreover, about 4.44 % of the firms (i.e., about 35 firms) had more than 10 patents each. This is to say, few firms account for most of the patents in our sample. Indeed, four firms account for 34.15% of all patents in our sample.

Figure 3.6 Distribution of the Number of Green Patents by Swedish Firms



Notes: The figure was compiled by the authors using PRV green patent data.

Most Common Y02 Classes

Table 3.3 reports the most common Y02 subclasses of the patents granted to Swedish firms. Overall, there is a large incidence of patents connected to transport technologies, particularly those directed at improving internal combustion energy efficiency (i.e., 416 occurrences) and engine management systems (i.e., 136 occurrences). There is also a large incidence of patents connected to the protection of human health via the reduction of air pollution or technologies that protect human health against extreme weather (i.e., 119 occurrences of subclasses y02a5020 and y02a5030, respectively). Finally, there is a large incidence of patents connected to nuclear fission reactions (198 occurrences) and patents connected to biofuel production (116 occurrences).

Table 3.3 Most Common Y02 Subclasses of Patents Granted to Swedish Firms

Type	Y02 subclasses	No. Occurrences	Patented Technology
Human health protection	y02a5020	119	Air quality improvement or preservation, e.g., vehicle emission control or emission reduction by using catalytic converters
	y02a5030	119	Against vector-borne diseases, e.g. mosquito-borne, fly-borne, tick-borne, or waterborne diseases whose impact is exacerbated by climate change

Type	Y02 subclasses	No. Occurrences	Patented Technology
Heat recovery	y02b3056	52	Energy efficient heating, ventilation, or air conditioning: Heat recovery units
Energy efficiency ICT	y02d3070	74	Reducing energy consumption in communication networks: in wire-line communication networks, e.g. low power modes or reduced link rate
Energy generation	y02e1072	61	Wind turbines with rotation axis in wind direction
	y02e3030	198	Nuclear fission reactors
	y02e5010	116	Technologies to produce fuel of non-fossil origin: Biofuels, e.g., biodiesel.
	y02e5030	83	Fuel from waste, e.g. synthetic alcohol, or diesel
	y02e6010	94	Enabling technologies; Technologies with a potential or indirect contribution to GHG emissions mitigation: Energy storage using batteries
Metal processing	y02p1020	129	Technologies related to metal processing: Reduction of GHG emissions by recycling
	y02p1025	64	Technologies related to metal processing: Process efficiency.
Final industrial goods	y02p7010	51	Climate change mitigation technologies in the production process for final industrial or consumer products: GHG capture, material saving, heat recovery, or other energy efficient measures, e.g. motor control, characterized by manufacturing processes, e.g. for rolling metal or metal working.
	y02p7050	69	Climate change mitigation technologies in the production process for final industrial or consumer products: Manufacturing or production processes characterized by the final manufactured product.
Transport	y02t1012	416	Improving internal combustion engine efficiencies.
	y02t1040	136	Engine management systems.
	y02t1062	66	Hybrid vehicles.

Type	Y02 subclasses	No. Occurrences	Patented Technology
	y02t1064	59	Electric machine technologies in electromobility.
	y02t1070	97	Energy storage systems for electromobility, e.g., batteries.
	y02t107072	54	Electromobility specific charging systems or methods for batteries, ultracapacitors, supercapacitors or double-layer capacitors.
	y02t1072	59	Electric energy management in electromobility.
Wastewater	y02w1010	71	Technologies for wastewater treatment: Biological treatment of water, wastewater, or sewage.

Notes: The table was compiled by the authors using PRV green patent data.

Summarizing, our analysis of green patenting in Sweden allows us to provide the following findings:

- **Patent Distribution and Ownership**: Green patents granted to Swedish entities represent only a fraction of the total green patents granted in Sweden. Specifically, only 13% of the total patents granted for use in Sweden between 1985 and 2018 were granted to Swedish entities, indicating a larger presence of non-Swedish entities in green patenting activities.
- **Patent Characteristics**: Patents granted to Swedish entities tend to have smaller family sizes and receive fewer citations compared to those granted to non-Swedish entities. This suggests potential differences in the scale and impact of innovation between Swedish firms and their non-Swedish counterparts in the green technology space.
- **Sectoral Distribution**: A significant portion of green patents granted to Swedish entities is concentrated in certain sectors, such as transportation and energy generation, highlighting areas of focus for Swedish innovation. In contrast, non-Swedish entities may have a broader distribution across different sectors, indicating a potentially diverse range of green technology development activities outside of Sweden.
- **Trends Over Time**: While the number of patents granted to non-Swedish entities has shown a sharp increase over recent years, the trend among Swedish entities has been relatively stable until more recent years, when an increasing trend is observed. This suggests differing patterns of innovation dynamics and growth trajectories between Swedish firms and non-Swedish entities in the green technology domain.
- **Concentration of Patents in Few Firms**: A significant concentration of green patents is observed among a small number of Swedish firms, indicating that a few entities contribute substantially to green innovation in Sweden.

4. Environmental policies that might drive green patenting

Sweden is often described as an environmental frontrunner due to the early implementation of progressive and innovative environmental policies. For instance, Sweden was among the first countries to establish comprehensive environmental legislation (Environmental Protection Act of 1969) and environmental institutions (the Swedish Environmental Protection Agency was established in 1967). The country has also been characterized by the early adoption of environmental policy innovations. For instance, the green tax reform in 1990-1991 reduced taxes on income and capital, and increased taxes on energy and emissions such as carbon dioxide and sulfur (Hysing, 2014). Furthermore, starting in 1992, Sweden implemented a charge on NOx emissions to reduce these emissions from combustion plants that produce energy (Bonilla et al., 2018). National policies have been complemented by a series of policies implemented by the European Union, which Sweden joined in 1995. For example, in 2005, the EU introduced the Emissions Trading System with the goal of reducing GHG emissions by means of a cap-and-trade program. Moreover, the EU Directive on industrial emissions (IED) implemented in 2010 tackled air pollutants from industrial sources by establishing emission limits and requirements on the adoption of the best available techniques for large industrial installations.[2]

Regulations on air pollutants and GHG emissions have been also complemented by policies promoting investments in renewable energies (Schusser and Jaraitė, 2018). The development of policies promoting energy from renewable energy sources (RES) was kicked off by the European Directive 2001/77/EC, allowing EU member states to implement different policy instruments to contribute to increasing the production of renewable energy. Sweden introduced a Tradable Green Certificates (TGCs) system in May 2003 (which was merged with the Norwegian TGC system in 2012). Under the TGC system, producers of electricity from renewable energy sources (RES-E) are given a tradable green certificate for each MWh of renewable energy they produce and feed into the grid. This provides them with two revenue streams: electricity sales in the electricity market and TGCs in the TGC market. This helps RES-E producers recover the extra cost of producing RES-E, compared to conventional electricity generation, incentivizing investments in RES-E. Furthermore, it creates a mandated demand for RES-E since electricity retailers and large energy-intensive firms are required to acquire certificates corresponding to a certain percentage of the total consumption of electricity (the so-called percentage requirement, which has increased over time).

Empirical studies analyzing some of the policies described above indicate that they have played an important role in reducing emissions and encouraging the adoption of cleaner technologies (see e.g., Jaraitė and Di Maria, 2012; Jaraitė et al., 2014; Bonilla et. al., 2015; Coria and Mohlin, 2017; Ustyuzhanina, 2022). In this report, we focus on their effect on green patenting. However, since the overall effect of the several policies that target innovation is expected to be larger than that of individual policies, this Chapter aims to provide an overview of the policies in place.

[2] IED is the main EU instrument regulating pollutant emissions from industrial installations. See, e.g., https://ec.europa.eu/environment/industry/stationary/ied/legislation.htm

Measuring and comparing the overall stringency of environmental policies across industrial sectors is not trivial because the number of policy instruments, their type, and stringency can vary widely across industries and firms. For instance, most policies focus to a great extent on large emitters.

These firms are often subject to pricing instruments and non-market instruments (such as emission limits or standards), while regulators tend to rely mostly on the use of non-market instruments for regulating smaller emitters. The large number of policy instruments regulating emissions from large emitters implies that using a single policy instrument, e.g., carbon taxes, to evaluate the effects of policy stringency can therefore only provide a partial assessment.

In this report, we will make use of the OECD Environmental Policy Stringency Index (EPS) to develop a list of relevant policy instruments that can influence green patenting. The latest version of the EPS consists of three equally weighted sub-indices, which respectively group market-based (e.g., taxes, permits, and certificates), non-market based (e.g., performance standards), and technical support policies. Stringency is defined as the degree to which environmental policies in each group put an explicit or implicit price on polluting or environmentally harmful behavior.

The EPS index has become a widely used tool for policy analysis since its creation in 2014 (see, e.g., Kruse et al., 2022). It has been used extensively in empirical studies to assess the overall stringency of environmental policies across countries and the effects of stricter policies on environmental and economic outcomes. Overall, such studies have found that responses of outcomes variables to environmental policy stringency are more salient when the EPS is used as a proxy for policy stringency rather than proxies that only focus on the use of market-based instruments addressing fossil fuel emissions (for instance, energy prices, see e.g., Marin and Vona, 2019). A possible explanation is that in many OECD countries, command and control policies are still quite predominant (see, e.g., Schmitt and Schulze, 2011). The EPS captures the use and the stringency of command-and-control policies addressing local pollutants (Herman and Shenk, 2021) and outperforms many other indicators of environmental policy stringency (Galeotti et al., 2020).

Empirical studies that focus on the effects of policy mixes on innovation represent a limited though rapidly expanding area of research (see, e.g., Costantini et al., 2017). They highlight the role of comprehensive policy mixes in enhancing innovation activities. Following these contributions, our analysis aims to provide an overview of relevant policies affecting green patenting.

In what follows, we describe the policies included in the Swedish EPS Index, the evolution of the EPS Index over time, and the incidence of the policies in the EPS Index in our data.

4.1 OECD Environmental Policy Stringency Index (EPS Index)

As previously mentioned, the EPS Index consists of three equally weighted subindices, which respectively group market-based, non-market-based, and technical support policies. The index focuses on policies aimed at curbing GHG emissions and local air pollution. Thus, it does not capture regulations across all sectors of the economy. For example, policies that regulate emissions from agricultural production or emission standards for new passenger cars are not included. Furthermore, in selecting policy instruments to be included in the composite stringency index, trade-offs arise between the broadest possible coverage and the availability and quality of data. Despite these limitations, the EPS is still a relevant reference for the analysis of the policies that might influence green patenting.

It is important to note that the policy instruments included in each category (i.e., market-based, non-market-based, and technical support policies) vary across OECD countries. Therefore, hereinafter we focus on providing a description of the policies included in the calculation of the EPS Index for Sweden. The policies included in the Swedish EPS Index are:

1. **Market-Based Policies**
   a. **The European Union's Emissions Trading System, EU ETS.** Implemented in 2005, this system covers mainly carbon dioxide emissions from electricity and heat generation, and energy-intensive industry sectors, (including oil refineries, steel works, and production of iron, aluminum, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids, and bulk organic chemicals). Participation in the EU ETS is mandatory for companies in these sectors, but in some sectors, only operators above a certain size are included. For instance, CO_2 emissions are regulated from combustion of fuels in installations with a total rated thermal input exceeding 20 MW; or from the production of cement clinker in rotary kilns with a production capacity exceeding 500 tons per day or in other furnaces with a production capacity exceeding 50 tons per day etc. (EU ETS Directive, 2003).
   b. **The Swedish Tradable Green Certificates System.** Implemented in May 2003, it is a system for trade in renewable energy certificates based on the obligation to source a mandated percentage of electricity from green sources. The buyers of TGCs are mainly electricity retailers and large energy-intensive firms, which are required to acquire certificates corresponding to a certain percentage of their total consumption of electricity. This percentage has increased over time, and it is expected to reach a peak in 2029 at a rate of 38.3%. The mean price of a TGC over the period 2004-2019 was equal to 200 SEK/certificate (EUR 20). This amount corresponded to about 66% percent of the price of electricity over the same period. However, during some periods, the price of TGCs was as high as the market price of electricity, and in some periods TGC prices were significantly higher than the market price of electricity.
   c. **The Swedish CO_2 Tax** is levied on all fossil fuels in proportion to their carbon content. The carbon tax was introduced in 1991 at a rate corresponding to SEK 250 (EUR 25) per ton of fossil carbon dioxide emitted and has gradually been increased to SEK 1 330 (EUR 122) in 2023. A lower tax rate has historically been applied to the industry outside the EU ETS, while currently, the industry covered by the EU ETS is entirely exempt from the carbon tax. As of 2018, the industry rate outside the EU ETS is the same as the general rate.
   d. **Nitrogen Oxides (NOx) Tax:** it regulates entities belonging to the heat and power sector, the pulp and paper industry, the waste incineration sector, and the chemical, wood, food, and metal industries. Initially, the charge only covered boilers and gas turbines with a yearly production of useful energy of at least 50 GWh, but in 1996 the threshold was lowered to 40 GWh and in 1997 further lowered to 25 GWh per year. From 1992 to 2007, the charge was 40 SEK/kg NOx. In 2008, the charge was raised to 50 SEK/kg NOx following a series of reports from the Swedish EPA which indicated that the impact of the charge system had diminished over the years. The revenue from the tax is repaid to the regulated firms in relation to their production of energy. Tax revenues are refunded to the same collective of polluters in proportion to their output of useful energy. As shown by Sterner and Höglund-Isaksson (2006), firms' net tax payment depends on their relative environmental effectiveness measured by their emissions intensity to the average emissions intensity of all regulated entities. Under such a system, firms with lower emissions intensity than the average are net beneficiaries of the refunding scheme.
   e. **Fuel Taxes:** European domestic fuel prices vary considerably among countries, primarily due to differences in tax rates. Although there is a minimum fuel tax mandated level in the

EU, fuel fiscal measures are determined at a national level and hence there are several fuel regimes across EU members. The stringency of the tax in Sweden is thus measured using the tax for a liter of diesel fuel used in transport for the industry as a share of the pre-tax diesel price. It is calculated by dividing the tax on diesel by the national pre-tax price paid by the industry for diesel. In 2020, the tax amounted to SEK 4.710/liter (about 49.76% of the pre-tax diesel price).

2. **Non-Market Based instruments (NMBI).**

The EPS Index accounts for the existence of emission limit values (ELV) on emissions of **nitrogen oxides (NOx)**, **sulfur oxides (SOx)**, and **particulate matter (PM)**. For each pollutant, the ELV corresponds to the maximum concentration of emissions permitted for a large, newly built coal-fired power plant, as a proxy for emissions standards in the energy generation sector. The lower the value of the ELVs, the more stringent the policy. The EPS also considers restrictions on the **sulfur content of diesel.** The indicator represents the stringency of the diesel fuel standard regarding the maximum concentration of sulfur permitted in diesel for automobiles. The lower the value, the more stringent the policy.

3. **Technology Support (TS) Policies**

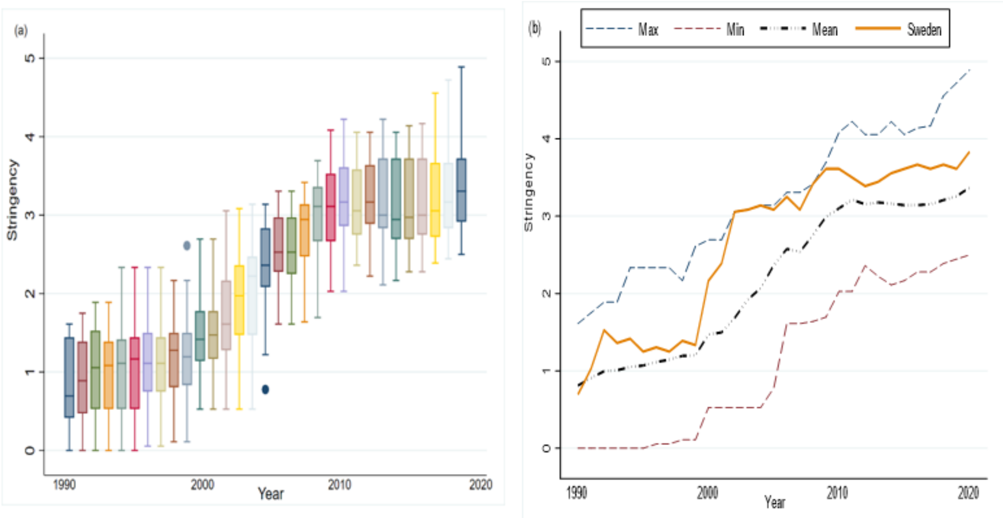
The EPS includes indicators accounting for:

a. **Public research and development (R&D) expenditure:** This indicator represents the amount spent by the government for R&D on low-carbon energy technologies relative to the size of the country's nominal GDP. It includes renewable energy sources, energy efficiency, carbon capture and storage (CCS), nuclear, hydrogen and fuel cells, other power and storage technologies, as well as other cross-cutting technologies and research as defined by OECD/IEA. The indicator is calculated by dividing a country's public R&D expenditure on low-carbon energy technologies by its nominal GDP.
b. **Renewable energy support for Solar:** Over the period 1998-2001, temporary investment aid for thermal solar energy was supported by the Swedish Government and it is included in the EPS Index. The indicator represents the level of price support for thermal solar energy relative to the global levelized cost of electricity (LCOE). The level of price support is divided by the global LCOE to account for the decline in the costs of renewable energy production over time.

The EPS Index ranges from zero (no policy) to six (most stringent). For each policy instrument, the raw data from all countries is ordered from the least to the most stringent observation per year (over the period 1990 to 2020). The lowest score of zero is assigned to observations with no policy in place. The remaining scores are assigned using the distribution of observations that have the policy in place. The highest score of six is assigned to observations with values above the 90^{th} percentile of observations that have the respective policy implemented. To assign the remaining scores, the difference between the 90^{th} and the 10^{th} percentile is divided into five equal bins that define the thresholds.[3]

[3] For example, in the case of renewable energy certificates, the 90th percentile is equal to 17% while the 10th percentile is at 2%. The difference between the 90th and 10th percentile (equal to 15) is divided by five. The resulting value (equal to 3 in this example) is the increment from one threshold to the next, defining the remaining five thresholds.

Figure 4.1 EPS Index in OECD Countries

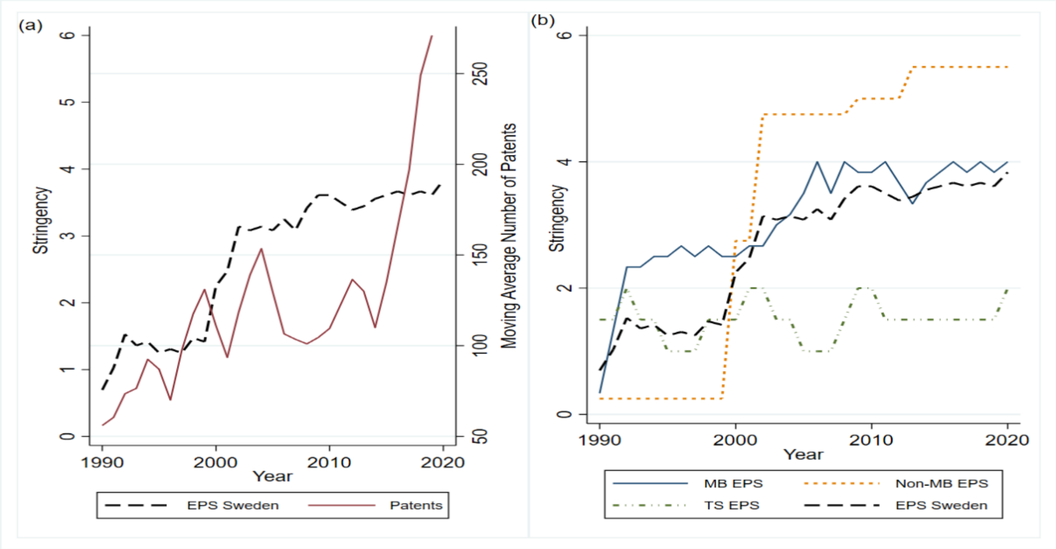


The EPS Index provides a useful cross-country comparison of the stringency of environmental policies. In Panel (a) of Figure 4.1we display the distribution of the EPS indices across OECD countries over the period 1990-2020, while in Panel (b) we display the development of the mean and the index for Sweden. It is evident that the stringency of environmental policies has increased over time and that there are significant differences in the stringency of environmental policies across countries. Furthermore, the EPS Index for Sweden has been systematically larger than the mean value of the EPS Index in OECD countries. However, the increasing trend in the EPS Index for Sweden has flattened in the most recent decade, losing its relative position as a frontrunner. For instance, in 2020, the countries with the most stringent environmental policies were France, Switzerland, Luxembourg, and Finland.

4.2 Swedish EPS Index and Evolution of Patents Over Time

Figure 4.2 displays the evolution of the EPS Index for Sweden (as calculated by OECD) and the number of Y02 patents in our database. In Panel (a) of Figure 4.2, we present the development of the EPS Index vs. the development of the number of Y02 patents. In Panel (b), we present the development of the different components of the EPS Index.

Figure 4.2 EPS Index and Green Patenting in Sweden.

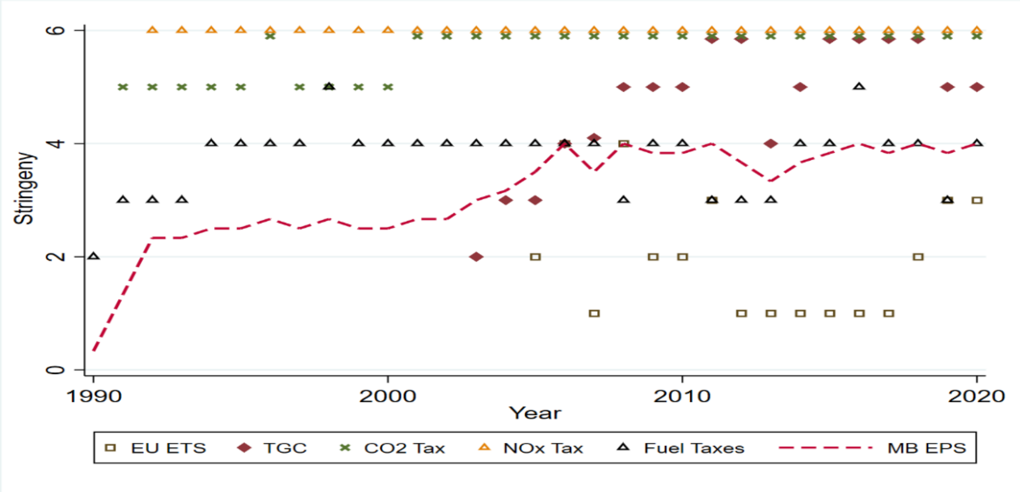


Notes: Information on the value of the EPS Index was downloaded from the OECD's website. In Figure 4.2 (a), we compute the moving average of green patents patents over a period of two years to better track trends in the number of patents.

Some interesting patterns emerge from Figure 4.2. For instance, in panel (a), there is a clear positive correlation between the increases in the level of the EPS Index and the increases in the number of patents. Furthermore, as shown in panel (b), over the period 1990-2000, the stringency of the market-based component of the EPS Index was larger than the stringency of the overall index. This is to say, the relative stringency of market-based policies was larger than that of the other elements of the EPS Index. Even though increases in the stringency of non-market-based policies have contributed to increases in the overall EPS Index, the dynamics of the overall EPS Index seem to be more closely correlated to the dynamics of the stringency of market-based instruments than to the dynamics of the non-market instruments and technology support. Finally, the level of stringency of technology support remained relatively stable over the period under analysis with significant decreases in certain years.

Figure 4.2 suggests that the set of market-based instruments included in the EPS Index might be significant drivers of green patenting in Sweden. In Figure 4.3 we explore the development of the different instruments included in the market-based component of the EPS Index for Sweden. Interestingly, even though carbon dioxide-reducing policies - such as the Swedish carbon tax - have systematically ranked as very stringent (i.e., stringency equal to five or six), there are other policy instruments that have also contributed to the overall stringency of the MB component of the EPS Index. For instance, the NOx charge and the TGC system.

Figure 4.3 Stringency of the Market-Based Instruments in the Environmental Policy Stringency Index



Notes: Information on the value of the EPS Index was downloaded from the OECD's website.

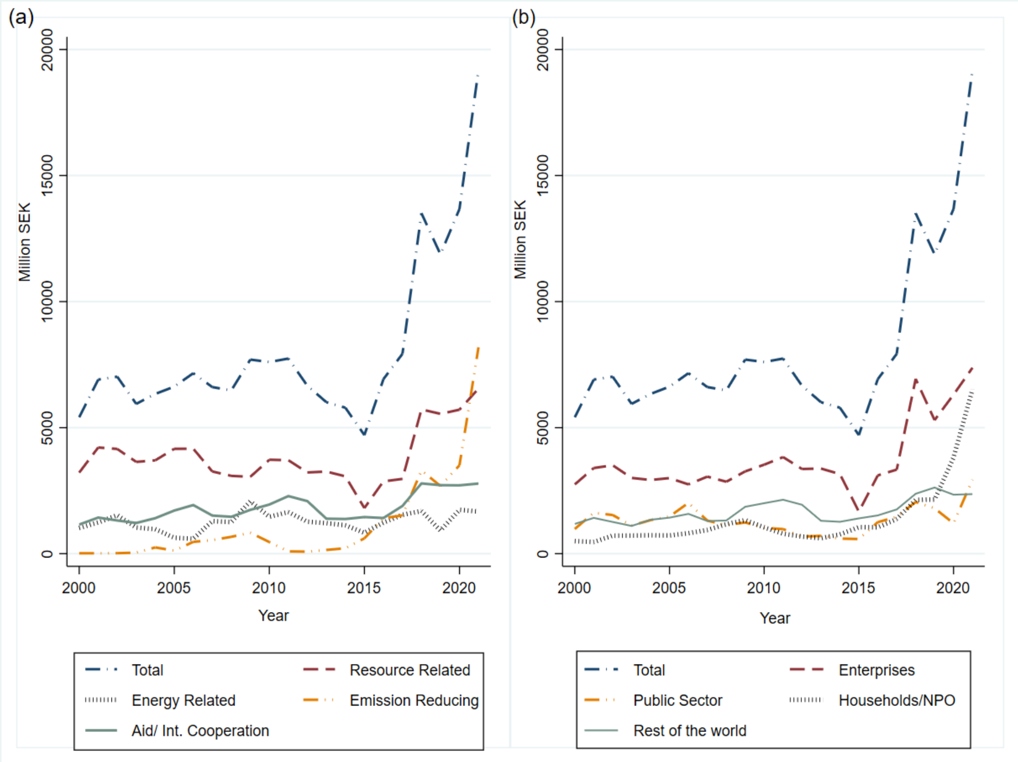
4.3 Other Policies of Relevance to Environmental Innovations and Green Patenting

In what follows, we discuss other policies of relevance to green patenting that are not incorporated into the EPS Index.

Environmentally Motivated Direct Subsidies

Environmental subsidies aimed at compensating firms for engaging in energy-saving and emissions-reducing projects and encouraging environment-related innovations are one of the most common market-based instruments used widely in many countries in the world (see, e.g., Popp, 2019). This is also the case in Sweden, where about 0.22% of GDP was utilized to support environmentally motivated direct subsidies over the period 2000-2021. Figure 4.4 displays the evolution of environmentally motivated direct subsidies in Sweden. In Panel (a) environmentally motivated direct subsidies are broken down by objective, while in Panel (b) they are broken down by recipient.

Figure 4.4 Total environmentally motivated direct subsidies



Source: The table was compiled by the authors using SCB data on Environmental Accounts.

The total environmentally motivated direct subsidies have increased significantly over time, particularly over the period 2015-2021. For instance, in 2021 the total environmentally motivated direct subsidies amounted to 19,188 million SEK, four times the amount in 2015. Resource-related and emission-reducing subsidies have increased the most over time. Some of the activities subsidized through resource-related subsidies include support for landscape and biodiversity (18%), measures for improving the environment in the agricultural sector (65%), support for sustainable cities (4%), and environmental research (6%). Some of the activities subsidized through emissions-reducing subsidies include different supports in the climate area (43.5%) and support for low-emission vehicles (42%). Energy-related subsidies account for 16% of the total subsidies (on average) and have mostly supported energy research (40%), and more efficient use of energy and energy technology (35%).

Concerning the entities receiving the subsidies, firms have received 46% of the total environmental subsidies, followed by the rest of the world (21%), household and non-profit institutions (17%), and the public sector (16%).

Industry Energy Prices

The fluctuation of energy prices has a price component and a policy component, where the price component is primarily driven by the international market price. Energy prices can thus be interpreted as an environmental policy instrument in the sense that higher energy prices reduce the consumption of energy and environmentally related externalities. Many empirical studies have used energy prices as a proxy for (the potential effects of) environmental regulation. For instance, Aghion et al. (2016) investigated the significance of energy prices for technological change by looking at the car industry using patent data between 1978 and 2007. They found that higher energy prices increase the propensity of clean innovation in the car industry. Similarly, Ley et al. (2016) calculated the effect of industry-specific energy prices on green patenting (where green patents are defined according to the OECD Indicator of Environmental Technologies). They find that a 10% increase in the average energy prices over the previous five years resulted in a 3.4% increase in the number of green inventions and a 4.8% increase in the ratio of green inventions to non-green inventions. This is to say, energy prices serve as an instrument to encourage green innovations.

Energy Efficiency Regulation

Energy efficiency is one of the most cost-effective ways to reduce emissions, improve energy security, enhance competitiveness, and make energy consumption more affordable for all consumers. (see, e.g., Malinauskaite et al., 2020). In 2009, the EU adopted the so-called 20-20-20 targets – 20% increase in energy efficiency, 20% cut in greenhouse gas emissions (from 1990 levels), and 20% renewables by 2020. To achieve these goals, a series of directives have been implemented. For instance, the 2012 Energy Efficiency Directive (EED) is an overarching directive, which introduced several measures, policy requirements, and tools to enable the EU to reach its 20% energy efficiency target by 2020. EED establishes legal obligations to establish energy-saving schemes and/or alternative measures in the EU member states, provisions on the setting of energy-efficiency targets, general energy-efficiency policies, energy audits, combined heat and power (CHP), and management systems for enterprises, among others. Further revisions were set for long-term trajectories by the amended EED with the energy efficiency target for 2030 set at least at 32.5% (to be achieved collectively across the EU).

The MURE database provides an overview of the energy policy measures implemented by different member states. Bertoldi and Mosconi (2020) analyzed the effects of such measures by means of an Energy Policy Intensity Index (accounting for all measures in place in different member states). Their analysis suggests that energy consumption in 2013 in Europe would have been about 12% higher in the absence of energy efficiency policies.

Some of the measures implemented in Sweden include energy mapping vouchers, providing small and medium-sized companies with an annual final energy use exceeding 0.5 GWh with financial support for energy mapping. The purpose of the mapping is to provide an overview of the energy use of a particular company as well as to give advice on how to increase energy efficiency. Furthermore, according to the law, all large enterprises are obliged to carry out quality-guaranteed energy mappings at least every fourth year. The mapping should show the amount of energy used annually and deliver recommendations for cost-efficient measures to reduce energy use.

Branch-specific networks for energy efficiency are also part of the Swedish policy for energy efficiency. These networks usually receive public funding and have as aim to be a forum for the exchange of experience and information on energy efficiency.

Policies reducing passenger vehicles' emissions rates

One of the most common approaches to regulate emissions from new passenger vehicles is to define emission standards. Since the 1970s, the key mechanism for regulating vehicle air pollutant emissions in Europe has been a regulatory/command and control policy that has progressively set increasingly stringent standards for emissions of air pollutants and GHGs (since 2009). A series of directives, known as Euro standards, define the acceptable limits for exhaust emissions of new road vehicles sold in the EU. The Euro standards, starting with the release of Euro 1, which entered into force in 1993, have since been amended regularly. The most recent Euro standard is Euro 6 for light passenger and commercial vehicles, which came into force in 2014 (Commission Regulation (EU) No 582/2011).

The main objective of the original European standards was the reduction of emissions of NOx, carbon monoxide (CO), PM2.5, and volatile organic compounds (VOCs), as well as carbon dioxide and other pollutants and subsequent amendments have implemented further limits. Furthermore, increasingly strict Euro standards require cleaner petrol and diesel fuels (the quality of which was regulated by Directive 2003/17/EC, e.g. low Sulphur content), leading to, for example, lower PM emissions. These increasingly stringent emissions standards have achieved positive results. They have led to the introduction of new vehicle technologies, which have achieved significant reductions in vehicle emissions over recent decades in Europe. For example, the latest standard (Euro 6) for diesel cars requires a reduction of almost 97 percent of PM emissions compared to the Euro 1 standard for a 20-year-older vehicle.

The EU first introduced mandatory CO_2 standards for new passenger cars in 2009. The 2009 regulation set a 2015 target of 130 g CO_2/km for the fleet average of all manufacturers combined. Individual manufacturers were allowed a higher CO_2 emission value, depending on the average vehicle weight of their fleet. The heavier the average weight of the cars sold by a manufacturer, the higher the CO_2 level allowed. A similar CO_2 standard for new light-commercial vehicles was introduced in 2011. It set a target of 175 g CO_2/km for 2017. The current target for the period 2020-2024 is 95 g CO_2/km for new passenger cars and 147 g CO_2/km for vans. In addition, many European countries have reformed their taxes on vehicle registration to link these taxes directly to the CO_2 emissions rates of the vehicles (see e.g., Klier and Linn, 2015). For instance, Sweden changed from a weight-based circulation to a linear CO_2-based tax in October 2006.

Also, it is important to mention the ongoing rapid electrification of passenger cars and the recent agreement reached by the European Parliament and Council ensuring all new cars sold to have zero CO_2 emissions from 2035.

Given that the Swedish sector of manufacturing of motor vehicles and other transport equipment is rather large (17% of total value added of manufacturing industry in 2022), it is very likely that above mentioned transport-related emission control policies might have influenced patenting in the Swedish transport sector.

Networks

The literature on the role of networks for environmental innovation draws on the idea that environmental innovations require more heterogeneous sources of knowledge with respect to other innovations. Environmental networks are thought to be more qualified and characterized by a greater presence of high-profile members outside the business world, such as universities and research organizations. Such a view has been supported by empirical analyses that show that environmentally innovative firms cooperate on innovation with external partners (such as universities and research organizations) to a greater extent than other innovative firms. For instance, Fabrizi et al. (2018) use data from EU Framework Programmes to measure research cooperation among EU countries in fields related to sustainable development and relate research cooperation to the capability to introduce environmental innovation (measured by green patents). They find that green European research networks involving external partners positively affect environmental innovation. Furthermore, a larger level of complexity and novelty also explain the existence of larger spillovers of green technologies compared to dirty ones. (Barbieri et al., 2020).

Tax Deductions for Research and Development

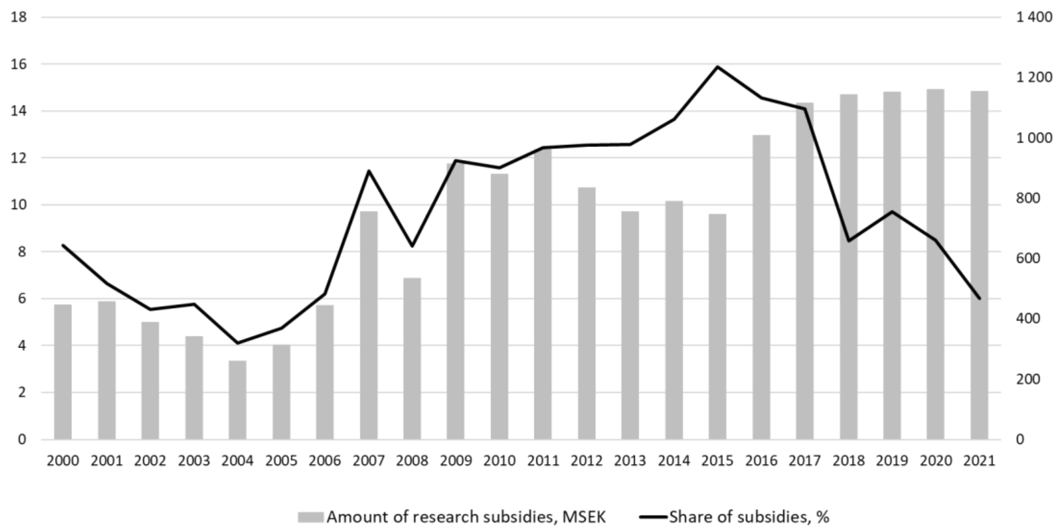
Since 2014, enterprises in Sweden have been able to make deductions from employer contributions for employees working in research and development. On April 1, 2020, and July 1, 2021, the incentive was strengthened by increasing the maximum amount that can be deducted, while the length requirement for hours worked in R&D was shortened. Both the number of enterprises that claim deductions for R&D and the amounts they claim have increased each year since the tax incentive was introduced in 2014. In 2020, the claims doubled compared to 2019 after the ceiling was raised on April 1, 2020. A recent evaluation suggests that the tax reduction has had a positive effect on increasing research activities in firms (see, e.g., Stavlöt and Svensson, 2022).

5. Analysis of the innovation subsidies that might have a relevant role in driving green patenting in Swedish manufacturing firms

The purpose of this Chapter is to provide a detailed analysis of the innovation subsidies that the Swedish Agency for Economic Grow Analysis has information for and an analysis of those subsidies that might have a relevant role in driving patenting and green patenting specifically.

As mentioned in Chapter 4 of the report, total environmentally motivated direct subsidies have increased significantly over time, particularly over the period 2015-2021. Firms have received approximately half of the total environmental subsidies. Some of these subsidies were directed to support research and development. On average, approximately 10% of total environmentally motivated subsidies were directed to support research in environment, energy and transport domains during the period 2000-2021 (see Figure 5.1). We also observe that even though the total amount of research-related direct subsidies has increased over time, the share of research-related direct subsidies has decreased remarkably since 2018 (see Figure 5.1). For example, research-related direct subsidies accounted on average for 14.5% of total subsidies during 2014-2017, but only 8.2% during 2018-2021.

Figure 5.1 Environmentally-oriented research subsidies, 2000-2021.



Source: Statistics Sweden, Swedish National Financial Management Authority and authors' compilations.

Within this chapter we will have a closer look at environmental subsidies that potentially have contributed to manufacturing firms' carbon-mitigating patents. To achieve this objective we will, first, describe and analyze firm-level research-related subsidy data as provided in the so-called MISS database. Second, in Chapter 6, we will merge subsidy data with firm-level patent data (see Chapter 3) to investigate whether there is any association between research motivated direct subsidies and green patenting in Swedish manufacturing firms.

5.1 MISS Database

Overall, to evaluate what effects state support has on various firm performance indicators, it is necessary to collect data on what kind of subsidies have been provided and who has been applying for and receiving such subsidies. Since in Sweden, there are many actors involved in allocating subsidies and many firms applying and receiving them (see, e.g., Torregrosa-Hertland et al., 2019), this is not an easy task.

The Swedish Agency for Growth Policy Analysis (Tillväxtanalys) has been responsible for the collection, management, and development of various forms of data at the firm level on the content and outcome of government support measures in business policy, regional growth policy and innovation policy. For this purpose Tillväxtanalys has created the "Micro database of state aid to industry" (in Swedish, Tillväxtanalys mikrodatabas över statliga stöd till näringslivet). This database is known as the MISS database. It has been used by Tillväxtanalys to analyze effects of various subsidy programs on various firm performance indicators. However, to the best of our knowledge, there has been no attempt to investigate the role of green innovation subsidies in driving firm green patenting behavior in the case of Swedish manufacturing firms.

Various Swedish governmental agencies and state-owned firms submit data to the MISS database. These include the Swedish Energy Agency (SEA, Energimyndiheten), the Swedish Agency for Economic and Regional Growth (Tillväxtverket, TVV), Sweden's Innovation Agency (Vinnova), Almi, EKN and others. The MISS database contains separate data tables for each support program. Most data tables contain information about firm organization number, project number, project name, date when a firm applied for a particular support, total amount granted, and amount paid during the year. For some support programs, the information provided does not allow determining the exact firm-year support amounts. This is the case, for example, for the ERUF (Europeiska regionala utvecklingsfonden) subsidy data table.

A drawback of the MISS database is its incomplete coverage of support provided by governmental agencies and state-owned companies, as highlighted in Tillväxtanalys (2023). Consequently, there is uncertainty regarding companies seemingly lacking in innovation support, as they might have received support from entities not reporting data to the MISS database. If companies received support from unreported sources, this bias would skew the estimation of the effects of support towards underestimation. This means that the actual impact of support on innovation and economic outcomes would likely be higher than what is reflected in the data.

Another drawback of the MISS database is that it does not provide information on the purpose of the financial support provided. In other words, there is no direct way to identify which subsidies are given specifically to support innovation or green innovation development in manufacturing firms. This means that it is up to an individual researcher to categorize which subsidies are (green) innovation-oriented and which are not. An alternative research strategy is simply to assume that even non-green innovation subsidies indirectly support firms in green patenting, since other than innovation subsidies free up funds to support firms' green research and development activities.

Moreover, the most common approach to distributing innovation subsidies is through a funding announcement, where companies compete by submitting applications to government agencies and state-owned companies. Companies applying for grants are ranked, and those with the highest ranking receive support. However, as described in Tillväxtanalys (2023), the handling of these processes is not accessible for evaluation purposes. This prevents us from fully understanding the selection processes and from identifying which characteristics of the companies increase their likelihood of receiving support.

With these caveats in mind, in our analysis of MISS subsidy data, we proceed in the following way. First, in our analysis we will focus only on those programs that provide direct grants for firms.[4] Second, we will select only those support programs (i.e., MISS data tables) that allow aggregating subsidies to firm-year level. Third, when possible, we will categorize each subsidy program/project into green innovation vs. non-innovation program/project by collecting additional information about the scope of support programs from actual program calls and, if available, about names of funded projects. This will allow identifying the scale of support given for green (or any) innovation projects. This exercise will lead to three firm-level variables: total direct subsidies, innovation-related direct subsidies, and green innovation-related direct subsidies.

In our analysis we will consider three subsidy tables, which are available in the MISS database: (1) direct subsidy programs managed by the Swedish Energy Agency (Energimyndiheten, SEA), (2) direct subsidy programs managed by the Swedish Agency for Economic and Regional Growth (Tillväxtverket, TVV), and (3) direct subsidy programs managed Sweden's innovation agency (Vinnova). In Table 5.1 we describe some of the variables that are available in each subsidy table, the number of firm-year observations, and whether it is possible to categorize each subsidy program (project) into green innovation vs. non-innovation program (project). In sections 5.2-5.4, we describe in detail each subsidy table.

Table 5.1 The description of MISS database subsidy tables used in the analysis

	Energimyndiheten (Swedish energy agency)	**Swedish Agency for Economic and Regional Growth (Tillväxtverket)**	**Sweden's innovation agency (Vinnova)**
Firm id	yes	yes	Yes
Years	2010-2018	2007-2018	2007-2024
Firm project id	yes	yes	Yes
Firm project name	no	no	Yes
Programme name	yes	yes	Yes
Programme no.	yes	no	No
Project application year	yes	yes	No
Decision year	yes	yes	Yes
Decision provided	only positive	positive, negative, partial, or information missing	only positive
Total applied amount	yes	yes	Yes

[4] State support might take many forms. A good description of different state support measures and their totals across EU countries and time is provided in "Sate aid Scoreboard 2022" database maintained by the European Commission: https://webgate.ec.europa.eu/comp/redisstat/databrowser/explore/all/all_themes?lang=en&display=card&sort=category.

	Energimyndiheten (Swedish energy agency)	Swedish Agency for Economic and Regional Growth (Tillväxtverket)	Sweden's innovation agency (Vinnova)
Amount received per year	yes	yes	Yes
Amount paid back	yes	yes	Yes
Possible to identify green innovation programs/projects	yes, only at program level	no	yes, to some extent at project level

Source: MISS database and authors' compilations.

5.2 Swedish Energy Agency subsidy programs

Table 5.2 lists the number and titles of the subsidy programs available in the Swedish Energy Agency's (SEA) subsidy table, the main eligibility criteria for receiving a particular support, whether a particular program could support green innovation or not, and the total number of observations associated with each subsidy program. To categorize subsidy programs into green innovation programs versus non-innovation programs, we read the law of each call to learn about the purpose, objectives and eligibility of each call. Additional information, if available, was obtained from the SEA's website. If the objective of a particular subsidy program was to promote green innovation, research and development of new products, and their large-scale application, when we assume that the call is aimed at promoting green innovation that could potentially lead to green patents.

The SEA's subsidy table contains information about 14 different subsidy programs. Nine of them could be considered as programs supporting green innovation. From Table 5.2 it is evident that most observations (80%) in the SEA's subsidy table are associated with the subsidy program "Förordning om statligt stöd till forskning och utveckling samt innovation inom energiområdet" (in English, "Regulation on state aid for research and development and innovation in the field of energy"). This subsidy program aims to promote research and development, including demonstration projects, and innovation in the field of energy. It provides investment support, support for consultancy services, support for start-ups, support for research and development projects, investment support for research infrastructure and other. Some support measures are available only for small and medium enterprises (SMEs), and some support measures are available for all types of firms.

Ten percent of observations in the SEA's subsidy table are associated with the subsidy program "Förordning om statligt stöd till energikartläggning" (In English, "Regulation on state aid for energy audits"), which provides support to perform firm energy efficiency audits in order to achieve efficient use of energy. The beneficiary company must draw up an energy plan showing the results of the energy audit and which of the measures proposed therein it intends to implement. In other words, this subsidy program is not directed to promote innovation. Support, with some exceptions, may be granted to firms with a final energy consumption of more than 0.3 GWh per year.

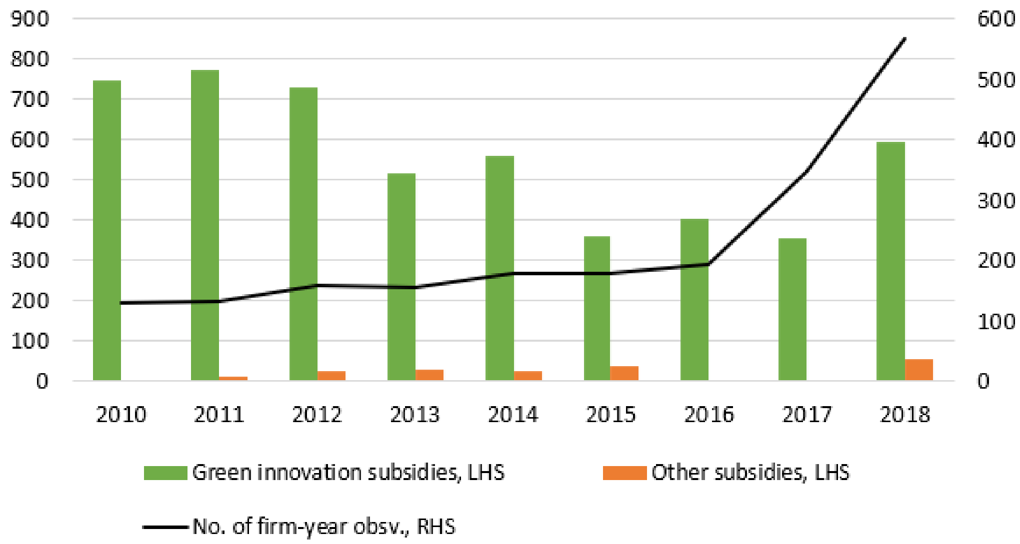
Other SEA support programs are much smaller in terms of observations available in the MISS database, hence, we do not provide their detailed description in the text.

Tabell 5.2 The description of the Swedish Energy Agency's raw subsidy data as available in the MISS database.

Call number	Call title in Swedish	Main eligibility criteria	Years available	Green innovation	No. of obsv.	% of obsv.
2008:761	Om statligt stöd till forskning och utveckling samt innovation inom energiområdet	Some support measures available only for small and medium-sized enterprises, but some for all types of firms	2010-2018	Yes	3 046	80.45
2009:1577	Om statligt stöd till energikartläggning	Firms with a final energy consumption of more than 0,3 GWh per year	2017-2018	No	389	10.27
1998:222	Om statligt stöd till energiforskning	All firms are eligible to apply	2010-2013	Yes	100	2.64
1998:653	Om statligt stöd till energiteknik	All firms are eligible to apply	2010-2012	Yes	74	1.95
1998:654	Om energiteknikbidrag	All firms are eligible to apply	2010-2012	Yes	47	1.24
2009:938	Om statligt stöd till åtgärder för produktion, distribution och användning av biogas och andra förnybara gaser	All firms are eligible to apply	2011-2015	No	39	1.03
2003:564	Om bidrag till åtgärder för en effektiv och miljöanpassad energiförsörjning	All firms are eligible to apply	2010-2018	Yes	34	0.9
2018:57:00	Om statligt stöd till energieffektivisering i industrin	Firms in the mining industry or the manufacturing industry that are large companies and that carried out an energy audit.	2018	No	31	0.82
N2018/02705/FÖF	Uppdrag att främja hållbara biobränslen för flyg 2018-04-26 (dnr N2018/02705/FÖF)	All firms are eligible to apply	2018	Yes	8	0.21
1997:634	Om statligt bidrag till investering för ombyggnad och anslutning av eluppvärmda byggnader till fjärrvärme	Residential houses	2010-2013	No	7	0.18
2017:1319	Om statligt stöd till åtgärder för att minska industrins processrelaterade utsläpp av växthusgaser	All firms are eligible to apply	2017-2018	Yes	6	0.16
1997:1322	Om bidrag till kommunal energi- och klimatrådgivning	Municipalities	2012-2014	No	3	0.08
2018:1545	Om stöd för utveckling och användning av flytande biogas	All firms are eligible to apply	2018	Yes	1	0.03
N2018/02934/FÖF	Uppdrag att inrätta ett innovationskluster för flytande biogas 2018-05-09 (dnr N2018/02934/FÖF)	All firms are eligible to apply	2018	Yes	1	0.03
					3 786	**100**

Figure 5.2 provides the distribution of aggregated SEA subsidies over time. In total, there are 2 034 firm-year observations. 1 056 unique firms received some support (positive net subsidy) from the SEA during the period 2010-2018: 661 firms received green innovation subsidies amounting to SEK 5.2 billion, and 412 firms received other than green innovation subsidies amounting to SEK 0.19 billion. In other words, the majority of SEA subsidies are directed towards promoting green innovation activities. Furthermore, it is evident that most of the green subsidies were distributed during the period 2010-2014.

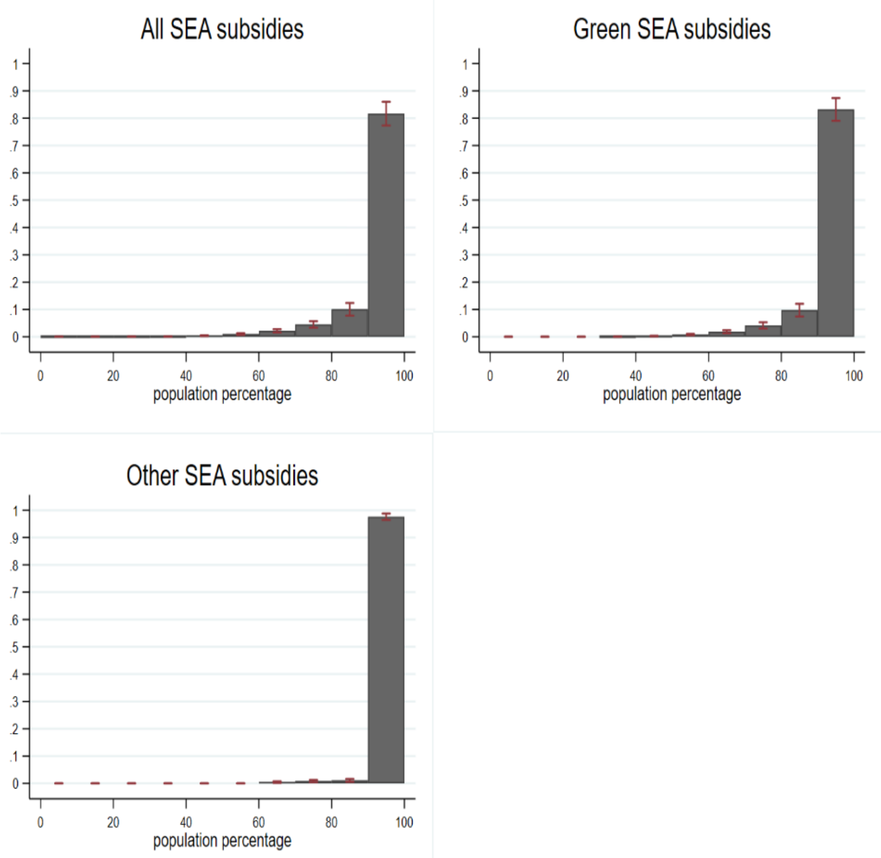
Figure 5.2 The description of SEA subsidies, in MSEK



Source: MISS database and the authors' calculations.

Figure 5.3 shows that ten percent of the firms in the SEA subsidy data received about 81 percent of all SEA subsidies (82% of all green), meaning that SEA subsidies are concentrated among a small number of firms and that these firms received much higher subsidies than the majority of the remaining firms the the period considered. This might imply several things. First, only a handful of firms are eligible to apply for SEA support. Second, some firms are more active in applying for and more successful in receiving SEA support.

Figur 5.3 Distribution of SEA subsidies across firms that received some SEA subsidies during the period 2010-2018



Source: MISS database and the authors' calculations.

5.3 Subsidy programs by the Swedish Agency for Economic and Regional Growth

Table 5.3 provides titles of subsidy programs available in the Swedish Agency for Economic and Regional Growth (TVV) subsidy table, the main eligibility criteria to receive a particular support, whether or not a particular program could support green innovation, broad innovation, or not, as well as total number of observations associated with each subsidy program. To categorize subsidy programs into green innovation or general innovation programs versus non-innovation programs, we read the law of each call to learn about each call's purpose-objectives and eligibility. Additional information, if available, was obtained from the TVV website. If the objective of a particular subsidy program was to promote green innovation, research, and development of new products and its large-scale application, when we assume that the call is directed at promoting carbon-reducing innovations that could potentially lead to carbon-mitigating patents.

From Table 5.3 it is evident that none of the listed TVV subsidy programs in the MISS database could be categorized as grants supporting green innovation, but some of them to some extent are supporting general innovation and research and development. However, since this subsidy table does not contain project names, we cannot exactly identify which firm-level projects could be classified as innovation projects.

Tabell 5.3 The description of the TVV subsidy data as available in the MISS database

Call title	Main eligibility criteria	Years available	Green innovation	Innovation	No. of obsv.	% of obsv.
Regionalt bidrag till företagsutveckling/Regional support for business development	Mainly SMEs	2007-2018	no	yes	17 975	43.72
Transportbidrag 2007-2013/Transport grants 2007-2013	Firms operating in Norrbotten, Västerbotten, Jämtland and Västernorrland	2007-2018	no	no	13 175	32.05
Såddbidrag/Seed grants	No information found	2007-2018	no	yes	2 600	6.32
Investeringsbidrag/Investment grants	All firms are eligible	2007-2018	no	no	2 073	5.04
Hemsändningsbidrag/Repatriation grants	No information found	2007-2018	no	no	1 378	3.35
Servicebidrag/Service grant	No information found	2007-2018	no	no	1 314	3.2
RIS (Regionalt investeringsstöd)/Regional investment support	Firms operating in Norrbotten, Västerbotten, Västernorrland, Jämtland and Dalarna, plus several additional geographical areas	2007-2018	no	yes	1 076	2.62
Såddlån/Seed loans	No information found	2007-2018	no	yes	784	1.91
Transportbidrag 2000-2006/Transport grants 2000-2006	Firms operating in Norrbotten, Västerbotten, Jämtland and Västernorrland	2007-2011	no	no	658	1.6
3-årigt sysselsättningsbidrag/3-year employment allowance	No information found	2008-2016	no	no	48	0.12
RUB (regionala utvecklingsbidraget)/Regional development grant	No information found	2007-2010	no	yes	24	0.06
Landsbygdslån/Rural loans	No information found	2007-2018	no	no	7	0.02
					41 112	**100**

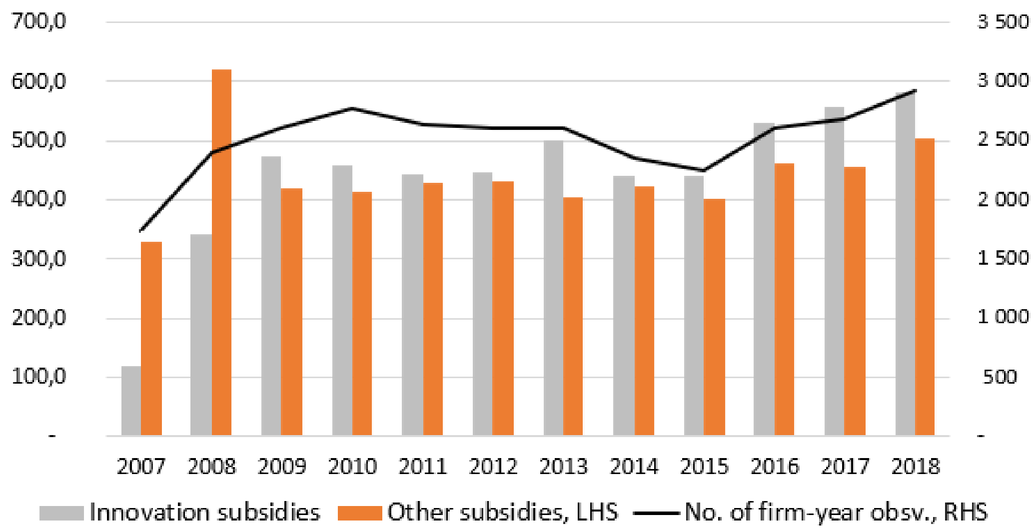
Notes: The number of observations contains duplicates in terms of firms and years. Information about main eligibility criteria was collected from TVV website by authors.

Most observations (44%) in the TVV subsidy table are associated with the subsidy program "*Förordning om regionalt bidrag till företagsutveckling*" (in English, "*Regional support for business development*"). The purpose of this subsidy program is to promote the sustainable growth of the beneficiary firms, thereby promoting sustainable regional growth. This state aid may be granted for expenditure on investments in buildings or facilities intended for permanent use, machinery or other equipment, but not vehicles, boats that are necessary for the operation of businesses in the archipelago, and product development, marketing, skills development or other similar purposes, provided that the expenditure is not related to the normal operation of the enterprise.

Another 32 percent of observations is the TVV subsidy table are associated with transport grants 2007-2013, which provide support for transportation of goods and products that have undergone significant processing in the manufacturing industry. This support is only available to firms operating in the four northernmost Swedish counties: Norrbotten, Västerbotten, Jämtland and Västernorrland. These grants are not used to support innovation activities within firms. Other support programs are much smaller in terms of observations available in our dataset, so we do not provide a detailed description of them.

Once we aggregate TVV subsidies to the level of firm, we find that 13 172 unique firms received some support from the TVV during the period 2007-2018: 12 237 firms received potentially innovation-related subsidies amounting to SEK 5.3 billion, and 2 250 firms received other than innovation subsidies amounting to SEK 5.3 billion. Figure 5.4 provides the distribution TVV subsidies over time. When compared to SEA subsidies (see Figure 5.2), it is evident that state support provided by the TVV is larger than the SEA support in terms of both the number of firms receiving support and the amount of support provided.

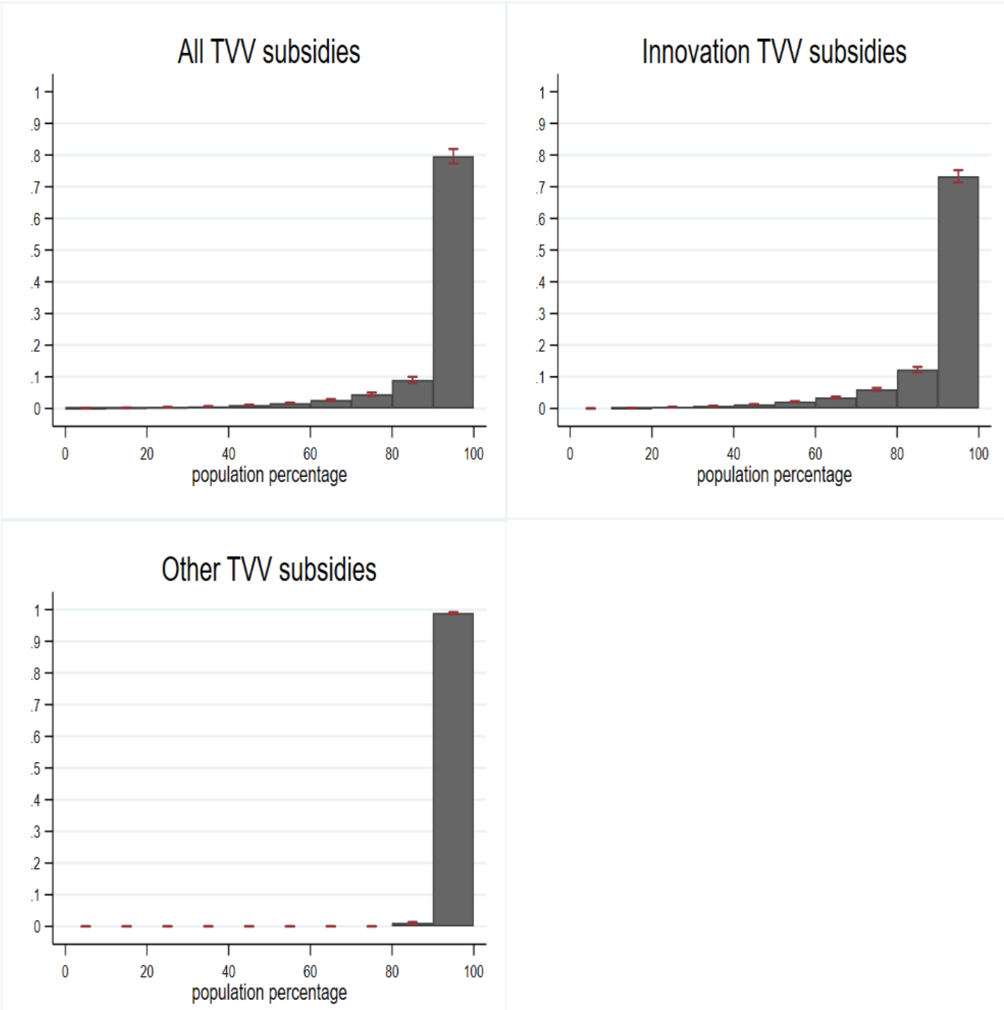
Figure 5.4 The description of firm-year observations in TVV subsidy table, in MSEK



Source: MISS database and the authors' calculations.

Figure 5.5 shows that ten percent of firms in the TVV subsidy data received about 80 percent of all TVV subsidies (73% of all innovation subsidies). TVV subsidies are even more concentrated when we consider other than innovation TVV subsidies (99% of other than innovation subsidies are received by 10% of firms). In other words, this suggests that TVV subsidies are concentrated among a small number of firms and that these firms receive much higher subsidies than the majority of the remaining firms. The same pattern was observed in the case of the SEA subsidies (see Figure 5.2).

Figure 5.5 Distribution of TVV subsidies across firms that received some TVV subsidies during the period 2007-2018



Source: MISS database and the authors' calculations.

5.4 Subsidy programs by the Sweden's innovation agency Vinnova

Sweden's innovation agency (Vinnova) funds research and innovation projects in various areas in order to build Sweden's innovation capacity. Vinnova subsidy table in the MISS database contains detailed information about almost 170 subsidy programs (almost 70 000 firm-year-project observations) for the period 2007-2024.[5]

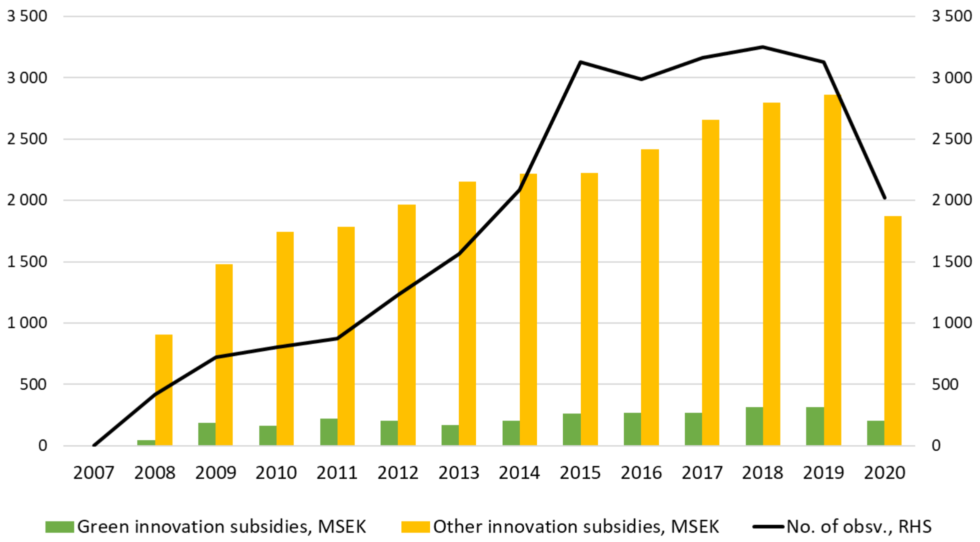
Although all Vinnova programs are aimed at supporting innovative activities, there is no easy way to identify which programs support only green innovation. The only exception is the program "Innovationer för hållbart samhälle" (Innovations for a sustainable society), which provides funding for projects that contribute to sustainable development.

[5] Due to space constrains, we do not summarize Vinnova support programs in this report.

The unique feature of Vinnova subsidy table is that it contains individual project names, which enabled us to search for a list of energy- or climate-related words in project titles in order to categorize projects into green innovation versus non-green innovation projects (see Appendix A). The text search returned that 10.0% of 66 989 firm-year-project observations could be classified as green innovation observations.

Once we aggregate firm-year-project observations to firm-year observations, we find that 8 910 unique firms received some support from Vinnova during the period 2007-2024: 1 028 firms received potentially green innovation-related subsidies amounting SEK 3.33 billion, and 8 499 firms received other innovation subsidies amounting to SEK 28.09 billion Compared to SEA and TVV subsidy programs, Vinnova support is the largest in monetary terms. Figure 5.6 shows the distribution of Vinnova support over time.

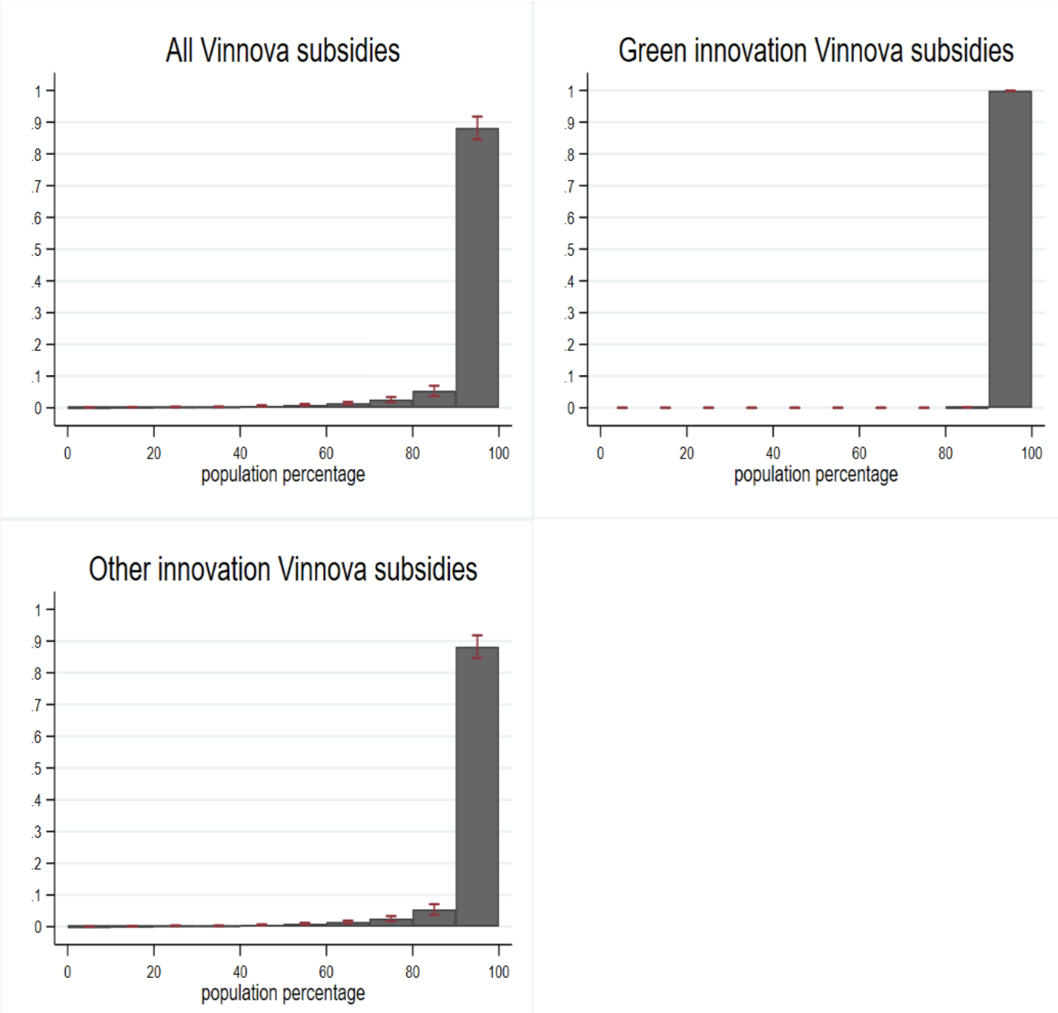
Figure 5.6 The description of Vinnova subsidies, in MSEK



Source: MISS database and the authors' calculations.

As in the case of SEA and TVV subsidies, Vinnova subsidies are not evenly distributed among firm beneficiaries. Figure 5.7 shows that 10 percent of firms that received some Vinnova support received almost 100 percent of green innovation subsidies and 88 percent of other innovation subsidies.

Figure 5.7 Distribution of Vinnova subsidies across firms that received some Vinnova subsidies during the period 2007-2024



Source: MISS database and the authors' calculations.

5.5 Aggregating MISS subsidy tables

To sum up, the data provided in the MISS database allowed us to aggregate three subsidy tables – SEA, TVV and Vinnova – into firm-year-level observations that we could merge and use in our further analysis. It is evident that all subsidies are concentrated as only a handful of firms received the majority of subsidies. However, the further analysis of the combined subsidy data reveals that different firms received different support, suggesting that concentration concerns are important at the subsidy table level.

Table 5.7 provides the descriptive statistics of the merged subsidy table for the period 2007-2018 for which we have green patent firm-level data available. We observe that, on average, firms in our sample received more subsidies which are not related to green innovation activities (MSEK 0.655 vs. MSEK 0.151). On the other hand, our aggregate subsidy table mainly contains information about subsidies directed to support some type of innovation (including green) as we observe that the average size of innovation-related subsidies is MSEK 0.696, while the average size of total subsidies is MSEK 0.805.

Tabell 5.7 The description of the merged subsidy table, 2007-2018.

	No. of firm-year obsv.	Mean	Median	Std. dev.	Min	Max
Total subsidies	50,299	0.805	0.100	6.196	0	352.1
Green innovation subsidies	50,299	0.151	0	2.105	0	197.0
Other than green innovation subsidies	50,299	0.655	0.098	4.995	0	294.5
All innovation-related subsidies	50,299	0.696	0.067	6.145	0	352.1

Source: MISS database and the authors' calculations. All monetary values in millions of SEK.

In Chapter 6, we will merge firm-level subsidy data with other firm-level data, including green patents, to investigate whether there is a relationship between green innovation subsidies (or total subsidies) and green patents.

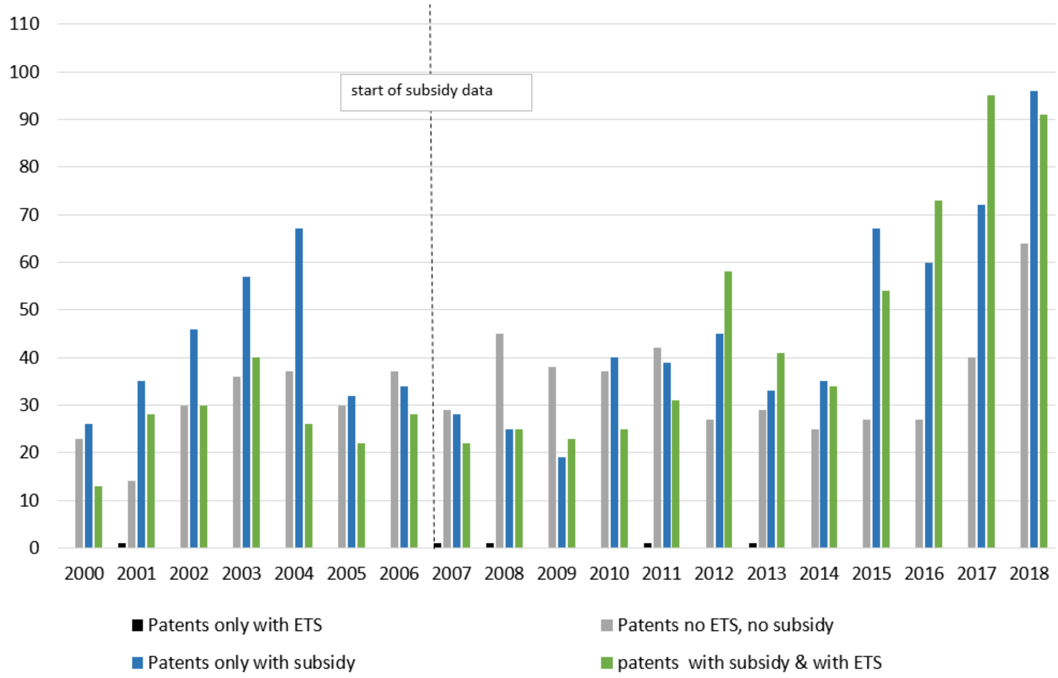
6. The role of environmental policies and innovation subsidies in green patenting

Our analysis of environmental policies in Sweden in Chapter 4 reveals a plethora of initiatives aimed at curbing emissions and fostering innovation. These initiatives span from comprehensive legal frameworks to inventive tax structures, potentially shaping both environmental progress and innovation dynamics. Examination of the correlation between the OECD Environmental Policy Stringency Index and patents indicates that market-based policies, such as emissions trading systems, may be particularly effective in stimulating innovation. However, due to limited firm-level data constraining causal analysis, our focus is directed solely towards investigating innovation subsidies and the EU ETS. These policies hold particular significance in stimulating the development of green technologies and reducing emissions. Furthermore, our analysis differentiates between green subsidies and general subsidies to discern their respective impacts on innovation. This distinction aims to pinpoint which subsidy type exerts the most significant influence on fostering innovation in green technologies.

6.1 Descriptive evidence

We begin our analysis with some descriptive results for the entire universe of firms. Figure 6.1 plots the number of green patents granted for firms with different policy exposures during the period 2000-2018. We divide firms into four groups: (1) firms that were only exposed to the EU ETS, (2) firms that only received subsidies during the period 2007-2018, (3) firms that were neither exposed to the EU ETS nor to subsidies, and (4) firms that were exposed to both the EU ETS and subsidies. There are 218 unique firms in group 1, 21 048 unique firms in group 2, 2 153 019 in group 3, and 103 unique firms in in group 4, suggesting that only about 1% of all firms received subsidies and that an even smaller percentage of firms were regulated by the EU ETS. Several interesting insights emerge from the comparison of granted patent counts across these firm groups. First, only subsidy-receiving firms granted more green patents overall than ETS firms that also received some subsidies (856 patents vs. 759 patents). Moreover, since 2011-2012 onward, we observe an increase in patenting activity among these firm groups. On the other hand, firms that were neither exposed to the EU ETS nor to subsidies granted a total of 637 patents, while firms that were only exposed to the EU ETS granted only 5 patents during the period 2000-2018.

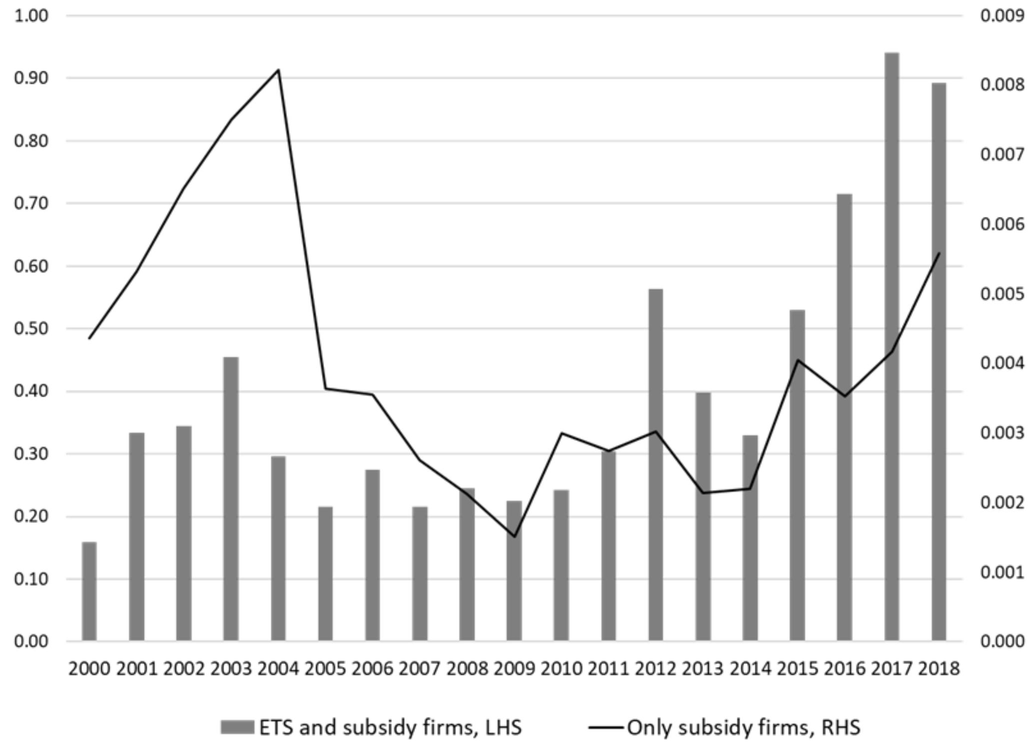
Figure 6.1. Granted green patent counts across firm groups with different policy exposure, 2000-2018.



Notes: Subsidy data is available only from 2007 onward. The figure is compiled by the authors using MISS and PRV databases.

The total number of patents granted annually across different groups of firms masks the average patenting behavior of firms. Therefore, we calculated the average annual number of green patents granted across the same firm groups as reported in Figure 6.1. Because of the very small average patent numbers for the 'ETS only' and 'no ETS and no subsidy' firm groups, in Figure 6.2 we report numbers only for 'ETS and subsidy' firms and for 'only subsidy' firms. It is evident that the average annual number of green patents for ETS firms that received subsidies during the period 2007-2018 is significantly higher than for firms that only received subsidies. The average patenting activity of the first group of firms increased remarkably during the period 2015-2018, when a firm had on average about 0.77 granted patents per year. Similar trends are observed for 'subsidy only' firms.

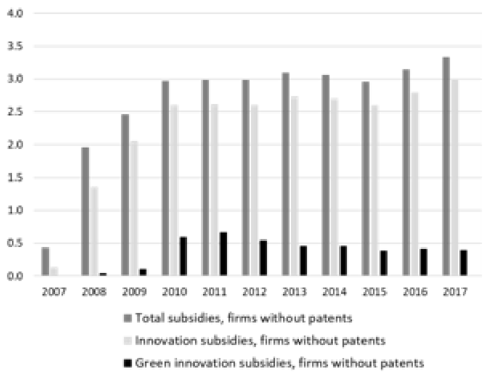
Figure 6.2 Average annual granted green patent counts for ETS firms with subsidies and for firms only with subsidies, 2000-2018

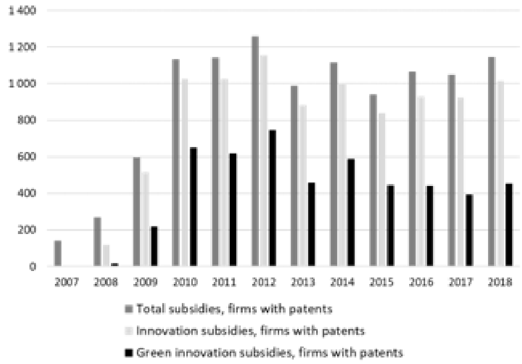


Notes: The figure is compiled by the authors using MISS and PRV databases.

In Figure 6.3 we report the average annual subsidies received by firms with green patents and without green patents. As in Chapter 5, we consider three subsidy categories: total subsidies, innovation subsidies, and green innovation subsidies. It is evident that firms with at least one granted patent received during the period 2000-2018, on average, received significantly more subsidies of any kind than firms without patents. The average *total* subsidy for firms with patents was th SEK 904.0, while for firms without any patents only th SEK 2.8 during the period 2007-2018. The average *innovation* subsidies for patenting and non-patenting firms were th SEK 785.8 and th SEK 2.4, respectively. And the average *green innovation* subsidies for patenting and non-patenting firms were th SEK 419.3 and th SEK 0.4, respectively. Another interesting insight is that, during the period 2010-2015, about half of average subsidies received by patenting firms are classified as green innovation subsidies.

Figure 6.3 Average subsidies for patenting and non-patenting firms in thousands of SEK



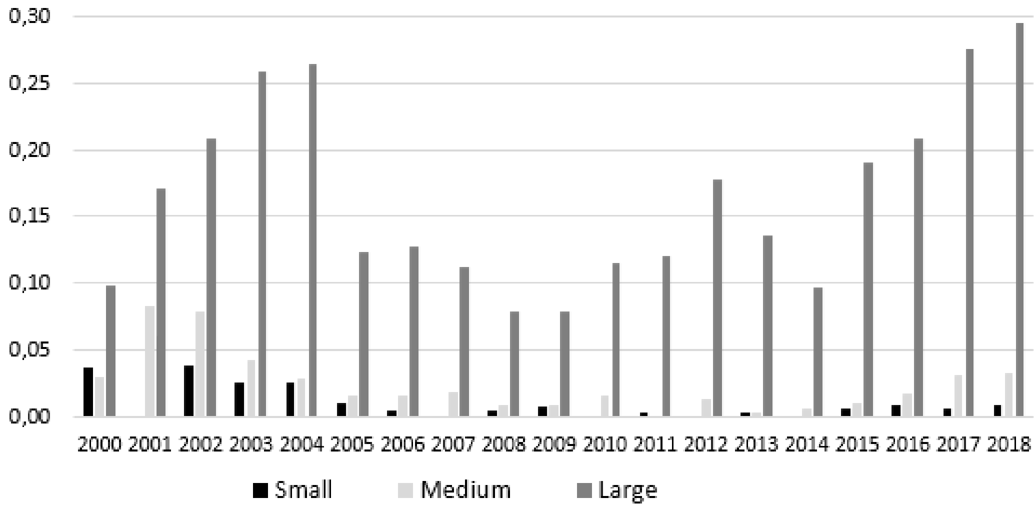


Notes: A patenting firm is defined as a firm that received at least one patent during the period 2000-2018. A non-patenting firm is a firm that did not receive any patents during the same period. The figure is compiled by the authors using the MISS and PRV databases.

Finally, we consider whether firms with large subsidies patented more green innovations than firms with small subsidies. As the descriptive statistics in Chapter 5 show, the size of subsidy payments varies a lot across firms. To categorize firms into small, medium and large subsidy recipients, we calculated the total amount of subsidies received during the period 2007-2018 for each firm. We define firms as small subsidy-recipients if they have received no more than SEK 1 million of subsidies. Medium subsidy recipients are firms that received between more than 1 million SEK and less than 5 million SEK. And large subsidy recipients are firms that received above SEK 5 million. This choice of categorization is clearly data-driven and arbitrary, but it seems to us to be the most sensible option given the distribution of subsidies. The same cut-off points are used for innovation subsidies, while for green innovation subsidies we use slightly different cut-off points as there are fewer firms that have received some green innovation subsidies (small: not more than 1 MSEK, medium: more than 1 MSEK, but not more than 2 MSEK, and large: more than 2 MSEK). We use the same categorization of firms in the regression analysis (see section 6.4).

Figure 6.4 shows the average granted green patent counts across firms belonging to different green innovation subsidy size categories. It turns out that, on average, large green innovation subsidy recipients granted more patents than small or medium green subsidy recipients. As reported in Figures 6.1 and 6.2, we observe that patenting activity is greater during the period 2015-2018. Similar patterns are observed for the total subsidy and innovation subsidy firm categories; therefore, we do not report them here.

Figure 6.4 Average annual granted green patent counts across green innovation subsidy categories



*Notes***:** The figure is compiled by authors using MISS and PRV databases.

Table 6.1 shows the sectoral distribution of total patents granted, total subsidies, innovation subsidies, green innovation subsidies, and green innovation subsidies per patent granted. It is evident that firms that operate in the manufacture of machinery and transport equipment (sector no. 8) hold about 71 percent of the total patents. The financial sector and the manufacture of coke, chemicals and basic metals are the second and third sectors in terms of patenting activity with 239 and 215 patents, respectively.

Tabell 6.1 Granted green patents and subsidies across sectors, 2000-2018.

Sector no.	Sector name	No. of granted patents	Total subsidies, MSEK	Innovation subsidies, MSEK	Green subsidies, MSEK	Green subsidies per patent, MSEK
1	Crop and animal production, forestry, fishing and aquaculture	11	101.8	90.7	23.0	2.09
2	Mining and quarrying	10	206.2	26.6	6.3	0.63
3	Manufacturing of food, beverages and tobacco	0	514.5	203.6	1.8	-
4	Manufacture of textiles, wearing apparel and leather products	2	68.3	56.8	3.9	1.94
5	Manufacture of wood products and paper, printins and reporduction of recorded media	12	2 241.7	528.8	19.7	1.64
6	Manufacture of coke, refined petroleum products, chemical, rubber, plastic, non-metallic mineral, basic metals and fabricated metal products	215	2 491.9	1 333.7	159.8	0.74
7	Manufacture of computers and electrical equipment	181	1 044.3	908.7	337.3	1.86
8	Manufacture of machinery and transport equipment + other manufacturing	1153	4 317.8	3 340.7	1 608.9	1.40
9	Electricity and gas	27	442.8	431.8	406.7	15.06
10	Water and waste	15	132.0	74.3	30.3	2.02
11	Construction and civil engineering	21	262.0	237.0	43.5	2.07
12	Wholesale and retail trade	129	1 302.5	784.9	130.1	1.01
13	Transport and postal activities	5	160.0	131.5	15.2	3.04
14	Accomodation and food and beverage service activities	2	600.7	590.4	0.1	0.03
15	Publishing, broadcasting activities and telecommunications and information services	22	1 609.4	1 602.8	93.9	4.27
16	Financial, real estate, legal, architectural and consultancy activities	239	6 348.5	6 292.5	1 367.4	5.72
17	Scientific and research activities	159	4 319.9	4 309.1	1 390.0	8.74
18	Other services	5	236.7	204.4	14.3	2.85
19	Education	1	197.0	196.2	19.3	19.27
20	Health care	2	77.0	76.8	2.5	1.25
21	Other mixed activities	0	939.1	890.7	122.5	-
1-21	All sectors	2 211	27 614.1	22 311.9	5 796.2	2.62

Sector no.	Sector name	No. of granted patents	Total subsidies, MSEK	Innovation subsidies, MSEK	Green subsidies, MSEK	Green subsidies per patent, MSEK
2-10	Manufacturing sectors	1 615	11 459.5	6 904.9	2 574.5	1.59
1 & 11-21	Agriculture and service sectors	596	16 154.6	15 407.0	3 221.6	5.41
	No sector assigned	46	12 885.3	12 710.6	1 771.9	38.52

*Notes***:** The figure is compiled by the authors using MISS, PRV and SS databases. It should be noted that the numbers of sectors do not correspond to the codes of SNI classifications.

The combined descriptive evidence is a promising start to our inference analysis, as we find that there is a positive correlation between green patenting activity and green innovation subsidies. Furthermore, we find that firms that received subsidies and were also exposed to the EU ETS patented about the same number of technologies as firms that only received subsidies. This underscores the importance of considering both types of policies (i.e., innovation and climate policies) when analyzing the primary drivers of green patenting behavior.

6.2 Methodology

The main challenge in identifying the causal effect of subsidies is that participation in various government subsidy programs is voluntary, and hence, non-random. In this case, the challenge when trying to identify the causal effect is that if subsidy receiving firms are systematically different from the non-subsidy group, we cannot attribute all the potential differences in green patent counts to the subsidy status. Rather, these differences could be explained by other factors, commonly referred as confounders.

From the descriptive statistics reported below in Table 6.2 it is evident that that subsidy-receiving firms are larger than non-subsidy receiving firms in terms of production value, wages and net investment. Large subsidy recipients are larger than small and medium subsidy recipients in terms of the same variables. Furthermore, subsidy recipients were granted with more patents than control firms in the pre-treatment period (2000-2006). Because some of the covariates differ substantially between the treated and control groups, the conventional regression analysis could be sensitive to specification and outliers (Imbens, 2015).

To address non-random selection, we adopt the propensity score matching (PSM) approach to ensure the similarity between the control and treated groups in terms of all relevant observable characteristics. PSM, a non-parametric estimation method proposed by Rosenbaum and Rubin (1983), is widely used to solve selection bias of samples. Based on all relevant observable characteristics, it identifies a control group that has similar properties as the treated group. This implies that the only difference between the control and the treated group is caused by the treatment variable of interest.

In particular, following the recent analysis in evaluating the heterogenous effects of various policies on green technologies (see, e.g., Bai et al. 2019; Marino et al. 2016; Tchorzewska et al. 2022), in this analysis, to estimate the effects of subsidies and the EU ETS on firm green patenting activity, we decided to utilize the categorical treatment matching approach. The advantage of categorical matching estimation method is that it is well suited for comparisons not only between treated and untreated but also between two categories of treatment groups. This helps to understand whether a given effect obtained from the single-treatment framework is simply driven by a single category of treated, or whether it is confirmed for all categories.

Suppose we have the outcomes of 4 different mutually exclusive treatment categories, where the 0-treatment group is a control group composed of untreated firms, and the 1-, 2-, and 3-treatment groups consist of small, medium, and large subsidy receivers, respectively (classification of firms according to the size of received subsidies is provided in Section 6.1). To estimate the treatment effects between different treatment groups, the unconfoundedness and common support assumptions must be satisfied (Rubin 1990). The unconfoundedness assumption says roughly that all the variables affecting both the treatment T and the outcome Y are observed (we call them covariates) and can be controlled for. A common support condition ensures that any combination of characteristics observed in the treatment group can also be observed among firms in the comparison group (control or another treatment group).

To implement the categorical treatment matching, first we need to run as many propensity score estimations as the number of categorical effects we are interested in. That is, first, we estimate the probability of receiving a particular subsidy size during the period 2007-2018[6] (e.g., large) conditional on the set of pre-treatment covariates. Second, we enforce the common support condition to ensure a significant overlap in the propensity scores of the treatment and the selected comparison group (e.g., large vs. small). Third, we compute the associated treatment effect on our outcome variables of interest.

We consider two pooled outcome variables – a sum of green patents granted during the period 2007-2018 and a sum of patents granted during the period 2015-2018. We chose to pool the number of patents granted and the subsidy payments received by firms because the annual mapping of subsidies to patents is not useful for two reasons. First, it takes time to patent a new invention. According to the European Patent Office, the patenting process typically takes 3-4 years. Second, for some subsidy programs annual subsidy payments are known for several years in advance, which means that firms could be forward-looking and plan their R&D expenditures and patent-related activities in advance. In other words, to assess the causal impact of subsidies on firms' patenting activity, it is preferable to examine how the total amount of subsidies received by firms affects the total number of patents granted during the specified period.

Since the choice of the observable covariates in the propensity score model must satisfy the unconfoundedness assumption, the selection of covariates is crucial. All the important variables that influence both the participation decision (i.e., applying and receiving subsidies or being part of the EU ETS) and the outcome variables should be included. Hence, economic theory, the policy setting and existing empirical evidence must be used as a guide. In addition, only variables that are unaffected by participation should be included in the model. To ensure this, we choose variables that are either fixed over time, or measured before participation.

In the case of evaluating subsidy effects, the propensity scores are measured using data for 2007 – the first year for which subsidy data is available. Since few firms received subsidies in that year, we think that the variables included in the matching are not affected by participation in subsidy programs. The explanatory variables include industry dummies to control for potential common demand or supply shocks to a given industry. The size variables are two: production value and labor expenditure. We expect bigger firms in terms of production and labor to have more resources to apply for various subsidies. Indeed, Table 6.2 shows that large and medium subsidy firms are larger in terms of production value and salaries than small subsidy firms or no subsidy firms. We also take into account past experience in innovation activities because we anticipate that firms that have successfully protected their green inventions with patents will be more inclined to do so in the future, thus increasing their likelihood of applying for financial support from subsidy programs. We use the number of patents during the period 2000-2006 as an experience variable. In addition, we include net investment for the year 2007 to control for the financial health of firms, as we expect firms with greater financial constraints to be more active in innovation activities than firms with more financial resources. We also control for the

[6] In the robustness analysis presented in Section 6.6, we also examine subsidies over a shorter timeframe, specifically the period from 2007 to 2014. We assess their impact on green patents obtained in the subsequent period (2015-2018).

status of the EU ETS, as we expect ETS firms to be more active in applying for green innovation subsidies in order to comply with EU ETS mandates.

In the case of estimating the effect of the EU ETS, the propensity scores are measured using annual averages for the period 2002-2004 – before the start of the EU ETS in 2005. We consider the same variables as above (sectoral dummies, production value, labor expenditure, and net investment), but exclude the ETS. We could also consider incorporating historical stationary CO_2 emissions or fossil fuel expenditure to improve the accuracy of estimating the probability of participation in the EU ETS. However, fossil fuel expenditure data is only accessible from 2005 onwards and only for a subset of firms, while stationary CO_2 emissions data is also limited to even smaller sample of firms. Finally, when we estimate the effects of the EU ETS and subsidies with respect to firms with different policy exposures (subsidies only, ETS only, no ETS and no subsidies), the propensity scores are measured in the same way as in the case of ETS firms.[7]

The control groups are selected by utilizing nearest neighbor matching. We use two neighbors to calculate the matched outcome. In addition, to ensure the quality of the matching, we set a caliper of 0.01, which defines the boundary of the neighborhood in which matching is allowed. As robustness test, we use several different methods of matching to control for the quality of matching (nearest neighbor with four neighbors and kernel), and the results reported in this report hold for all of them. The summary of the results of these robustness tests is available from the authors upon request.

6.3 Data

Data sources

The data used in the empirical analysis were collected from four sources. From the Swedish Intellectual Property Office (Patent och Registrerings Verket, PRV) we received data about Y02 patents granted to Swedish firms (see Chapter 3 for more details). ETS regulation status was retrieved from the European Union's Transaction Log. Subsidy data was received from the MISS database managed by the Swedish Agency for Growth Policy Analysis (Tillväxtanalys). The organization of subsidy data is described in Chapter 5 of this report. Other firm-level variables, such as production value, labor cost, investment, firm sectoral classification and others, were provided by Statistics Sweden (SS). Data from all datasets were merged using firm identifications numbers. Data analysis was performed remotely by using Tillväxtanalys' remote desktop connection.

In our analysis, we consider firm-level data for the period 2000-2018. Subsidy data are available from 2007 onwards. This means that we assume that subsidy payments for the period 2000-2006 were zero, even though this was not the case (see, e.g., Figure 5.1 in Chapter 5). In our empirical analysis, we will consider firms that operate in the manufacturing sector (SNI codes from 05 to 39). We exclude from the analysis firms that reported missing values for production value,

[7] There might be concerns that we do not observe some variables that influence treatment assignment and outcome simultaneously. Heckman et al. (1997a) and Dehejia and Wahba (1999) show that omitting important variables can increase bias in resulting estimates. In our analysis, management quality and labor skills could be important predictors of patenting behavior and innovation subsidy recipients. We argue that such variables might correlate with the firm's performance indicators, such as the firm's previous patenting behavior and the firm's paid wages which should partly correlate with labor skills. Nevertheless, future research might consider finding additional data about firm managerial characteristics.

wages and net investment for the year 2007. As a result, our analysis will cover about 73% of patents granted during the period 2000-2018 and 40% of all subsidies distributed during the period 2007-2018 (see Table 6.1).

Descriptive statistics

Table 6.2 describes the main variables used in the empirical analysis, favoring the comparisons across the three subsidy categories of firms. The first three variables are the treatment variables: total subsidies, innovation subsidies, and green innovation subsidies received during the period 2007-2018. The subsidy variables are used to categorize firms into three subsidy size groups – small, medium and large (see Section 6.1 for more details).

Next, two outcome variables are summarized: the sum of patents granted during the period 2007-2018 and the sum of patents granted during the period 2015-2018. The remaining listed variables are the covariates used to measure the propensity scores in order to determine the control group. Firms in Table 6.2 are divided into four groups: small subsidy recipients, medium subsidy recipients, large subsidy recipients, and non-recipients. The control group consists of 52 868 firms, while the treated groups consist of 2 825, 620, and 292 firms, respectively. It is worth noting that subsidy recipients are larger than non-subsidy receiving firms in terms of production value, wages and net investment. Large subsidy recipients are larger than small and medium subsidy recipients in terms of the same variables. Moreover, subsidy recipients were granted with more patents than control firms in the pre-treatment period (2000-2007). Comparing the average outcome variables across the three subsidy groups, we observe that the highest level of green patenting activity is associated with the highest level of subsidies, followed by the medium level of subsidies.

Tabell 6.2 Descriptive statistics: subsidy recipients vs. non-recipients

	No subsidy recipients			**Small subsidy recipients**			**Medium subsidy recipients**			**Large subsidy recipients**		
Variable	Mean	Std. dev.	N	Mean	Std. dev.	N	Mean	Std. dev.	N	Mean	Std. dev.	N
Treatment variables												
Total subsidies	0	0	52 868	0.226	0.239	2 825	2.259	1.083	620	27.881	62.818	292
Innovation subsidies	0	0	52 868	0.196	0.228	2 825	1.682	1.184	620	14.494	56.548	292
Green innovation subsidies	0	0	52 868	0.009	0.070	2 825	0.176	0.597	620	7.047	33.794	292
Outcome variables												
Green patents (07-18)	0.003	0.351	52 868	0.040	0.868	2 825	0.090	0.731	620	2.414	31.846	292
Green patents (15-18)	0.001	0.122	52 868	0.018	0.476	2 825	0.047	0.517	620	1.329	17.923	292
Pre-treatment variables												
Green patents (00-06)	0.001	0.081	52 868	0.049	1.159	2 824	0.050	0.450	620	0.884	5.594	292
Production value, 2007	15.7	165.7	52 868	113.0	791.1	2 824	326.7	1643.7	620	1820.1	8841.3	292
Wages, 2007	2.1	15.4	52 868	14.5	85.4	2 824	32.7	120.4	620	196.1	872.8	292
Net investment, 2007	0.7	39.5	52 868	6.2	73.1	2 824	23.9	234.9	620	59.1	266.8	292
ETS dummy	0.004	0.060	52 868	0.013	0.112	2 824	0.048	0.215	620	0.072	0.259	292

Notes: All monetary variables are measured in millions of SEK. The table is compiled by the authors using MISS, PRV, and SS data.

Tabell 6.3 Descriptive statistics: firms with different policy exposure

	ETS and subsidy firms				**Subsidy only firms**				**ETS only firms**				**No ETS and no subsidy firms**		
Variable	Mean	Std. dev.	N		Mean	Std. dev.	N		Mean	Std. dev.	N		Mean	Std. dev.	N
Treatment variables															
Total subsidies	26.9	89.9	87		2.1	12.9	3 650		0.0	0.0	194		0.0	0.0	52 674
Innovation subsidies	18.3	84.6	87		1.2	9.7	3 650		0.0	0.0	194		0.0	0.0	52 674
Green innovation subsidies	11.5	50.3	87		0.3	5.7	3 650		0.0	0.0	194		0.0	0.0	52 674
Outcome variables															
Green patents (07-18)	6.575	57.543	87		0.082	1.716	3 650		0.021	0.227	194		0.003	0.352	52 674
Green patents (15-18)	3.598	32.370	87		0.042	0.988	3 650		0.000	0.000	0		0.001	0.122	52 674
Pre-treatment variables															
Green patents (00-06)	2.149	8.839	87		0.066	1.296	3 650		0.005	0.072	194		0.001	0.081	52 674
Production value (02-04)	4 133.1	10 100.0	81		128.0	1 422.8	3 261		517.8	1 060.5	177		11.8	129.8	45 238
Wages (02-04)	374.2	879.9	81		18.1	161.6	3 261		52.8	100.6	177		1.9	15.9	45 238
Net investment (02-04)	234.8	507.7	81		4.4	30.7	3 261		47.5	88.9	177		0.6	10.4	45 238
ETS dummy	1.000	0.000	87		0.000	0.000	3 650		1.000	0.000	194		0.000	0.000	52 674

Notes: All monetary variables are measured in millions of SEK. The table is compiled by the authors using MISS, PRV and SS data.

Table 6.3 presents a similar structure as the previous table, but compares the main variables across the following four firm groups: (1) ETS and subsidy-receiving firms, (2) subsidy only receiving firms, (3) ETS only firms, and (4) no ETS firms and no subsidy firms. It should be noted that in this table the main monetary covariates are the averages for the period 2002-2004. We observe that ETS and subsidy-receiving firms are on average larger in terms of production value, labor expenditure, and net investment than 'subsidy only' or 'ETS only', or 'no ETS no subsidy' firms. This group of firms was also more active in green patenting. For example, during the period 2000-2006, ETS and subsidy firms had on average 2.15 green patents, while only subsidy firms or only ETS firms had 0.07 and 0.005 green patents, respectively. The number of green patents is also larger for ETS and subsidy firms in later periods.

6.4 Main results

Matching quality

To ensure that the treatment and control groups are properly balanced, we followed a common procedure for estimating the standardizes bias before and after matching. In case of all matching exercises, the main values of the variables used in matching did not present significant differences between the treated and control groups. The summary of all balancing tests is available from the authors upon request.

The matching estimates are summarized in Tables 6.4-6.6. They contain the average treatment effects on the treated (ATT) and the corresponding standard errors and t-values. The tables are constructed to facilitate a comparison of the effects between firms exposed to different level of subsidies (see Table 6.4) and the effects of different policy mixes (see Tables 6.5-6.6).

Heterogenous impacts of subsidies on green patents

First, in Table 6.4, we compare the green patenting behavior of firms with different subsidy exposures (small, medium and large total subsidy receivers) with untreated firms (non-recipients of subsidies). We separately estimate the effects of total subsidies (panel A), innovation subsidies (panel B), and green innovation subsidies (panel C) on the number of green patents for the period 2007-2018 and on green patent counts for the period 2015-2018. When we do not consider subsidy size, we find that green patenting activity did not differ between subsidy recipients and non recipients. This is also true for innovation subsidy recipients and green innovation subsidy recipients.

However, when we consider different levels of subsidies, we find that matched medium and large innovation subsidy recipients had more green patents than non-subsidy recipients. Interestingly, large subsidies had twice the effect on the number of patents granted as medium subsidies. This result holds for patents granted during the long period (2007-2018) and the short period (2015-2018). More precisely, firms receiving medium innovation subsidies had on average 0.061 more green patents during the period 2007-2018, while firms receiving large innovation subsidies had on average 0.147 more green patents during the same period compared to non-recipients. In the case of patent counts over the period 2015-2018, the effect of medium innovation subsidies is 0.025, while the effect of large innovation subsidies is 0.058. On the other hand, the effect of small innovation subsidies on green patents is positive and statistically significant only at 10%. Furthermore, we find that the estimated ATT coefficients are positive and statistically significant between large and small doses of innovation subsidies, but not between medium and small or large and medium.

Tabell 6.4 The effects of subsidies on green patents: ATT matching estimates

A: The effect of total subsidies on green patents									
Granted patents (2007-2018)		No subsidy	Small	Medium		Granted patents (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	-0.005				Subsidy	diff.	0.004		
	s.e.	0.019					s.e.	0.008		
	t-stat	-0.287					t-stat	0.573		
Small	diff.	-0.010				Small	diff.	-0.002		
	s.e.	0.020					s.e.	0.007		
	t-stat	-0.507					t-stat	-0.239		
Medium	diff.	0.041*	0.050			Medium	diff.	0.011	0.029	
	s.e.	0.022	0.036				s.e.	0.012	0.023	
	t-stat	1.898	1.384				t-stat	0.976	1.223	
Large	diff.	0.053	0.171**	-0.118		Large	diff.	0.020	0.079*	-0.121**
	s.e.	0.049	0.073	0.074			s.e.	0.017	0.045	0.053
	t-stat	1.062	2.347	-1.589			t-stat	1.205	1.762	-2.279
B: The effect of innovation subsidies on green patents										
Granted patents (2007-2018)		No subsidy	Small	Medium		Granted patents (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	0.015				Subsidy	diff.	0.009		
	s.e.	0.020					s.e.	0.008		
	t-stat	0.761					t-stat	1.050		
Small	diff.	0.010				Small	diff.	0.009*		
	s.e.	0.007					s.e.	0.005		
	t-stat	1.411					t-stat	1.822		
Medium	diff.	0.061***	0.011			Medium	diff.	0.025***	0.001	
	s.e.	0.023	0.046				s.e.	0.009	0.031	
	t-stat	2.699	0.250				t-stat	2.741	0.031	
Large	diff.	0.147**	0.209**	-0.026		Large	diff.	0.058**	0.078**	-0.007
	s.e.	0.071	0.101	0.068			s.e.	0.027	0.033	0.024
	t-stat	2.166	2.071	-0.385			t-stat	2.166	2.329	-0.314
C: The effect of green innovation subsidies on green patents										
Granted patents (2007-2018)		No subsidy	Small	Medium		Granted patents (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	0.375				Subsidy	diff.	0.254		
	s.e.	0.445					s.e.	0.236		
	t-stat	0.842					t-stat	1.080		
Small	diff.	-0.019				Small	diff.	-0.052		

	s.e.	0.101					s.e.	0.079		
	t-stat	-0.192					t-stat	-0.656		
Medium	diff.	0.008	-0.019			Medium	diff.	0.016	0.010	
	s.e.	0.018	0.082				s.e.	0.016	0.032	
	t-stat	0.446	-0.235				t-stat	1.000	0.302	
Large	diff.	1.320	0.410**	0.359**		Large	diff.	0.713	0.127*	0.115
	s.e.	1.012	0.160	0.173			s.e.	0.575	0.066	0.069
	t-stat	1.305	2.564	2.079			t-stat	1.241	1.929	1.664

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

However, the effects of green innovation subsidies on firms' patenting behavior are less clear, as we do not find that small, medium or large green subsidy recipients patented more patents than firms that did not receive any green innovation subsidies. However, when we compare large green subsidy recipients to small green subsidy recipients or large to medium, we find that large doses of green innovation subsidies resulted in more green patents on average. For instance, large green innovation subsidy firms were granted with 0.41 more patents than small green innovation subsidy firms during the period 2007-2018. A very similar ATT estimate is for large vs. medium comparison. On the other hand, this result is weaker when we consider granted green patents for the period 2015-2018.

The policy mix – Subsidies and the EU ETS

In Table 6.5 we compare the effect of combined policies, that is the EU ETS and subsidies versus subsidy only, ETS only, or no ETS and no subsidy on green patenting behavior. Given the small number of observations under both policy regimes, in this analysis, we do not consider the size level of subsidies. In the treatment group, we have all ETS firms that received some subsidies during the period 2007-2018, while in the control 'only subsidy' group, we include all firms that received some subsidies during the same period.

Tabell 6.5 The effects of the policy mix on green patents: ATT matching estimates

A: The effects of the EU ETS and subsidies on green patents				
Granted patents (2007-2018)		Subsidy only	ETS only	No ETS, no subsidy
ETS & any subsidy	diff.	-0.714	0.058	0.015
	s.e.	0.471	0.050	0.129
	t-stat	-1.516	1.164	0.116
Granted patents (2015-2018)				
ETS & any subsidy	diff.	-0.589*	0.019	-0.060
	s.e.	0.345	0.019	0.107
	t-stat	-1.708	1.000	-0.560
B: The effects of the EU ETS and innovation subsidies on green patents				
Granted patents (2007-2018)		Innovation subsidy only	ETS only	No ETS, no innovation subsidy
ETS & innovation subsidy	diff.	-2.234***	0.047	0.087

	s.e.	0.779	0.032	0.056
	t-stat	-2.868	1.431	1.557
Granted patents (2015-2018)				
ETS & innovation subsidy	diff.	-1.181***	0.042	0.000
	s.e.	0.431	0.029	0.023
	t-stat	-2.739	1.430	0.000
C: The effects of the EU ETS and green innovation subsidies on green patents				
Granted patents (2007-2018)		Green innovation subsidy only	ETS only	No ETS, no green innovation subsidy
ETS & green innovation subsidy	diff.	-1.022	0.050	-1.981
	s.e.	1.424	0.050	0.934
	t-stat	-0.717	1.000	-2.120
Granted patents (2015-2018)				
ETS & green innovation subsidy	diff.	-0.935	0.050	-0558**
	s.e.	1.052	0.050	0.267
	t-stat	-0.889	1.000	-2.092

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

Interestingly, we do not find that the policy mix increases firms' green patenting activity. This result holds whether we compare ETS companies that have received subsidies, or ETS companies that have received innovation or green subsidies with companies that have only received subsidies, or that have only been regulated by the ETS, or that have been neither ETS nor subsidy-receiving firms. Oppositely, we find that ETS firms that are also innovation subsidy recipients patented fewer technologies than only subsidy receiving firms. Panel B in Table 6.5 shows that ETS and innovation subsidy firms on average had 1.18 fewer patents than firms that only received innovation subsidies. This result does not hold when only green innovation subsidies are considered. However, given the small number of observations in the policy mix group and the fact that some treated firms were excluded from the matching process because it was difficult to find good control firms for them (in total, there are 72 ETS firms that received some innovation subsidies, but only 47 remained after the matching exercise), these results should be interpreted with caution.

Finally, in Table 6.6 we report the estimated treatment effect of the EU ETS on green patenting activity. These results contribute to the now rather large literature evaluating the effects of various cap-and-trade programs on technological responses of regulated firms. In this exercise, we consider several treatment groups and several control groups to better understand the role of subsidies with respect to the EU ETS. In column A of Table 6.6 we report the results from matching, where we consider all ETS firms and all non-ETS firms. In column B of the same table, we consider only ETS firms without subsidies and we compare them to non-ETS firms without subsidies. And in column C, we use ETS firms with subsidies and compare them to non-ETS firms with subsidies. The ATT estimates reported in column A show that ETS firms had fewer patents than non-ETS firms. This result is significant when considering both outcome variables: patents granted during the periods 2007-2018 and 2015-2018, with significance levels of 10% and 5%, respectively. This finding contradicts from the results of other similar studies that estimate the causal effect of the EU ETS on low-carbon patenting by using matching (see, e.g., Calel and Dechezleprêtre 2016 for 18 EU countries, Calel 2020 for the UK). However, it goes in line with the results of earlier empirical studies on cap-and-trade programs that have found no effect or even a negative effect on the development and patenting of new technologies, suggesting that firms favored the adoption of existing technologies over innovation (see, e.g., Calel 2020 for a review of this topic).

Tabell 6.6 The effects of the EU ETS on green patents: ATT matching estimates

		A: ETS vs. non-ETS	B: ETS without subsidies vs. non-ETS without subsidies	C: ETS with subsidies vs. non-ETS with subsidies
Granted patents (2007-2018)	diff.	-0.261*	-0.006	-0.714
	s.e.	0.136	0.022	0.471
	t-stat	-1.917	-0.263	-1.516
Granted patents (2015-2018)	diff.	-0.224**	-0.015	-0.589*
	s.e.	0.094	0.010	0.345
	t-stat	-2.380	-1.437	-1.708

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

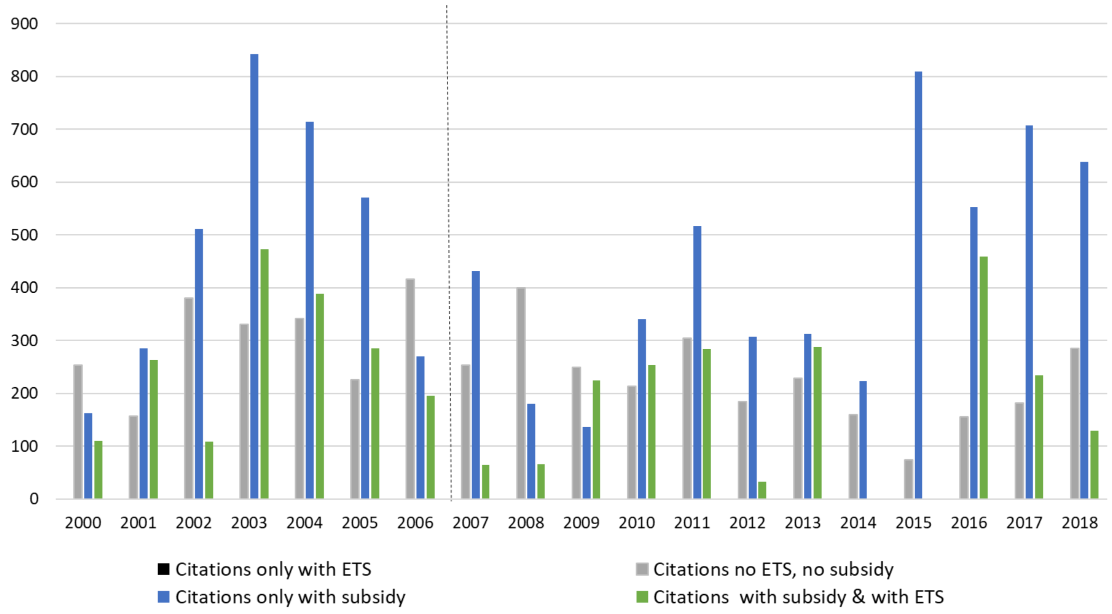
When comparing ETS firms without subsidies to non-ETS firms without subsidies, and ETS firms with subsidies to non-ETS firms with subsidies, we do not find evidence suggesting that ETS firms, with or without subsidies, were more active in patenting green technologies than similar non-ETS firms. However, as also reported in Table 6.5, we observe a weak, yet positive, negative effect on patents when comparing ETS firms with subsidies to non-ETS firms without subsidies.

6.5 Additional results

The analysis above, using the number of patents granted as the outcome variable, does not take into account the quality and the diffusion of patents. Patent citations are another indicator of innovation. The number of citations a given patent receives within a given time window (e.g., within the first ten years after publication) reflects the technological and commercial importance of a patent (OECD 2009). It has been found that the number of citations of a patent application receives is strongly correlated with the economic value of patents (Trajtenberg, 1990). The number of technical classes (as indicated by the number of CPC classes) assigned to a patent application has also been used as a proxy for the value of a patent and the technical diversity associated with the invention (Guellec and Van Pottelsberghe de la Potterie, 2002).

Hence, we replicate our analysis by using the number of patent citations and the number of technical classes as the outcome variables. As before, we consider two time periods – the period 2007-2018 and the period 2015-2018, which means that we have four additional outcome variables: the number of patent citations during the period 2007-2018 and during the period 2015-2018; and the number of technical classes assigned to patents during the period 2007-2018 and 2015-2018.

Figure 6.5 Green patent citations across firm groups with different policy exposure, 2000-2018



Notes: Subsidy data is available only from 2007 onward. The figure is compiled by the authors using MISS and PRV databases.

Figure 6.5 shows the distribution of patent citations across firms with different policy exposures during the period 2000-2018. Interestingly, we observe that inventions patented by firms that only received subsidies during the period 2007-2018 received more citations than inventions patented by subsidized and ETS firms. This disparity is particularly pronounced during the period 2015-2018, and it was not evident when comparing the number of green patents across the same groups of firm (see Figure 6.1), highlighting the importance of including variables that reflect patent quality alongside patent counts when investigating the effects of various policies on firms' technological responses.

Tables 6.7-6.8 summarize the effects of different levels of subsidies (small, medium and large) on the number of green patent citations and the number of technical classes assigned to patents. Panel B in Table 6.7 shows that different levels of innovation subsidies (except medium) had the positive effects on the number of green patent citations. The size of the estimated coefficients is positively correlated with the subsidy size categories, implying that large innovation subsidy recipients patented inventions that received more citations during the period 2007-2018 than small size innovation subsidy recipients. In the case of patent citations for a shorter time window (2015-2018), we find that only firms with medium-size innovation subsidies received more patent citations than no innovation subsidy receiving firms.

Tabell 6.7 The effects of subsidies on the number of green patent citations: ATT matching estimates

A: The effect of total subsidies on the number of green patent citations										
Patent citations (2007-2018)		No subsidy	Small	Medium		Patent citations (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	3.808*				Subsidy	diff.	0.104*		
	s.e.	2.195					s.e.	0.057		
	t-stat	1.735					t-stat	1.824		

Small	diff.	0.011			Small	diff.	0.010		
	s.e.	1.578				s.e.	0.030		
	t-stat	0.007				t-stat	0.329		
Medium	diff.	5.447*	3.278		Medium	diff.	0.041	-0.019	
	s.e.	3.132	4.233			s.e.	0.030	0.105	
	t-stat	1.739	0.774			t-stat	1.402	-0.179	
Large	diff.	34.420*	57.158*	5.952	Large	diff.	0.938*	1.379*	0.267
	s.e.	20.278	23.053	12.075		s.e.	0.532	0.664	0.459
	t-stat	1.697	2.479	0.493		t-stat	1.764	2.078	0.580
B: The effect of innovation subsidies on the number of green patent citations									
Patent citations (2007-2018)		No subsidy	Small	Medium	Patent citations (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	7.023***			Subsidy	diff.	0.147		
	s.e.	2.500				s.e.	0.147		
	t-stat	2.809				t-stat	1.000		
Small	diff.	2.281**			Small	diff.	0.059		
	s.e.	0.927				s.e.	0.059		
	t-stat	2.420				t-stat	1.000		
Medium	diff.	5.278	1.183		Medium	diff.	0.068**	0.064	
	s.e.	3.334	5.967			s.e.	0.031	0.238	
	t-stat	1.583	0.198			t-stat	2.225	0.268	
Large	diff.	42.187**	82.057**	10.306	Large	diff.	1.072	1.674*	0.955
	s.e.	18.322	42.841	13.081		s.e.	0.804	1.000	0.837
	t-stat	2.303	1.915	0.788		t-stat	1.333	1.674	1.142
C: The effect of green innovation subsidies on the number of green patent citations									
Patent citations (2007-2018)		No subsidy	Small	Medium	Patent citations (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	75.228			Subsidy	diff.	3.572		
	s.e.	79.007				s.e.	2.934		
	t-stat	0.952				t-stat	1.218		
Small	diff.	22.052			Small	diff.	-0.558		
	s.e.	32.497				s.e.	0.810		
	t-stat	0.679				t-stat	-0.690		
Medium	diff.	10.623	-21.923		Medium	diff.	-	-0.135	
	s.e.	8.840	59.284			s.e.	-	0.355	
	t-stat	1.202	-0.370			t-stat	-	-0.379	
Large	diff.	209.708	44.119	142.128*	Large	diff.	8.949	1.761	2.814
	s.e.	197.019	33.299	72.647		s.e.	7.412	1.662	1.778
	t-stat	1.064	1.325	1.956		t-stat	1.207	1.060	1.583

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

Similar patterns are observed for the number of technical classes assigned to green patents. Panel B of Table 6.8 shows that innovation subsidies of any size (small, medium, or large) lead to patented inventions with more technical classes. This finding holds true for both outcome variables – for the periods 2007-2018 and 2015-2018. In the case of green innovation subsidy recipients, we observe that only large subsidy recipients patented technologies with a larger scope, i.e. more technological classes (see panel C in Table 6.8).

Tabell 6.8 The effects of subsidies on the number of technical patent classes: ATT matching estimates

A: The effect of total subsidies on the number of technical patent classes										
Technical patent classes (2007-2018)		No subsidy	Small	Medium		Technical patent classes (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	3.256				Subsidy	diff.	0.140		
	s.e.	3.789					s.e.	0.135		
	t-stat	0.859					t-stat	1.039		
Small	diff.	-0.585				Small	diff.	0.001		
	s.e.	3.530					s.e.	0.110		
	t-stat	-0.166					t-stat	0.005		
Medium	diff.	13.346**	10.598			Medium	diff.	0.3447**	0.290	
	s.e.	5.940	7.821				s.e.	0.175	0.377	
	t-stat	2.247	1.355				t-stat	1.967	0.769	
Large	diff.	22.043	60.158**	-8.706		Large	diff.	0.582	1.987**	-1.382*
	s.e.	20.023	26.419	17.979			s.e.	0.396	1.074	0.786
	t-stat	1.101	2.277	-0.484			t-stat	1.467	1.851	-1.759
B: The effect of innovation subsidies on the number of technical patent classes										
Technical patent classes (2007-2018)		No subsidy	Small	Medium		Technical patent classes (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	7.833*				Subsidy	diff.	0.218		
	s.e.	4.117					s.e.	0.147		
	t-stat	1.903					t-stat	1.482		
Small	diff.	3.051**				Small	diff.	0.136*		
	s.e.	1.336					s.e.	0.065		
	t-stat	2.283					t-stat	2.091		
Medium	diff.	13.578**	6.275			Medium	diff.	0.479**	0.143	
	s.e.	6.722	10.963				s.e.	0.160	0.629	
	t-stat	2.020	0.572				t-stat	3.001	0.227	
Large	diff.	50.158*	94.950**	-7.821		Large	diff.	1.496*	2.078**	0.116
	s.e.	26.633	45.987	17.194			s.e.	0.801	0.987	0.603
	t-stat	1.883	2.065	-0.455			t-stat	1.868	2.105	0.192
C: The effect of green innovation subsidies on the number of technical patent classes										
Technical patent classes (2007-2018)		No subsidy	Small	Medium		Technical patent classes (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	177.430				Subsidy	diff.	8.235		
	s.e.	139.344					s.e.	6.922		
	t-stat	1.273					t-stat	1.190		

Small	diff.	-4.208				Small	diff.	-1.455		
	s.e.	29.390					s.e.	1.903		
	t-stat	-0.143					t-stat	-0.765		
Medium	diff.	2.262	-17.538			Medium	diff.	0.049	-0.212	
	s.e.	5.040	28.104				s.e.	0.049	0.713	
	t-stat	0.449	-0.624				t-stat	1.000	-0.297	
Large	diff.	474.292	112.597*	139.026*		Large	diff.	21.528	3.754*	2.686**
	s.e.	343.226	62.754	73.287			s.e.	17.426	1.936	1.342
	t-stat	1.382	1.794	1.897			t-stat	1.235	1.939	2.001

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

Tables 6.9-6.10 summarize the effects of different policy mixes on green patent citations and technology classes assigned to green patents. As in Table 6.5, we compare the outcomes of ETS and subsidy receiving firms to firms that received only subsidies, or ETS firms, or firms that were neither ETS nor subsidy firms.

Tabell 6.9 The effects of the policy mix on the number of green patent citations: ATT matching estimates

A: The effects of the EU ETS and subsidies on the number of green patent citations				
Patent citations (2007-2018)		Subsidy only	ETS only	No ETS, no subsidy
ETS & any subsidy	diff.	-283.018	9.692	41.194
	s.e.	275.224	6.624	36.173
	t-stat	-1.028	1.463	1.000
Patent citations (2015-2018)				
ETS & any subsidy	diff.	-12.625*	0.019	-0.067
	s.e.	7.073	0.019	0.129
	t-stat	-1.785	1.000	-0.520
B: The effects of the EU ETS and innovation subsidies on the number of green patent citations				
Patent citations (2007-2018)		Innovation subsidy only	ETS only	No ETS, no innovation subsidy
ETS & innovation subsidy	diff.	-632.553*	6.140	39.577
	s.e.	327.917	5.860	43.157
	t-stat	-1.929	1.048	0.917
Patent citations (2015-2018)				
ETS & innovation subsidy	diff.	-21.723***	0.023	-0.192
	s.e.	8.360	0.023	0.148
	t-stat	-2.598	1.000	-1.298
C: The effects of the EU ETS and green innovation subsidies on the number of green patent citations				
Patent citations (2007-2018)		Green innovation subsidy only	ETS only	No ETS, no green innovation subsidy
ETS & green innovation subsidy	diff.	-468.000	1.200	-110.538

	s.e.	811.530	1.200	119.186
	t-stat	-0.577	1.000	-0.927
Patent citations (2015-2018)				
ETS & green innovation subsidy	diff.	-20.609	0.100	-3.904**
	s.e.	21.597	0.100	1.870
	t-stat	-0.954	1.000	-2.088

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

We compare the effect of combined policies, that is the EU ETS and subsidies versus subsidy only, ETS only, or no ETS and no subsidy on green patenting behavior. Given the small number of observations under both policy regimes, in this analysis, we do not consider the level of subsidies. In the treatment group, we have all ETS firms that received some subsidies during the period 2007-2016, while in the control 'only subsidy' group, we include all firms that received some subsidies during the same period.

Tabell 6.10 The effects of the policy mix on the number of technical patent classes: ATT matching estimates

A: The effects of the EU ETS and subsidies on the number of technical patent classes				
Technical patent classes (2007-2018)		Subsidy only	ETS only	No ETS, no subsidy
ETS & any subsidy	diff.	-176.250	34.154	59.463
	s.e.	184.193	23.647	37.869
	t-stat	-0.957	1.444	1.570
Technical patent classes (2015-2018)				
ETS & any subsidy	diff.	-13.089	0.923	-0.082
	s.e.	8.262	0.923	1.301
	t-stat	-1.584	1.000	-0.063
B: The effects of the EU ETS and innovation subsidies on the number of technical patent classes				
Technical patent classes (2007-2018)		Innovation subsidy only	ETS only	No ETS, no innovation subsidy
ETS & innovation subsidy	diff.	-570.766**	38.791	72.115
	s.e.	247.397	28.428	42.379
	t-stat	-2.307	1.365	1.702
Technical patent classes (2015-2018)				
ETS & innovation subsidy	diff.	-27.606***	1.116	0.423
	s.e.	10.403	1.116	0.986
	t-stat	-2.654	1.000	0.429
C: The effects of the EU ETS and green innovation subsidies on the number of technical patent classes				
Technical patent classes (2007-2018)		Green innovation subsidy only	ETS only	No ETS, no green innovation subsidy
ETS & green innovation subsidy	diff.	-283.304	25.800	-379.154*
	s.e.	546.269	27.011	217.403

	t-stat	-0.519	0.955	-1.744
Technical patent classes (2015-2018)				
ETS & green innovation subsidy	diff.	-22.457	2.250	-10.673*
	s.e.	25.083	2.250	6.637
	t-stat	-0.895	1.000	-1.608

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

As in the case of green patent counts (see Table 6.5), we find that ETS firms that were also recipients of innovation subsidies patented green inventions with lower numbers of citations and fewer technology classes assigned to these inventions than subsidy-only firms (see panels B in Tables 6.9 and 6.10). This result does not hold when only green innovation subsidies are considered. The combined results on the effects of the policy mix on firms' technological responses imply that only subsidy recipients not only patented more green inventions, but also more valuable and broader inventions than both ETS and subsidy receiving firms.

Finally, in Tables 6.11-6.12 we report the ATTs of the EU ETS on the number of green patent citations and the number of technical classes assigned to green patents. As with green patent counts, we compare all ETS firms to all non-ETS firms. Then, we consider only ETS firms without (with) subsidies and we compare them to non-ETS firms without (with) subsidies.

Panels B in Tables 6.11-6.12 show that ETS firms had, on average, 1.18 fewer patents than firms that received only innovation subsidies. The ATT estimates reported in columns A show that ETS firms had patented inventions with fewer citations and fewer technical patent classes than non-ETS firms. This result is significant when using the outcome variables for the 2007-2018 and 2015-2018 periods. These findings are in line with the results reported for green patent counts, suggesting that the EU ETS did not induce more and higher quality patented green technologies in the case of Swedish manufacturing firms.

Tabell 6.11 The effects of the EU ETS on green patent citations: ATT matching estimates

		A: ETS vs. non-ETS	**B: ETS without subsidies vs. non-ETS without subsidies**	**C: ETS with subsidies vs. non-ETS with subsidies**
Patent citations (2007-2018)	diff.	-102.294	-0.456	-283.018
	s.e.	69.834	2.373	275.224
	t-stat	-1.465	-0.192	-1.028
Patent citations (2015-2018)	diff.	-4.380**	-0.070	-12.625*
	s.e.	1.843	0.047	7.073
	t-stat	-2.376	-1.508	-1.785

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

Tabell 6.12 The effects of the EU ETS on the number of green patent technical classes: ATT matching estimates

		A: ETS vs. non-ETS	B: ETS without subsidies vs. non-ETS without subsidies	C: ETS with subsidies vs. non-ETS with subsidies
Technical patent classes (2007-2018)	diff.	-75.159	-1.684	-176.250
	s.e.	48.896	2.785	184.193
	t-stat	-1.537	-0.605	-0.957
Technical patent classes (2015-2018)	diff.	-5.298**	-0.237*	-13.089
	s.e.	2.286	0.138	8.262
	t-stat	-2.317	-1.722	-1.584

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

6.6 Robustness tests

As a robustness test to strengthen the causal interpretation of the results, we replicated our analysis by using total subsidies received during the period 2007-2014 as the treatment variable and total patents granted during the period 2015-2018 as the outcome variable. The matching estimates of this exercise are summarized in Tables 6.13-6.15.

Consistent with our main results reported in Table 6.4, we find that firms that received large total subsidies or large green innovation subsidies during the period 2007-2014 patented more inventions than small subsidy recipients (see Panels A and C in Table 6.13). However, this result only holds at the 10% level of statistical significance.

Tabell 6.13 The effects of subsidies received during the period 2007-2014 on the number of granted patents during the period 2015-2018: ATT matching estimates

A: The effect of total subsidies (2007-2014) on green patents				
Granted patents (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	0.025**		
	s.e.	0.010		
	t-stat	2.435		
Small	diff.	-0.010		
	s.e.	0.008		
	t-stat	-1.320		
Medium	diff.	0.032	0.024	
	s.e.	0.026	0.029	
	t-stat	1.236	0.825	
Large	diff.	0.061	0.052*	-0.139*
	s.e.	0.102	0.030	0.081
	t-stat	0.595	1.736	-1.716
B: The effect of innovation subsidies (2007-2014) on green patents				
Granted patents (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	0.019*		
	s.e.	0.010		
	t-stat	1.895		

Small	diff.	0.002		
	s.e.	0.005		
	t-stat	0.403		
Medium	diff.	0.044	0.045	
	s.e.	0.030	0.030	
	t-stat	1.504	1.500	
Large	diff.	0.069	0.073	-0.096
	s.e.	0.059	0.087	0.137
	t-stat	1.160	0.845	-0.704
C: The effect of green innovation subsidies (2007-2014) on green patents				
Granted patents (2015-2018)		No subsidy	Small	Medium
Subsidy	diff.	-0.060		
	s.e.	0.109		
	t-stat	-0.552		
Small	diff.	0.024		
	s.e.	0.024		
	t-stat	1.000		
Medium	diff.	-0.083	-0.032	
	s.e.	0.098	0.041	
	t-stat	-0.851	-0.773	
Large	diff.	0.148	0.100*	0.024
	s.e.	0.136	0.062	0.565
	t-stat	1.086	1.603	0.042

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

Similarly, as in Table 6.5, in Table 6.14 we compare the effect of combined policies, that is the EU ETS and subsidies versus subsidy only, ETS only, or no ETS and no subsidy on green patenting behavior. In the treatment group, we have all ETS firms that received some subsidies during the period 2007-2014, while in the control 'subsidy only' group, we include all firms that received some subsidies during the same period. Contrary to the results reported in Table 6.5, which considers subsidies for the entire period 2007-2018, we do not find that ETS firms that are also innovation subsidy recipients patented fewer technologies than only subsidy receiving firms, but instead we find that the patenting behavior did not differ between these two groups of firms.

Tabell 6.14 The effects of the policy mix (with subsidies for 2007-2014 period) on the number of granted patents: ATT matching estimates

A: The effects of the EU ETS and subsidies (2007-2014) on green patents				
Granted patents (2015-2018)		Subsidy only	ETS only	No ETS, no subsidy
ETS & any subsidy	diff.	-0.109	-0.047	0.027
	s.e.	0.133	0.037	0.027
	t-stat	-0.822	-1.268	1.000
B: The effects of the EU ETS and innovation subsidies (2007-2014) on green patents				

Granted patents (2015-2018)		Innovation subsidy only	ETS only	No ETS, no innovation subsidy
ETS & innovation subsidy	diff.	-2.346	-0.021	-0.133
	s.e.	1.866	0.026	0.122
	t-stat	-1.257	-0.813	-1.092
C: The effects of the EU ETS and green innovation subsidies (2007-2014) on green patents				
Granted patents (2015-2018)		Green innovation subsidy only	ETS only	No ETS, no green innovation subsidy
ETS & green innovation subsidy	diff.	-7.286	0.000	-0.846*
	s.e.	6.567	0.000	0.519
	t-stat	-1.109	-	-1.629

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

Table 6.15 also reports the results from comparing patenting behavior between ETS firms and non-ETS firms, between ETS firms without subsidies and non-ETS firms without subsidies, and between ETS firms with subsidies to non-ETS firms with subsidies. The ATT estimates reported in column A show that ETS firms had fewer patents than non-ETS firms during the period 2015-2018. This result is in line with the results reported in Table 6.6. Furthermore, we do not find evidence suggesting that ETS firms, with or without subsidies, were more active in patenting green technologies than similar non-ETS firms. These findings also support the previous findings reported in Table 6.6.

Tabell 6.15 The effects of the EU ETS on the number of granted patents: ATT matching estimates

		A: ETS vs. non-ETS	**B: ETS without subsidies vs. non-ETS without subsidies**	**C: ETS with subsidies vs. non-ETS with subsidies**
Granted patents (2015-2018)	diff.	-0.224**	-0.003	-0.109
	s.e.	0.094	0.013	0.133
	t-stat	-2.380	-0.193	-0.822

Notes: This table report the ATTs estimates from the nearest neighbor matching with two neighbors and the caliper set at 0.01. *** p < = 0.01, ** p < = 0.05, * p < = 0.1.

6.7 Some concluding remarks

The combined results of this empirical analysis led us to conclude that high levels of innovation subsidies or of green innovation subsidies contribute significantly to the development of green technologies among manufacturing firms. This result highlights the importance of considering the different levels of subsidies, as the average treatment effect of total subsidies masks substantial heterogeneity across subsidy size groups. Our results clearly show that increasing the amount of innovation subsidies increases the subsequent number of green technology patents. This result also holds for other patent variables that consider the quality and scope of patented inventions, that is, the number of patent citations and the number of assigned technology classes, implying that the number of green patents granted is correlated with quality-weighted patent variables. For the sample of manufacturing firms, we find that medium size subsidies already induce significantly higher patenting activity, while large subsidies lead to even higher patent counts. Oppositely, our findings suggest that low levels of subsidies do not promote patenting activity, presumably implying the importance of not spreading the limited public funds too thinly if the goal is to increase the innovative capacity of the manufacturing sector in tackling climate change. However, we do not find such a strong correlation between the level of subsidies and various green patenting outcomes when we use total subsidies or green innovation subsidies. This suggests the importance of disaggregating subsidies by purpose.

Our results on policy mix suggest that there are no observable synergies between emissions trading and innovation subsidies, and that large and innovation-targeting subsidies are more effective incentivizing the development and patenting of green technologies than emission trading schemes. Unfortunately, the effect of large green innovation subsidies combined with emissions trading is inconclusive due to the large correlation between the two of them in terms of selection into treatment. Future research could explore the existence of synergetic effects of ETS depending on the size of subsidies in more detailed.

Our results raise the question why the combined policies do not lead to more patented inventions. There are many possible answers. The most obvious is that the EU ETS and innovation or green innovation subsidies pursue very different objectives and none of them has a clear goal to develop and patent new climate-related technologies. In other words, both regulations create incentives for research and development activities within a firm, but the outcome of the policy mix might not necessarily lead to more granted patents. In other words, we need to consider other outcome variables to better understand firms' technological responses to the combination of the EU ETS and innovation-related subsidies. These variables might include R&D expenditure, innovation-related investments and expenditure, trademarks, patent applications, and others.

Furthermore, we find that the EU ETS itself did not induce more patented green technologies and more higher quality patents; instead, it led to fewer green patents compared to non-ETS firms. This result contradicts the findings of other studies that have estimated the causal effects of the EU ETS on carbon-mitigating patents. However, it is consistent with the results of studies evaluating the effects previous cap-and-trade programs on patenting behavior.

6.8 Limitations and future research

Our analysis has several limitations. Due to data unavailability, we could not control for each firm's energy use and associated carbon dioxide emissions. This potentially affected the estimation of the effects related to the EU ETS, since in the matching we tried to control for all relevant variables to explain patenting behavior, except for the level of emissions or other variables that determine the regulatory status of the EU ETS. A similar matching configuration was used by Calel and Dechezleprêtre (2016). The matching allowed us to form groups of similar ETS and non-ETS firms, but inevitably lead to the loss of a number of ETS firms for which no good match could be found. This means that our results on the effects of the EU ETS on green patenting apply only to a subset of ETS firms. The overall effect of the EU ETS on green patenting may be different in the case of Sweden than in other countries.

Another limitation concerns the shortcomings of the MISS database. First, it is the incomplete coverage of support provided by governmental agencies and state-owned companies. If there are unreported sources of support that affect either the treated group, the control group, or both, without this information, the estimated difference in outcomes between the two groups may not accurately capture the full impact of the support. In particular, if some companies in the control group received unreported support, their outcomes would be more similar to those of the treated group. This would reduce the observed difference between the control and treated groups, leading to an underestimation of the true treatment effect. Alternatively, if unreported support only affected the treated group, it would artificially inflate their outcomes relative to the control group, leading to an overestimation of the treatment effect. Overall, the bias would likely result in an underestimation of the true effect of government subsidies on the treated group.

Second, the lack of documentation on the allocation processes for support could introduce an attribution bias in the sense that the matching method aims to create a control group that is similar to the treated group in terms of observable characteristics. However, if the allocation process is not transparent and certain firms are systematically favored or disadvantaged in receiving support based on unobservable factors, these differences may not be captured in the matching process. For example, suppose the allocation process favors companies with strong political connections, but this information is not observable in the data used for matching. As a result, the control group may not include companies with similar political connections as those in the treated group. If differences in outcomes between the treated and control groups are observed, they may be incorrectly attributed to the treatment (support) rather than to the unobserved factor (political connections) influencing the allocation process. Other such criteria used by evaluators to rank and select grant winning projects could include project and management characteristics or the potential impact of the R&D project. Such information is rarely available to researchers. To mitigate attribution bias, it is crucial to improve the documentation of allocation processes and the factors that influence funding decisions.

Another limitation is related to the choice of outcome variables. Althought patents have been used extensively as a measure of technological change in the induced innovation literature, the advantages and drawbacks of patents are well analyzed and understood (see, e.g., OECD 2009). Further research might try to consider a broader picture of technological responses within firms that are exposed to different environmental policies or that are successful in receiving state support to develop new technologies. As a robustness test, future research could replicate our analysis by using R&D expenditures, innovation-related investments and expenditures. Furthermore, future studies might consider not only climate-related patents but also other patents as we might expect some green innovation subsidies to spill over to other areas than climate.

Furthermore, it would be interesting for future studies to investigate if and how innovation subsidies affect employment outcomes, the size of firms, especially in the context of the COVID19 pandemic. Have green innovation subsidies increased competitiveness of Swedish manufacturing firms? It would be also useful to expand the analysis by including other environmental policies, most importantly, carbon dioxide and energy taxes. These questions remain open for future research.

7. Discussion and policy implications

Technological advancements play a pivotal role in balancing economic growth with environmental protection. However, two types of market failures impede the development of new green technologies: firstly, the private sector lacks sufficient incentive for research and development (R&D) due to knowledge spillovers and credit market failures, which deter lenders from funding high-risk, high-reward investments like R&D. Secondly, demand for environmental innovations is driven by regulations that may be challenging to enforce or not stringent enough to significantly impact innovation. Given these joint market failures, combining environmental policies with green innovation subsidies becomes a viable policy option. This report examines the combined impact of direct public innovation subsidies and the European Union Emission Trading Scheme (EU ETS) on green innovation activity among industrial firms in Sweden, aiming to evaluate the overall effectiveness of both policies and their relative efficiency in fostering green innovation.

Our analysis of green patenting in Sweden shows that green patents granted to Swedish entities represent a minority among the total patents granted in Sweden, with only 13% attributed to Swedish firms, highlighting a larger presence of non-Swedish entities in green patenting activities. Moreover, a significant concentration of green patents is observed among a small number of Swedish firms. Furthermore, patents granted to Swedish entities tend to have smaller family sizes and receive fewer citations compared to non-Swedish counterparts, suggesting differing scales and impacts of innovation. While Swedish firms focus on sectors such as transportation and energy generation, non-Swedish entities demonstrate a broader sectoral distribution, indicating diverse green technology development activities beyond Sweden. Trends over time show a relatively stable trend in patent grants to Swedish entities until recent years, where an increasing trend is observed, contrasting with a sharp increase in patents granted to non-Swedish entities. This underscores distinct patterns of innovation dynamics and growth trajectories between Swedish and non-Swedish firms in the green technology domain.

Our analysis of environmental policies in Sweden indicates that Sweden has implemented a plethora of initiatives aimed at reducing emissions and fostering innovation. These policies, ranging from comprehensive legislation to innovative taxation schemes, have potentially influenced both environmental outcomes and innovation dynamics. Analysis of the correlation between the OECD Environmental Policy Stringency Index (EPS) and patents suggests that market-based policies, such as emissions taxes and trading systems, may be particularly effective in stimulating innovation. However, due to limited firm-level data hindering the investigation of causal effects, our report focuses solely on the examination of innovation subsidies and the EU ETS. These policies are of particular interest due to their significance in incentivizing green technology development and emissions reduction efforts. Moreover, within the realm of subsidies, we make a crucial distinction between green innovation subsidies and innovation subsidies (at large) to ascertain their respective impacts on innovation. This differentiation aims to determine which type of subsidy yields the most substantial effect on fostering innovation in green technologies.

Our analysis of innovation subsidies indicates that there is a large concentration of innovation subsidies among a small number of firms, where these firms receive much higher subsidies than most of the remaining firms under the period of consideration. The large concentration of innovation subsidies in a few firms could stem from various factors. Firstly, these firms might possess superior capabilities or resources that make them more competitive in securing subsidies, such as strong R&D infrastructure, established track records of innovation, or influential networks within the industry or government. Secondly, administrative barriers or complexities in accessing subsidy programs might deter smaller or less resourceful firms from applying, further exacerbating the concentration of subsidies among larger or more established players. Moreover, strategic decisions by policymakers to concentrate funding on firms deemed to have the highest potential for driving innovation or achieving policy objectives could also contribute to this concentration. The concentration of innovation subsidies underscores the importance of understanding the dynamics of subsidy allocation and its impact on firm-level innovation strategies and outcomes.

The empirical analysis conducted in this study leads to several noteworthy conclusions regarding the impact of innovation subsidies on green patenting. Firstly, it is evident that substantial levels of subsidies significantly contribute to green patenting. Medium-sized subsidies already induce significantly higher patenting activity, with larger subsidies leading to even greater patent counts. Conversely, low levels of subsidies do not appear to stimulate patenting activity. This underscores the importance of considering the varying levels of subsidies, as the average treatment effect may obscure significant heterogeneity across subsidy-size groups. Our findings also indicate that increasing the amount of innovation subsidies correlates not only with a subsequent increase in green patents but also with proxies for patent quality and scope.

Our report also shows that the impact of innovation subsidies on green patenting outweighs that of green innovation subsidies. This observation is not only attributable to the higher average value of innovation subsidies compared to green innovation subsidies but also suggests that subsidies serve as a significant signaling mechanism. Firms receiving substantial subsidies likely gain access to preferential conditions that foster innovation, posing challenges for researchers to precisely quantify and control. These conditions may include lower interest rates or access to highly skilled human capital attracted to environments conducive to innovation. Exploring these dimensions is suggested as an area for future investigation and analysis.

Furthermore, our findings indicate that the combination of emissions trading with innovation subsidies may not yield significant synergistic effects, suggesting that large subsidies specifically aimed at innovation are more effective in stimulating the development and patenting of green technologies compared to reliance solely on emission trading schemes. This observation underscores the idea that while emissions trading schemes can contribute to reducing CO2 emissions, achieving substantial progress in emissions reduction through technological innovation may necessitate supplementary measures beyond emissions trading alone. It's noteworthy that emissions reductions can also be achieved through alternative means, such as improving fuel efficiency and adopting fuel switching, which may not always entail the development of patentable innovations. Future research could replicate our analysis by using additional metrics such as R&D expenditure, innovation-related investments, and expenditure. This expanded approach could provide a more comprehensive assessment of the impact of CO2 emissions trading on various innovation outcomes beyond patenting alone.

Additionally, it is important to consider that firms operating under emissions trading schemes may prioritize measures to reduce emissions to comply with regulations and minimize compliance costs, but their core business strategies may not always prioritize the pursuit of innovations leading to patents. In contrast, non-ETS firms receiving significant subsidies may possess both the infrastructure and expertise required for innovation, as well as the ability to secure and effectively utilize substantial innovation subsidies, thereby facilitating innovation efforts. This disparity suggests that one simple explanation for the observed lack of synergies between environmental policies and innovation subsidies is that they target different types of firms with distinct priorities and capacities. To enhance the synergies between environmental policies and innovation subsidies, policymakers need to consider the diversity of firms within industries and tailor policy interventions accordingly. This may involve targeted support for both innovating and adopting firms, as well as measures to facilitate knowledge transfer, collaboration, and technology diffusion across the entire ecosystem. Additionally, efforts to reduce barriers to adoption, such as providing technical assistance, training, or financial incentives, can help ensure that innovations reach their full potential and contribute to meaningful environmental outcomes.

While our analysis suggests that emissions trading schemes may not exhibit strong synergies with innovation subsidies, it is still possible that other environmental policies better target innovation. Therefore, expanding the scope to encompass other policies that might impact innovation is also recommended as a promising avenue for future research. Additionally, considering the Environmental Policy Stringency (EPS) as an indicator of overall policy stringency could enrich our understanding of how various environmental policies interact with innovation incentives. By incorporating these additional policies into the analysis, one could gain a more comprehensive understanding of their collective impact on environmental innovation and emissions reduction. This broader perspective would enable a more nuanced assessment of policy effectiveness and provide valuable insights into the most impactful strategies for fostering innovation in green technologies.

While the MISS database serves as a crucial resource for understanding the impact of innovation support on green patenting, our analysis has underscored significant shortcomings in the data. Two key recommendations emerge: firstly, there is an urgent need to enhance the completeness of support data by ensuring accurate reporting of all sources, particularly those from governmental agencies and state-owned companies. This step would bolster transparency and enable more robust evaluations of support programs. Secondly, documentation surrounding selection processes requires improvement to enhance clarity and accessibility for evaluators. Thorough documentation would help researchers in comprehending the criteria for support allocation, thus mitigating biases in control group creation. By improving the completeness of support data and enhancing documentation of selection processes, policymakers and researchers can enhance the validity of impact evaluations and make more informed decisions regarding resource allocation and policy development.

We conclude the report with some suggestions for further research. One of them is the analysis of patent variations over time and the factors driving such variations. By undertaking such analysis, researchers can contribute to a deeper understanding of the evolving landscape of innovation and patenting practices, thus informing policymakers and industry stakeholders alike. An additional area for further research is the analysis of the allocation of innovation subsidies among firms to understand the underlying determinants and implications of subsidy concentration. This analysis could explore factors influencing firms' access to subsidies, such as organizational capabilities, industry characteristics, and government policies, and assess the effectiveness of subsidy allocation mechanisms in promoting equitable innovation outcomes. A final suggestion is to evaluate the impact of environmental policies and innovation subsidies on a broader range of outcomes, such as technology adoption, and environmental performance. This comprehensive assessment could provide insights into the multifaceted effects of policy interventions on other measures of innovation and on environmental sustainability.

References

Acemoglu, D., Aghion, P., Bursztyn, L., and Hemous, D. (2012). The environment and directed technical change. American economic review, 102(1), 131-66.

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R., and Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. Journal of Political Economy, 124(1), 1-51.

Angelucci, S., Hurtado-Albir, F.J. and Volpe, A. (2018). Supporting global initiatives on climate change: The EPO's "Y02-Y04S" tagging scheme. World Patent Information, 54, S85-S92.

Ahlvik, L., and van den Bijgaart, I. (2024). Screening green innovation through carbon pricing. Journal of Environmental Economics and Management, 124, 102932.

Bai, Y., Song, S., Jiao, J., and Yang, R. (2019). The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. Journal of Cleaner Production, 233, 819-829.

Barbieri, N., Marzucchi, A., and Rizzo, U. (2020). Knowledge sources and impacts on subsequent inventions: Do green technologies differ from non-green ones? Research Policy, 49(2), 103901.

Bertoldi, P., and Mosconi, R. (2020). Do energy efficiency policies save energy? A new approach based on energy policy indicators (in the EU Member States). Energy Policy, 139, 111320.

Bloom, N., Van Reenen, J. and Williams, H. (2019). A toolkit of policies to promote innovation. Journal of economic perspectives, 33(3), 163-84.

Bonilla, J., J. Coria, K. Mohlin and Sterner, T. (2015). Refunded Emission Payments and Diffusion of NO_x Abatement Technologies in Sweden, Ecological Economics 116, 132-145.

Bonilla, J., J. Coria and Sterner, T. (2018). Technical Synergies and Trade-offs between Climate and Local Air Pollution in Sweden. Environmental and Resource Economics 70(1), 191-221.

Calel, R. (2020). Adopt or innovate: Understanding technological responses to cap-and-trade. American Economic Journal: Economic Policy, 12(3), 170-201.

Calel, R., and Dechezleprêtre, A. (2016). Environmental policy and directed technological change: evidence from the European carbon market. Review of economics and statistics, 98(1), 173-191.

Christiansen, V., and Smith, S. (2015). Emissions taxes and abatement regulation under uncertainty. Environmental and Resource Economics, 60(1), 17-35.

Coria, J. and Mohlin, K. (2017). On Refunded Emissions Payment and Technological Diffusion. Strategic Behavior and the Environment 6(3), 205–248.

Costantini, V., Crespi, F., and Palma, A. (2017). Characterizing the policy mix and its impact on eco-innovation: A patent analysis of energy-efficient technologies. Research Policy, 46(4), 799-819.

Dechezleprêtre, A. and Glachant, M. (2014). Does foreign environmental policy influence domestic innovation? Evidence from the wind industry. Environmental and Resource Economics, 58(3), 391-413.

Dehejia, R.H. and Wahba, S. (2002). Propensity score matching methods for nonexperimental causal studies. Review of Economics and Statistics 84(1), 151–161.

Deleidi, M., Mazzucato, M., and Semieniuk, G. (2020). Neither crowding in nor out: Public direct investment mobilising private investment into renewable electricity projects. Energy Policy, 140, 111195.

ETS Directive (2003). Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC.

Eugster, J. (2021). The impact of environmental policy on innovation in clean technologies. International Monetary Fund.

Fabrizi, A., Guarini, G. and Meliciani, V. (2018). Green patents, regulatory policies and research network policies. Research Policy, 47(6), 1018-1031.

Imbens, G. W. (2015). Matching methods in practice: Three examples. Journal of Human Resources, 50(2), 373-419.

Fankhauser, S., Bowen, A., Calel, R., Dechezleprêtre, A., Grover, D., Rydge, J. and Sato, M. (2013). Who will win the green race? In search of environmental competitiveness and innovation. Global Environmental Change, 23(5), 902-913.

Galaasen, S.M. and Irarrazabal, A. (2021). R&D heterogeneity and the impact of R&D subsidies. The Economic Journal, 131(640), 3338-3364.

Galeotti, M., Salini, S., and Verdolini, E. (2020). Measuring environmental policy stringency: Approaches, validity, and impact on environmental innovation and energy efficiency. Energy Policy, 136, 111052.

Guellec, D., & Van Pottelsberghe de la Potterie, B. (2002). The value of patents and patenting strategies: countries and technology areas patterns. Economics of Innovation and New Technology, 11(2), 133-148.

Heckman, J., Ichimura, H. and Todd, P. (1997a). Matching as an econometric evaluation estimator: evidence from evaluating a job training programme. Review of Economic Studies 64(4), 605–654.

Herman, K. S., and Shenk, J. (2021). Pattern Discovery for climate and environmental policy indicators. Environmental Science & Policy, 120, 89-98.

Hysing, E. (2014). A green star fading? A critical assessment of Swedish environmental policy change. Environmental Policy and Governance, 24(4), 262-274.

Howell, S. T. (2017). Financing innovation: Evidence from R&D grants. American economic review, 107(4), 1136-1164.

Jaffe, A. B., Newell, R. G., and Stavins, R. N. (2003). Chapter 11 – Technological change and the environment. In Mäler, K.-G. and Vincent, J. R., editors, Environmental Degradation and Institutional Responses, Volume 1 of Handbook of Environmental Economics, p. 461-516. Elsevier.

Jaffe, A. B., Newell, R. G., and Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. Ecological Economics, 54(2-3), 164-174.

Jaraitė, J., and Di Maria, C. (2012). Efficiency, productivity and environmental policy: a case study of power generation in the EU. Energy Economics, 34(5), 1557-1568.

Jaraite, J., Kazukauskas, A., and Lundgren, T. (2014). The effects of climate policy on environmental expenditure and investment: evidence from Sweden. Journal of Environmental Economics and Policy, 3(2), 148-166.

Johnstone, N., Haščič, I., and Popp, D. (2010). Renewable energy policies and technological innovation: evidence based on patent counts. Environmental and resource economics, 45(1), 133-155.

Klier, T., and Linn, J. (2015). Using taxes to reduce carbon dioxide emissions rates of new passenger vehicles: evidence from France, Germany, and Sweden. American Economic Journal: Economic Policy, 7(1), 212-242.

Kemp, R. (2000). Technology and Environmental Policy—Innovation effects of past policies and suggestions for improvement. Innovation and the Environment, 1, 35-61.

Kemp, R. and Pontoglio, S. (2011). The innovation effects of environmental policy instruments - A typical case of the blind men and the elephant? Ecological Economics, 72, 28-36.

Kruse, T., Dechezleprêtre, A., Saffar, R., and Rober, L. (2022), "Measuring environmental policy stringency in OECD countries: An update of the OECD composite EPS indicator", OECD Economics Department Working Papers, No. 1703, OECD Publishing, Paris, https://doi.org/10.1787/90ab82e8-en.

Ley, M., Stucki, T., and Woerter, M. (2016). The impact of energy prices on green innovation. The Energy Journal, 37(1).

Lilliestam, J., Patt, A., and Bersalli, G. (2021). The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical expost evidence. WIREs Climate Change, 12(e681).

Malinauskaite, J., Jouhara, H., Egilegor, B., Al-Mansour, F., Ahmad, L., and Pusnik, M. (2020). Energy efficiency in the industrial sector in the EU, Slovenia, and Spain. Energy, 208, 118398.

Marin, G., and Vona, F. (2019). Climate policies and skill-biased employment dynamics: Evidence from EU countries. Journal of Environmental Economics and Management, 98, 102253.

Marino, M., Lhuillery, S., Parrotta, P., and Sala, D. (2016). Additionality or crowding-out? An overall evaluation of public R&D subsidy on private R&D expenditure. Research Policy, 45(9), 1715-1730.

Nesta, L., Vona, F. and Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. Journal of Environmental Economics and Management, 67(3), 396-411.

OECD, "OECD Patent Statistics Manual," OECD technical report (2009).

Petrin, T. (2018). A literature review on the impact and effectiveness of government support for R&D and innovation (Vol. 5, p. 2018). ISIGrowth.

Popp, D. (2019). Environmental policy and innovation: a decade of research. NBER Working Paper 25631. http://www.nber.org/papers/w25631

Rosenbaum, P. R., and Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. Biometrika, 70(1), 41-55.

Rubin, D. B. (1990). Formal mode of statistical inference for causal effects. Journal of statistical planning and inference, 25(3), 279-292.

Schmitt, S., and Schulze, K. (2011). Choosing environmental policy instruments: An assessment of the environmental dimension of EU energy policy. European Integration Online Papers, 15(1).

Schusser, S., and Jaraitė, J. (2018). Explaining the interplay of three markets: Green certificates, carbon emissions and electricity. Energy Economics, 71, 1-13.

Stavlöt, U., and Svensson, R. (2022). Evaluation of the R&D Tax Incentives in Sweden.

Sterner, T., and Höglund-Isaksson, L. (2006). Refunded emissions payments theory, distribution of costs, and Swedish experience of NOx abatement. Ecol. Econ. 57, 93–106.

Tchórzewska, K. B., Garcia-Quevedo, J., & Martinez-Ros, E. (2022). The heterogeneous effects of environmental taxation on green technologies. Research Policy, 51(7), 104541.

Torregrosa-Hetland, S., Pelkonen, A., Oksanen, J., & Kander, A. (2019). The prevalence of publicly stimulated innovations–A comparison of Finland and Sweden, 1970–2013. Research Policy, 48(6), 1373-1384.

Trajtenberg, M. (1990). A penny for your quotes: patent citations and the value of innovations. The RAND Journal of Economics, 172-187.

Tyllväxanalysis 2023. (Myndigheten för tillväxtpolitiska utvärderingar och analyser). Rapport: 2023:08. Förslag till förbättrade förutsättningar för en evidensbaserad näringspolitik.

Ustyuzhanina, P. (2022). Decomposition of air pollution emissions from Swedish manufacturing. Environmental Economics and Policy Studies, 24(2), 195-223.

Appendix A

To identify a list of energy- or climate-related words to search for in project titles of Vinnova's calls for research proposals we departed from keywords used in the classification of patents in the YO2 category. The projects were categorized into green innovation versus non-green innovation projects depending on whether the keywords were found in the project title.

We made use of the text analysis tool available at https://voyant-tools.org/. We uploaded PDF documents describing the YO2 codes and the technologies included under each code in detail (See Table 3.1). We obtain a list of the most common words in the PDF descriptions, which is presented below.

Keywords (English)

Adaptation, Adaptation Technologies, Aeronautics, Air quality, Air quality improvement, Batter(ies), Bio-packaging, Buildings, Capture, Charging Systems, Climate Adaptation, Climate Mitigation, Communication Network(s), Communication Technologies, Disposal, Electric Vehicles, Electromobility, Electronic Waste, Energy Conversion, Energy Distribution, Energy Efficiency, Energy Generation, Energy Recovery, Energy Storage, Energy Transmission, Extreme weather, Extreme weather resilience, Flood Prevention, Green infrastructure, Greenhouse Gas, Health Protection, Heat Recovery, Hybrid Vehicles, Invasive species, ICT, Lightning, Maritime Transport, Mitigation, Mitigation Technologies, Non-fossil, Nuclear Power, Plug-in, Process Efficiency, Railways, Recycled Materials, Renewable Energy, Renewables, Resilience, Sequestration, Smart Grids, Solar Power, solar, Storms, Thermal Insulation, Vector-borne, Vector-borne Diseases, Wastewater, Wastewater Treatment, Waste Management, Water Conservation, Water use, Wind Power, Wind Turbines, wave power

To obtain a list of keywords in Swedish, we use the translation of the keywords from English to Swedish. We additionally search for all relevant Swedish synonyms. This lead to the list of Swedish keywords described below.

Keywords (Swedish)

Anpassning, Anpassningsteknik, Avfall, Avfallshantering, Avloppsbehandling, Batterier, Biogas, Biopackning, Belysningstekniker, Elfordon, Elektroniskt avfall, Energiforskning, Energieffektivitet, Energiförsörjning, Energikonvertering, Energilagring, Energiteknik, Energitransmission, Elektromobilitet, Ej fossilt, Extrema Väderförhållanden, Flyg, Flygteknik, Förnybara, Förnybara gaser, Förnybar energi, Fjärrvärme, Grön infrastruktur, Grön teknik, Hållbar energi, Hållbar energiförsörjning, Hållbar infrastruktur, Hållbar teknik, Hybridbilar, Hälsoskydd, Icke-fossilt, Invasiva arter, Kommunikationsteknik, Kommunikationsnätverk, Klimat Mitigering, Klimatanpassning, Klimatanpassningsteknik, Klimatpåverkan, Koldioxidavskiljning, Koldioxidbindning, Koldioxidinfångning, Koldioxidlagring, Koldioxidreduktion, Koldioxidupptagning, Kraftgenerering, Kraftproduktion, Kraftöverföring eldistribution, Kärnkraft, Laddningssystem, Luftkvalitet, Luftkvalitetsförbättring, Luftreningsåtgärder, Miljöanpassad energiförsörjning, Miljövänlig energiproduktion, Miljövänlig teknik, Motståndskraft mot extremt väder, Nätverkskommunikation, Process Effektivitet, Processoptimering, Processrelaterade utsläpp, Smarta elnät, Solenergi, Sjötransport, Stormar, Termisk isolering, Utsläppsminskning, Vattenanvändning, Vattenkonservering, Vektorburna sjukdomar, Vindkraft, Vindkraftverk, Översvämningsskydd.

Growth analysis

Swedish Agency for Growth Policy Analysis

Tillväxtanalys
Studentplan 3, 831 40 Östersund
Telefon: 010-447 44 00
E-post: info@tillvaxtanalys.se
Webb: www.tillvaxtanalys.se