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Innovation under dual policies: The impact of R&D subsidies and emissions trading on green patenting in Sweden ☆

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ABSTRACT

This paper examines whether the EU Emissions Trading Scheme (EU ETS) and innovation subsidies interact to enhance green innovation at the firm level. Using staggered difference-in-differences and matched samples, we find no evidence of synergetic effects: firms subject to both the EU ETS and innovation subsidies do not outperform those subject only to subsidies in terms of green patenting outcomes. By contrast, subsidies alone have a clear positive impact on green innovation. Firms receiving subsidies generate more green patents, receive more citations, and develop technologies with greater technical scope, especially when subsidy amounts are large. These findings imply that, while environmental policies like the EU ETS might create demand for green innovation, substantial subsidy support is essential to overcome market failures and promote the development and patenting of green technologies.

1. Introduction

Technological advancements are pivotal in balancing economic growth with environmental protection (e.g., Kemp, 2000; Fankhauser et al., 2013; Popp, 2019). 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 innovation subsidies with emissions pricing emerges as a viable policy option. This study investigates the combined effect of public innovation subsidies and the European Union's Emission Trading System (EU ETS) on green innovation activities among industrial firms in Sweden. In particular, it examines whether the combination of these policies leads to a greater increase in green innovation than either policy alone.

Theoretical studies (e.g., Acemoglu et al., 2012; Christiansen and Smith, 2015; Yi et al., 2021) suggest that combining innovation subsidies with emissions pricing effectively directs technological change toward green innovations. Relying exclusively on either innovation subsidies or carbon pricing would require excessively stringent policies to achieve high levels of green innovation, leading to significant economic burdens. In contrast, a policy mix – where subsidies complement emissions pricing – can achieve similar levels of innovation at lower economic costs, thereby enhancing social welfare. While empirical studies have demonstrated the complementary effects of environmental and innovation policies at the aggregate level (e.g., Fabrizi et al., 2018), they often overlook firm-level heterogeneity, failing to capture how individual firms respond differently to policy incentives. Understanding these firm-level dynamics is essential, as policy exposure varies widely

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depending on firm characteristics. Size, industry, financial resources, technological capabilities, and path dependency all play a crucial role in shaping both a firm's ability to innovate and the type of innovation it undertakes (e.g., Barbieri et al., 2020; Bolton et al., 2023).

Firms subject to emissions pricing must reduce their emissions, but compliance strategies can include non-innovative approaches such as process optimization or purchasing allowances rather than engaging in costly innovation activities that can lead to green patenting (e.g., Brown et al., 2022). While innovation subsidies can help alleviate financial constraints, they are typically application-based, requiring firms to actively seek out and qualify for funding. As a result, not all firms may pursue these opportunities, and those that do are often better positioned in terms of financial and technological resources (e.g., Bronzini and Piselli, 2016; Le and Jaffe, 2017).

Our study investigates how the combination of R&D subsidies and emissions pricing affects individual firms. By analyzing the interaction of these policies at the firm level, we aim to determine whether a synergistic effect exists. Specifically, we ask whether firms subject to both policies tend to patent more green technologies than those affected by only one policy. If such synergy exists at the firm level, it suggests that combined policies enhance a firm's capacity for green innovation. Conversely, if the synergistic effect is not observable at the firm level, it may indicate that innovative firms are developing green technologies that are later adopted by high-polluting firms, which may lack the resources, capabilities, or incentives to develop these technologies themselves.

Understanding whether or not synergies arise at the firm can help guide policy choices. Firm-level synergies would call for targeted support, such as funding or subsidies, to boost green innovation within high-polluting firms. In contrast, the absence of such synergies would suggest prioritizing broader measures such as technology transfer and adoption incentives. Hence, our findings offer practical insights for crafting effective policy combinations that promote both environmental goals and innovation—especially relevant given the widespread global adoption of such policies (see, e.g., Yi et al., 2021).

We investigate the combined and separate impacts of public innovation subsidies and the EU ETS on green innovation among industrial firms in Sweden over the period 2007–2018. Green innovation is measured by the number of patents granted for climate change mitigation and adaptation technologies, the number of citations those patents receive, and the number of technical classes assigned to them. Subsidy data are based on direct funding awarded to firms by various Swedish government agencies, and we distinguish between total direct subsidies and innovation-related subsidies. Our empirical strategy combines a staggered difference-in-differences (DID) approach – exploiting variation in the timing of firms' first subsidy receipt – with matching techniques to address potential selection bias due to non-random participation in public subsidy programs.

We begin by examining whether there are synergistic effects between subsidies and participation in the EU ETS at the firm level. Specifically, we test whether firms subject to both policies exhibit higher levels of green innovation than those subject to only one. We then assess the individual effects of each policy in isolation—first by estimating the impact of the EU ETS on green patenting using matched ETS and non-ETS firms, and subsequently by estimating the effects of receiving subsidies. Finally, we examine heterogeneity in policy effects along three dimensions: the size of subsidy support, firm size, and variation across cohorts and over time.

Our results show no evidence of a synergistic effect between the EU ETS and either total direct subsidies or innovation-related subsidies. In other words, firms subject to both the EU ETS and subsidies do not produce more patents or higher-quality patents than those subject to only one of the two policies. Moreover, participation in the EU ETS alone does not lead to increased green patenting compared to matched non-ETS firms. By contrast, we find that subsidies are positively associated with green patenting outcomes. These effects are strongest when measured over accumulated post-treatment periods and are more consistent for total direct subsidies than for innovation-related ones. The heterogeneity analysis shows that larger subsidies are particularly effective in fostering both the quantity and quality of green innovation, and that larger firms exhibit a stronger response to subsidy support.

These findings suggest that while environmental regulations such as the EU ETS might create demand for green technologies, they are not sufficient to drive firm-level innovation in the absence of complementary financial support. Public subsidies, especially at larger levels, remain important for overcoming market failures and enabling the development of green technologies.

This paper is organized as follows. Section 2 provides a brief overview of existing studies on the effects of environmental policies and direct R&D subsidies on green innovation. Section 3 describes the relevant institutional setting. In Section 4, we outline the empirical strategy. Section 5 presents the data used in this article and provides descriptive statistics. In Section 6, we summarize and discuss the results of the empirical analysis of the effects of the EU ETS and innovation subsidies on firms' green patenting outcomes, disentangling their effects and investigating their complementarities. Finally, Section 7 provides the conclusions, some policy recommendations, and directions for future research in environmental policy and green innovation.

2. Brief literature review and theoretical considerations

This study contributes to the economic literature in three ways. First, it examines the effects of the EU ETS on green patenting. Second, it assesses the impact of innovation subsidies on green patenting. Third, and most importantly, it investigates the combined effects of these policies at the firm level, providing new insights into their potential synergies.

Concerning the effects of the EU ETS on green patenting, the evidence is mixed (see Teixidó et al. (2019) for a review). Calel and Dechezleprêtre (2016) found that the EU ETS significantly increased low-carbon patenting by regulated firms across various EU countries, with an increase of up to 10% compared to non-regulated firms. Calel (2020) later found an even more pronounced 25% increase in low-carbon patenting among British ETS-regulated firms from 2000 to 2012, suggesting that the EU ETS fosters the development of new low-carbon technologies rather than merely the adoption of existing ones. However, studies focusing on Sweden have been less conclusive. Gulbrandsen and Stenqvist (2013) investigated whether the EU ETS has influenced the climate strategies of pulp and paper companies. They found that, while firms became more conscious of their carbon emissions and the need to manage them, the EU ETS has not significantly promoted low-carbon technological innovation. Furthermore, Löfgren et al. (2014) found no significant effect of the EU ETS on the likelihood of investments to reduce CO_2 emissions in Sweden from 2002 to 2008. That study found that substantial investments in bioenergy and district heating were driven by other policies or by profitability, suggesting that these investments would have occurred without the EU ETS. A similar conclusion was reached by Jaraite et al. (2014), who found that the EU ETS did not encourage Swedish manufacturing firms to invest in air pollution control. Thus, while some EU countries have observed positive effects of the EU ETS on green patenting, its impact in others – such as Sweden – remains uncertain, as green patenting appears to be influenced by other regulatory factors.

We also contribute to the literature on the effects of innovation subsidies on green patenting—a relationship complicated by the endogenous nature of subsidy allocation. Because firms must apply for subsidies, those receiving support often differ systematically from those that do not, typically being more innovative, better financed, or already engaged in green technology development. This selection bias poses challenges for separating the causal effects of subsidies from the influence of other factors that determine firms' R&D activities (see, e.g., Bajgar and Srholec, 2025). To address this, recent studies have employed quasi-experimental methods such as matching and regression discontinuity designs (RDD). Matching techniques pair treated and untreated firms with similar observable characteristics – such as size, R&D intensity, or prior patenting – to control for confounding factors and approximate the conditions of a randomized experiment. In contrast, RDD leverages sharp cutoffs in the subsidy assignment process – such as eligibility thresholds or scoring rules – to compare firms just above and below the cutoff, to approximate random assignment around the discontinuity. For instance, Howell (2017) and Santoleri et al. (2024) use RDD designs to study the effects of R&D grants from the U.S. Department of Energy and the European Union's Small and Medium-sized Enterprises R&D grants program (the SME Instrument), respectively. Howell (2017) found that grants significantly increased patenting and follow-on venture capital investment among early-stage energy startups, particularly those facing financial constraints. Santoleri et al. (2024) showed that firms receiving SME Instrument funding experienced higher innovation output, faster employment growth, and lower exit rates compared to similarly ranked but unfunded firms, highlighting the causal impact of financial support on firm performance. Our study contributes to this literature by providing causal evidence on the impact of public subsidies on green innovation, using a staggered difference-in-differences framework that exploits variation in the timing of firms' first subsidy receipt, combined with matching to address selection bias.

Finally, our study contributes to the growing literature on policy mixes by examining how the combination and sequencing of environmental policy instruments and direct government support influence green innovation. A substantial body of research has explored interactions between policy instruments, as for example, the combined effects of tax credits and innovation subsidies on firms' R&D expenditure. Evidence shows that firms using both direct and indirect support often achieve greater additionality in R&D spending than those relying on a single instrument (e.g., Bérubé and Mohnen, 2009; Neicu, 2019). More recently, scholars have examined policy sequencing, whereby firms receive different R&D instruments over time, shaping their innovation trajectories. Lenihan et al. (2024) demonstrate that sequencing R&D policies can be highly effective, with some sequences outperforming others. Extending this insight to the environmental domain, Tchorzewska et al. (2025) argue that "carrots" (subsidies or tax credits) should precede "sticks" (environmental taxes), since financial support first lowers the barrier of high upfront costs, while subsequent taxation reinforces and sustains the transition by making pollution more costly. In addition, beyond general R&D support, recent studies stress the interplay between green and non-green innovation activities. Green technology development often relies on advances in non-green domains, which remain underexplored in debates on the green economy (see, e.g., Barbieri et al., 2023; Ayoub and Lhuillery, 2024).

Our study extends the literature on policy mixes by examining the synergies between emissions pricing and innovation subsidies at the firm level. While previous research suggests that combining environmental and innovation policies can enhance incentives for green innovation at the country or firm level (see, e.g., Fabrizi et al., 2018; Greco et al., 2022), it remains unclear whether these effects hold at the firm level since firm-specific factors – such as financial constraints, technological capabilities, and existing technological trajectories – critically shape responses to policy incentives. Fabrizi et al. (2018) used cross-country panel data to assess how environmental regulatory policies affected green patenting, drawing on the OECD Environmental Policy Stringency (EPS) index. This index includes sub-indices that distinguish between the aggregate stringency of market-based instruments and command-and-control policies, allowing separate analysis of their respective impacts on green innovation. Their analysis showed that market-based instruments were positively associated with green patenting, and they reported a significant interaction effect between regulatory stringency and participation in EU-funded research networks, suggesting complementarity between regulation and research support. Greco et al. (2022) took a firm-level approach using survey data from German firms to examine the effect of a policy mix, where environmental regulation is defined based on firms' self-reported exposure to legal requirements or environmental standards, and policy support includes subsidies or technical assistance for environmental goals. They found that firms exposed to both instruments were more likely to implement process eco-innovations than those exposed to either one alone. While both studies provide valuable evidence of policy complementarity, neither isolates the role of specific emissions pricing mechanisms, such as the EU Emissions Trading System, nor do they test for interaction effects between such pricing instruments and innovation subsidies at the firm level.

For a synergy between emissions pricing and innovation subsidies to exist at the firm level, both policies must influence the same firms. If high-polluting firms – those participating in the EU ETS – actively engage in green innovation in response to both policies, then emissions pricing and subsidies reinforce each other, driving technological change. However, if only non-polluting firms invest in green R&D, then the two policies operate independently rather than complementing each other, and no firm-level synergy emerges. Thus, the key question is whether high-polluting firms – those directly affected by emissions regulations – are incentivized to pursue green innovation when exposed to both policies.

Why might we expect them to do so? One reason is that emissions pricing increases compliance costs, which pushes firms toward cost-minimizing strategies. Without additional financial support, firms may prioritize short-term solutions, such as purchasing allowances or optimizing existing processes, rather than investing in new technologies. However, when subsidies are available, they reduce financial risks and shape the direction of technological change, making firms more likely to develop advanced green technologies rather than settle for incremental efficiency improvements (Bustamante and Zucchi, 2024).

Another reason is that firms are often reluctant to invest in costly innovation without clear long-term incentives. The combination of regulatory pressure and financial support provides a stable investment environment, increasing firms' willingness to commit to green R&D (Li et al., 2025). The presence of both policies ensures that firms do not just innovate for compliance but also develop new technologies with broader applications beyond short-term regulatory needs.

Despite these theoretical reasons for synergy, high-polluting firms may still not engage in green innovation due to path dependency. Recent research suggests that high-polluting firms often focus on enhancing their existing fossil fuel-based technologies rather than transitioning to new, cleaner alternatives (Bolton et al., 2023). Since their production networks and expertise are deeply embedded in carbon-intensive processes, even with financial support, they may prefer investing in technologies that enhance efficiency within their current systems rather than adopting disruptive green innovations. If this is the case, emissions pricing and subsidies do not reinforce each other effectively, as firms subject to regulatory pressure remain locked into brown R&D rather than transitioning to green alternatives. Thus, whether emissions pricing and innovation subsidies work synergistically at the firm level remains an open empirical question.

3. Institutional setting

We investigate the combined effects of the EU ETS and innovation subsidies in Sweden, a country widely recognized as a leader in innovation and environmental policy, making it an ideal case for assessing their impact on green patenting. Sweden consistently ranks among the top-performing nations in R&D intensity and innovation output. Between 2007 and 2018, its Gross Expenditure on R&D as a percentage of GDP averaged 3.27%, compared to 1.93% in the EU27 and 2.33% in the OECD (OECD, 2024). This reflects Sweden's substantial investment in research and innovation, surpassing both EU and OECD averages. Moreover, its R&D funding structure aligns with that of OECD countries,

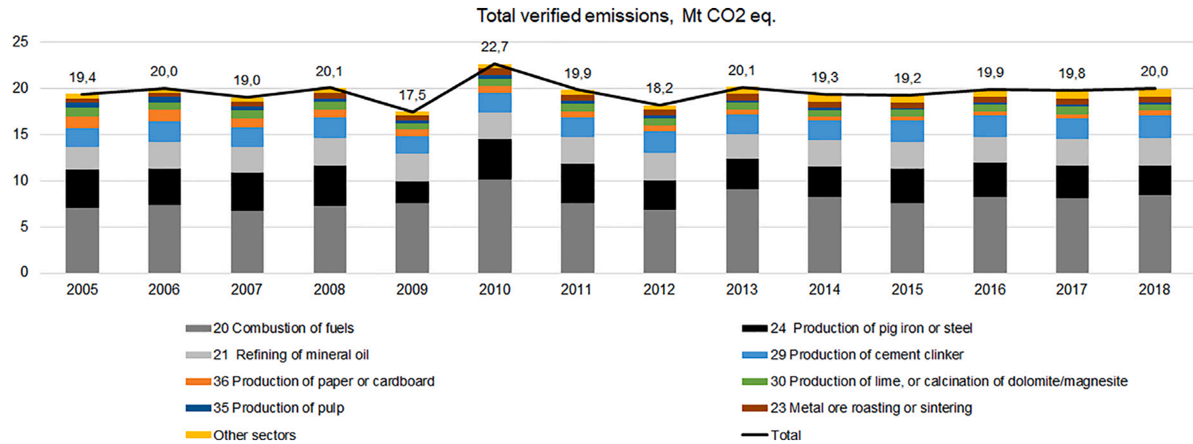

Fig. 1. Total CO_2 emissions under the EU ETS, 2005–2018.
Source: EUTL data viewer (EEA, 2025) and authors' calculations.

where business enterprises play a dominant role, while the public sector accounts for approximately 26% of total R&D expenditure (Torregrosa-Hetland et al., 2019). Sweden also stands out in intellectual property creation, particularly in green technology and high-tech industries. In 2024, its patents and trademarks were 143.1% and 120.6% of the EU average, respectively (European Commission, 2024), underscoring its global competitiveness in innovation. Beyond its innovation strength, Sweden is an environmental frontrunner, known for its early adoption of progressive environmental policies. It was among the first countries to establish comprehensive environmental legislation, create dedicated environmental institutions, and implement tax reforms that shifted the burden from income and capital to energy consumption and emissions (Hysing, 2014). As a member of the European Union, Sweden has also been subject to EU environmental regulations, including the EU ETS.

The EU ETS is the largest international cap-and-trade system in the world and the main policy instrument adopted by the EU's member states in 2005 for decarbonizing their economies. It covers all EU member states plus Iceland, Liechtenstein and Norway. The EU ETS covers more than 10,000 power-generating plants and industrial facilities, representing approximately 40% of the EU's total greenhouse gas emissions.

The EU ETS puts a cap on overall carbon emissions and obliges firms to surrender emission permits, so-called European Union Allowances (EUAs), equal to their emissions (one EUA per ton of CO_2 equivalent emitted) at the end of each compliance year. The EU ETS has been divided into several trading phases, with successively more stringent emissions caps for each phase. Our study fully covers the first two trading phases and six years of the third trading phase.

Swedish CO_2-intensive firms have been covered by the EU ETS since its first phase. About 700 Swedish installations, belonging to about 300 industrial and energy firms, have been regulated by the EU ETS, without significant fluctuations throughout the years. Our analysis covers 294 ETS firms. Historically, Swedish ETS firms were allocated more EUAs than they surrendered (see, e.g., EEA, 2025. Total verified CO_2 emissions, measured in million tonnes of CO_2 equivalent, remained relatively stable during the period 2005–2018 (see Fig. 1). Combustion installations, as well as installations involved in the production of iron or steel, mineral oil refining, and cement clinker production, accounted for over 80% of total emissions.

Finally, although Sweden does not represent the average country regarding R&D investment and environmental policy ambition, its specific context provides valuable insights into the interaction between public innovation subsidies and environmental regulations. Because Sweden has strong policies and a highly innovative industrial sector, it is an ideal case to investigate how these policy instruments contributed and interacted in shaping innovation dynamics. The insights from Sweden's experience can be valuable for other countries looking to strengthen green innovation incentives, particularly those aiming to scale up both R&D support and environmental regulations.

4. Empirical strategy

4.1. The identification of the synergistic effects

Our empirical strategy consists of several steps that reflect the main research questions of our study. First, our goal is to estimate the synergistic effects of subsidies and the EU ETS on firms' green patenting behavior. The main challenge in identifying these effects is that participation in various government subsidy programs is voluntary and, hence, non-random. In this case, if subsidy-ETS firms are systematically different from the remaining firms, we cannot attribute all the potential differences in green innovation activity to the subsidy and ETS status. Because some covariates might differ substantially between the treated and control groups, conventional regression analysis could be sensitive to specification and outliers (Imbens, 2015).

To address non-random selection when estimating our policy-relevant treatment effect, we will restrict our analysis to two firm samples. First, we will analyze firms subject to the EU ETS, distinguishing between those that have received subsidies and those that have not. Second, we will investigate the synergistic effect by analyzing the sample of firms that received subsidies at least once during the period under consideration. Within this sample, we will compare the green innovation activity of firms that received only subsidies with that of firms that received both subsidies and were also subject to the EU ETS.

This approach assumes that ETS firms – with and without subsidies – had similar motivations to apply for various subsidy programs and presumably followed the same parallel trends before receiving subsidies. Similarly, firms in the subsidy sample – under ETS and without EU ETS – might also be comparable in terms of motivation to apply for subsidies and should follow similar innovation trends prior to subsidy treatment. We assess the plausibility of the parallel trends assumption by considering pre-treatment dynamics of green innovation outcomes in Section 6.

Furthermore, to identify the synergistic effects, we exploit the staggered timing of firms' first subsidy receipt. Our empirical framework is based on the difference-in-differences approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups (different groups consist of firms with different starting treatment years). We use the augmented inverse-probability weighting estimator to estimate the dynamic average treatment effects on the treated (ATET) by considering five relative years before the start of treatment and seven relative years after the start of treatment. In addition, we estimate the aggregate average treatment effects on the treated.

4.2. The identification of the effects of the EU ETS

The second step is to estimate the causal effects of the EU ETS on firms' green innovation outcomes. Ideally, we would like to compare ETS firms with non-ETS firms that are similar in all dimensions prior to the implementation of the EU ETS. We try to obtain this by matching ETS firms to similar non-ETS firms, which is a commonly used approach in studies estimating the causal effects of the EU ETS (e.g., Calel and Dechezleprêtre, 2016; Dechezleprêtre et al., 2023). In particular, we adopt the propensity score matching (PSM) approach to ensure similarity between the control and treated groups with respect to all relevant observable characteristics. PSM, a non-parametric estimation method proposed by Rosenbaum and Rubin (1983), is widely used to reduce sample selection bias. Based on all relevant observable characteristics, it identifies a control group with properties similar to those of the treated group. This implies that the treatment variable of interest causes the only difference between the control and the treated group.

Since the choice of the observable covariates in the propensity score model must satisfy the unconfoundedness assumption, selecting covariates is crucial. All the important variables that influence the participation in the EU ETS and the outcome variables should be included. Hence, economic theory, the policy setting, and existing empirical evidence are used as guides. In addition, only variables unaffected by participation should be included in the model. To ensure this, we choose variables fixed over time or measured before participation.

Given that we do not have CO_2 emissions and/or fossil fuel use data for all firms, the propensity scores are measured using annual averages of economic variables, such as production value, labor expenditure, and net investment, for the period 2002–2004 — before the start of the EU ETS in 2005.[1] We also control for the firm's sector as well as for the firm's experience in green innovation activity proxied by the number of green patents granted during the period 2000–2006.

The control group is selected using 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.

After applying matching, we compare the green innovation outcomes of ETS and non-ETS firms before and after the implementation of the EU ETS using Callaway and Sant'Anna's (2021) DID approach as described in Section 4.1. As in the case of the synergistic effects, we estimate the dynamic and aggregate ATETs. The dynamic treatment effects will help us to assess the plausibility of the parallel trends assumption, that is, that in the absence of the EU ETS, conditional on our estimated propensity scores, the potential innovation outcomes of ETS firms would have followed parallel trends with those of matched non-ETS firms.

4.3. The identification of subsidy effects

The next step of our empirical strategy is to estimate the causal effect of subsidies on firms' green innovation outcomes. As before, we apply the staggered timing of firms' first subsidy receipt and estimate the aggregate and dynamic ATETs by using Callaway and Sant'Anna (2021) DID approach.

The aggregate ATET and dynamic ATET of subsidies are estimated by using the full sample and the matched sample of subsidy firms to similar non-subsidy firms. The motivation for using the matched sample is to reduce sample selection bias and to ensure the similarity between the subsidy firm group and the non-subsidy firm group. As mentioned before, we estimate the effects of total direct subsidies and innovation-related subsidies. Furthermore, we perform the equivalent analysis for the energy and transport sectors. From all samples, we exclude firms regulated by the EU ETS to avoid any confounding effects on the outcomes of interest from this policy.

For the analysis with the matched sample, the propensity scores are measured using data for the year 2006. The matching is performed within the sector. The matching variables include the firm size variables, such as production value and labor expenditure. We also consider 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; this increases their likelihood of applying for financial support from subsidy programs. We use the number of green patents granted from 2000–2006 as an experience variable. In addition, we include net investment to control for the financial health of firms, as we expect firms with greater financial resources to be more active in innovation activities than firms with more financial constraints.

As in the case of estimating the effects of the EU ETS, we select the control group using nearest-neighbor matching. Specifically, we use two nearest neighbors to compute the matched outcomes. To ensure the quality of the matches, we apply a caliper of 0.01, which defines the maximum allowed distance for a valid match.

4.4. Heterogeneity analysis

Finally, we performed an heterogeneity analysis to examine how policy impacts vary along three dimensions: the size of subsidy support, firm size, and the timing of treatment across cohorts and over time.

First, we analyze whether firms that received large subsidies between 2007 and 2018 were more active in green patenting than firms without subsidies. To this end, we classify firms into two groups—large-subsidy firms and other firms—based on the total amount of direct subsidies received over the sample period. Firms receiving more than SEK 1 million in total subsidies are defined as large-subsidy recipients. Although this threshold is somewhat data-driven, it aligns well with the distribution of subsidies in our dataset. The same cut-off is applied to innovation-specific subsidies, and firms with small subsidies (less than SEK 1 million) are excluded from this analysis.

Second, we examine whether policy effects differ by firm size. Firms are grouped into three categories based on their average employment level during the observed period: large firms (at least 250 employees), medium-sized firms (51–249 employees), and small firms (50 or fewer employees). This classification captures relevant variation in firm size while ensuring sufficient observations within each category.

As in the main analysis, we estimate both aggregate and dynamic ATETs by subsidy and firm size using the full and matched samples (excluding ETS firms when appropriate), applying the same matching procedure described in Section 4.3.

Finally, we explore heterogeneity across treatment cohorts and calendar years, estimating cohort-specific and time-specific ATETs to assess whether the effects of subsidies and their interaction with the EU ETS vary with the timing of policy exposure.

5. Data

5.1. Data sources

We collected our data from four sources. Firm-level variables, such as production value, labor cost, investment, and firm sectoral classification were obtained from Statistics Sweden's (SS) Business Register, which contains all Sweden's companies, authorities and organizations.

[1] We considered 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 onward and only for a subset of firms, while stationary CO_2 emissions data is limited to an even smaller sample of firms.

The data on green patents granted to Swedish firms were purchased from the Swedish Intellectual Property Office (Patent och Registrerings Verket, PRV). The PRV provided data on patents granted by the PRV and the European Patent Office (EPO). All patents filed at EPO and PRV are categorized using the Cooperative Patent Classification (CPC), which includes a class Y02 pertaining to 'technologies or applications for mitigation or adaptation against climate change'. The Y02 class provides the most accurate tagging of climate change mitigation and adaptation patents available today and is becoming the international standard for climate and green innovation studies (see, e.g., Calel and Dechezleprêtre, 2016. A complete list of Y02 subclasses used in this analysis is provided by Coria and Jaraite (2024).

The list of Swedish firms regulated by the EU ETS was obtained from the European Union Transaction Log (EUTL). The EUTL tracks the implementation of the EU ETS across all regulated entities on annual basis.

Subsidy data was received from the Micro Database of State Aid to Industry (so-called MISS database), managed by the Swedish Agency for Growth Policy Analysis (Tillväxtanalys). The MISS database includes direct subsidy programs from the Swedish Energy Agency (SEA), the Swedish Innovation Agency (Vinnova), and the Swedish Agency for Economic and Regional Growth (TVV). These agencies play a central role in financing innovation, collectively providing the vast majority of government funding allocated to firms through both national and EU sources (see the Supplementary Material for more information about the structure of funding for research and innovation in Sweden).

The MISS database contains separate data tables for each support program. Most data tables contain information about firm organization, project number, project name, date when a firm applied for a particular support, total amount granted, and amount paid during the year. However, for some support programs, the information provided does not allow for determining the exact firm-year support amounts.[2]

For our analysis, we organized the subsidy data in several steps. First, we focused exclusively on subsidy programs that provide direct grants to firms. Second, we selected only those direct support programs that allowed us to aggregate subsidies at the firm-year level. Third, we categorized each subsidy program/project into innovation versus non-innovation by collecting additional information about the scope of support programs from actual program calls and, if available, from the names of funded projects. This process led to two firm-level variables: total direct subsidies and innovation-related direct subsidies.

In our analysis, we considered firm-level data for 2000–2018. Subsidy data were available from 2007 onward. This means that we did not observe subsidy payments for the period 2000–2006. In our empirical analysis, we considered all firms that operate in the manufacturing, energy, waste and water sectors, corresponding to SNI codes 05 to 39 in the Swedish Industrial Classification. These codes cover a broad range of industries, including mining and quarrying (05–09), manufacturing (10–33), including pulp and paper (17), petroleum refining (19), chemicals (20–21), nonmetallic minerals (23), metals (24–25), machinery, transport and other manufacturing (28–33), electricity, gas and steam supply (35), and water and waste sectors (36–39). In total, our sample consists of 806,668 firm-year observations and covers about 73% of patents granted during the period 2000–2018 and 40% of subsidies distributed during the period 2007–2018.

5.2. Descriptive statistics

Table 1 describes the main variables of interest across four firm policy-mix groups: (1) "ETS and subsidy firms", (2) "subsidy-only firms", (3) "ETS-only firms", and (4) "no ETS and no subsidy firms". Table 1 presents information on both the treatment and outcome variables. The treatment variables comprise total subsidies, innovation subsidies, and a dummy variable indicating whether a firm is regulated under the EU ETS or not. We consider three outcome variables: the number of green patents granted, the number of citations that green patents received, and the number of technical classes assigned to the patents. Patent citations measure patent quality and knowledge spillovers, as highly cited patents indicate greater technological impact and influence on subsequent innovations. Meanwhile, technological classes capture the breadth of applicability, where patents classified across multiple fields suggest a higher degree of generality and cross-sectoral relevance (Barbieri et al., 2020). Total and innovation subsidies are expected to positively affect all these dimensions. However, larger subsidies might provide firms with the financial capacity to engage in higher-risk, novel innovations that are more likely to be granted patents, accumulate citations, and generate broader technological spillovers.[3] The remaining variables listed in Table 1 are the covariates used to estimate propensity scores, which are employed to construct the control groups in the matched sample analysis.

From Table 1, we observe that the group "ETS and subsidy firms" on average received larger amounts of total subsidies and innovation subsidies than the group "subsidy-only firms" (MSEK 1.457 vs. MSEK 0.128 of total subsidies, MSEK 0.990 vs. MSEK 0.069 of innovation subsidies). Fig. 2 compares the average annual total subsidies (black bars) and innovation-related subsidies (gray bars) received by the two groups of firms over the 2007–2018 period. "ETS and subsidy firms" received substantially higher average total and innovation subsidies throughout the period, peaking in 2011, with average total subsidies exceeding 4.5 MSEK and innovation subsidies reaching nearly 4 MSEK. After 2011, both types of subsidies declined but remained consistent (see panel A in Fig. 2). In contrast, "subsidy-only firms" received considerably lower subsidy amounts across all years, with both total and innovation subsidies averaging well below 0.5 MSEK per year (see panel B in Fig. 2).

"ETS and subsidy firms" were also more active in green patenting. For example, during the period 2000–2018, they had, on average, 0.473 green patents, while "subsidy-only firms" and "ETS-only firms" had 0.009 and 0.001 green patents, respectively. Similar patterns are observed when we compare the number of patent citations and the number of technical classes assigned to green patents granted across firms with different policy mixes. Fig. 3 presents the average number of green patents granted for firms with different policy mixes during the period 2000–2018. We observe that, on average, "ETS and subsidy firms" patented considerably more green technologies than other firms during the entire period under consideration. Patenting activity has increased for "ETS and subsidy" firms since 2012, while "subsidy-only firms" were patenting more green technologies during the years 2000–2004 and from 2015 onward (see panels A and B in Fig. 3). Patenting activity of other firm groups – "ETS-only firms" and "no ETS and no subsidy firms" – exhibits no distinct patterns. Furthermore, "ETS and subsidy firms" were, on average, larger in production value, labor expenditure, and net investment than "subsidy-only firms" or "ETS-only firms"or "no ETS and no subsidy firms".

Finally, Fig. 4 displays the distribution of subsidies (both total and average per firm) and the number of green patents granted (both total and average per firm) across the sectors under consideration. The machinery and transport sector stands out as the largest recipient of both total and innovation-related subsidies and also as the sector with

[2] A more detailed description of the MISS database and how we organized subsidy data for our research purposes is provided in Coria and Jaraite (2024).

[3] As explained previously, emissions pricing under the EU ETS may have a more uncertain impact on all these outcomes, as firms might prioritize sector-specific compliance strategies rather than pursuing broad, high-impact innovations. The interaction between subsidies and the EU ETS could enhance these outcomes if highly polluting firms are also the ones driving green innovation and use subsidies to develop transformative technologies with spillover effects. However, if highly polluting firms are not the primary green innovators, then a synergistic effect should not be expected.

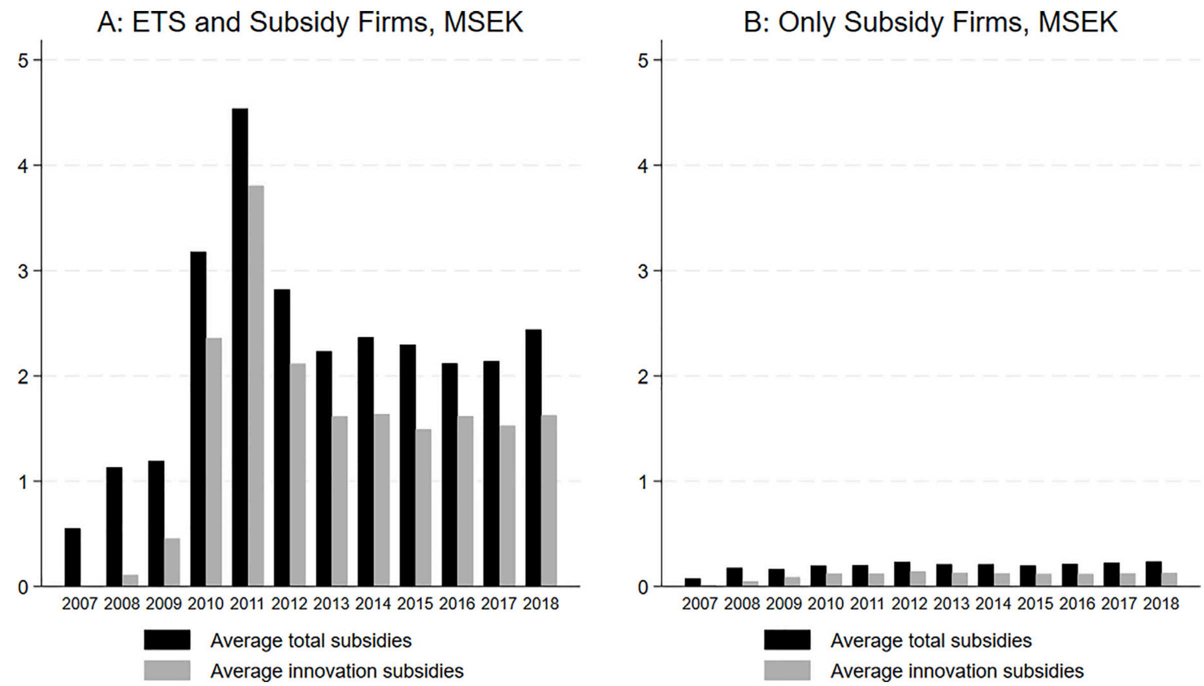

Fig. 2. Average Subsidies Over Time.
Source: Authors' calculations using MISS subsidy data.

the highest number of patented green technologies (see Panels A and C in Fig. 4). Sectors that, on average, received more innovation-related subsidies, such as computers and electronic products, and machinery and transport, also tend to exhibit higher average patenting output, suggesting a potential link between innovation subsidies and green innovation (see Panels B and D in Fig. 4). However, despite receiving the largest average innovation subsidies, firms in the electricity and gas sector show limited patenting activity, possibly indicating a different focus for the subsidies received.

The patterns described above also suggest that the sectors receiving the most innovation-related subsidies and producing the most green patents, such as machinery and transport, and computers and electronics, are not the ones responsible for most industrial CO_2 emissions. As described in Section 3, Sweden's highest-emitting sectors include combustion, iron and steel, oil refining, and cement production. These sectors, although covered by the EU ETS, show little green patenting activity. While there is some overlap between EU ETS firms and subsidy recipients, the firms with the highest CO_2 emissions under the EU ETS are generally not those receiving substantial innovation subsidies or producing green patents. This limited overlap suggests that we should not necessarily expect a synergistic effect between the two policies at the firm level.

6. Results

6.1. The synergistic effects of subsidies and the EU ETS

In this section, we present the results for the synergistic ATETs by using ETS firm sample and subsidy firm sample. In other words, this analysis provides estimates of the ATETs of receiving subsidies on green innovation outcomes for firms subject to the EU ETS, and conversely, the effects of EU ETS participation for firms that received subsidies.

A close inspection of the dynamic synergistic ATETs confirms the absence of pre-trends across all green innovation outcome measures, at least over the five pre-treatment periods observed in our data (see Figures A1–A6 in Appendix A).[4] Furthermore, the dynamic ATET estimates do not provide evidence of synergistic effects in either the ETS firm sample or the subsidy firm sample. In other words, ETS firms did not exhibit increased green innovation activity after receiving subsidies, nor did subsidy firms show greater engagement in green innovation after their inclusion in the EU ETS.

Table 2 presents the aggregate ATETs across our three outcome variables, where we also report results across four columns, each representing a different specification of the outcome variables. Column 1 measures contemporaneous effects in the year of first subsidy receipt. Column 2 captures forward effects by shifting the outcome variables two years ahead, accounting for implementation and patenting lags. Column 3 presents accumulated outcomes, summing each innovation measure over all post-treatment years, reflecting the cumulative nature of innovation activity. Finally, Column 4 considers the forward-lagged version of the accumulated outcomes, capturing the delayed build-up of cumulative innovation effects.

We begin by comparing firms subject to the EU ETS that received subsidies to those that did not (see Panel A in Table 2). Across all panels and outcome variables, we find no strong evidence of the synergistic effect. In the case of granted patents and technical classes, the ATET estimates are positive in most specifications but small and statistically insignificant. For example, in Column 1, the ATET for granted patents is 0.57 for ETS & subsidy firms and 0.64 for ETS & innovation subsidy firms, with standard errors exceeding the point estimates in both cases. The results for patent citations and technical classes are similar: the estimated ATETs are positive, but large standard errors make these estimates statistically insignificant. In Column 3, which considers accumulated outcomes, we observe a relatively large estimate for citations among ETS & subsidy firms (ATET = 20.58), statistically significant

[4] To preserve space, we provide all figures with dynamic ATETs in Appendices A–D.

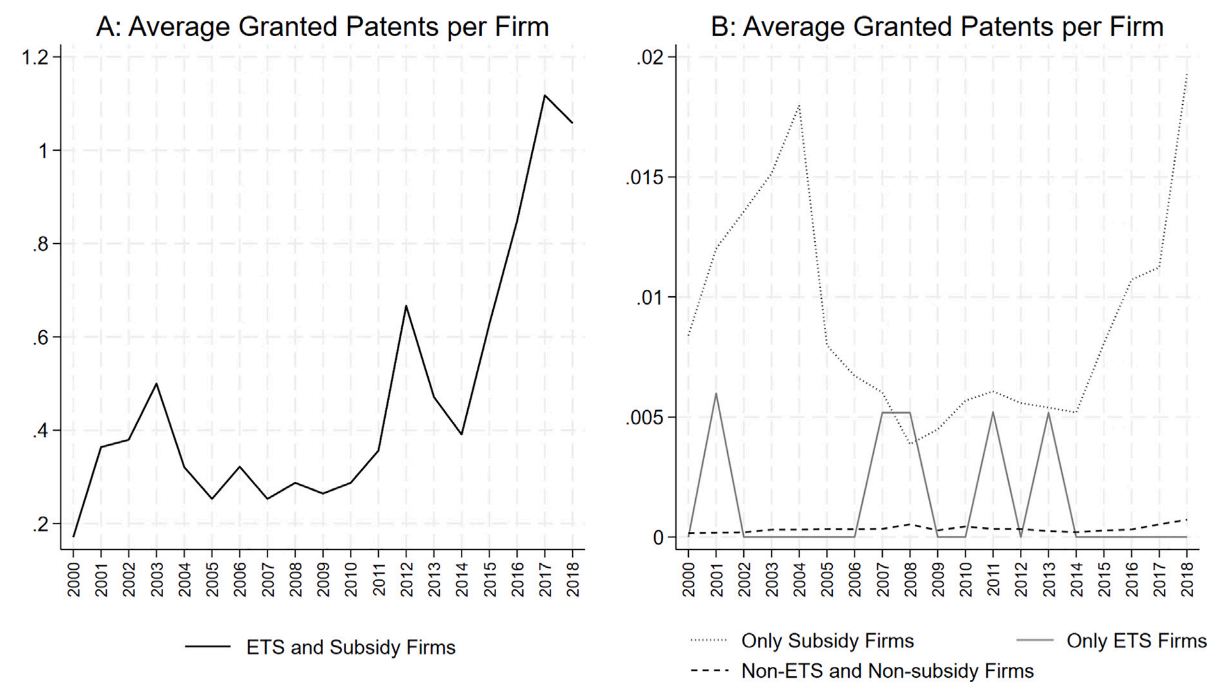

Fig. 3. Average Green Patent Counts Across Firms with Different Policy Exposure.
Source: Authors' calculations using PRV patent data.

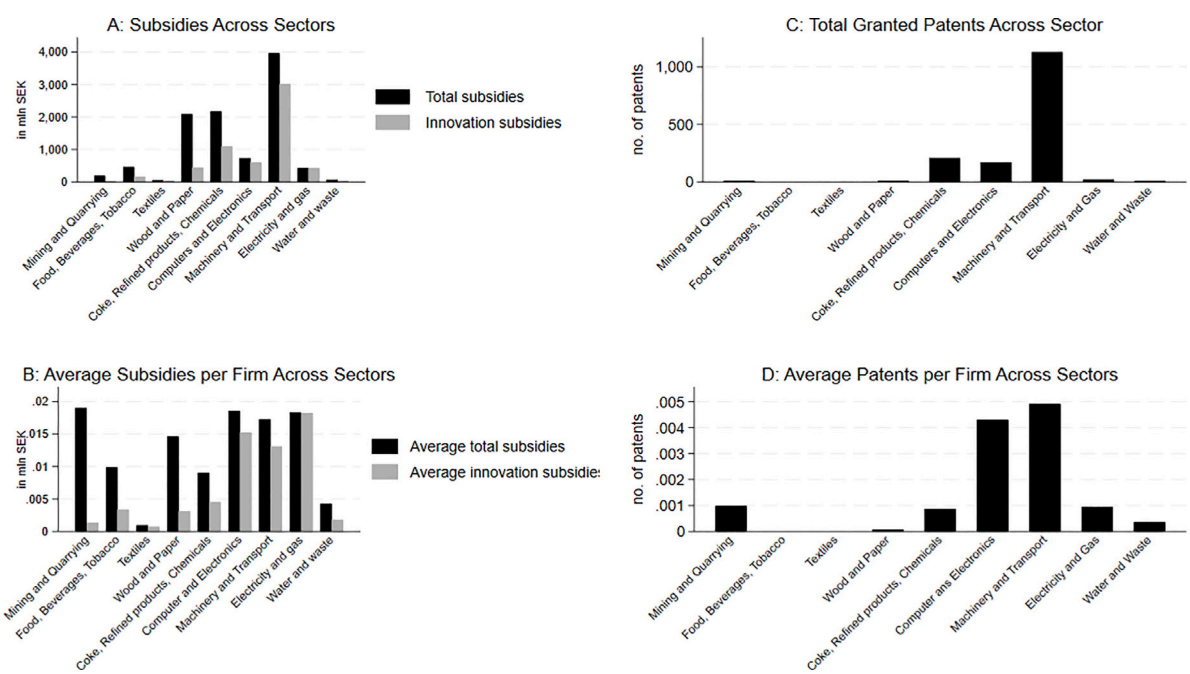

Fig. 4. Subsidies and Green Patents Across Sectors.
Source: Authors' calculations using PRV patent data and MISS subsidy data.

at the 10% level. However, the effect is not consistently observed across other cols or subsamples, limiting the strength of this finding. Overall, these results suggest that among ETS-regulated firms, those that received subsidies do not systematically innovate more – at least in terms of green patents, citations, or technical scope – than their non-subsidized counterparts.

Next, we restrict the sample to firms that received at least one subsidy during the observation period and compare those subject to the EU ETS with those that were not (see Panel B in Table 2). This analysis is first conducted using the full sample of firms across all sectors, and then only for firms operating in the energy and transport sectors, where most Swedish green patents are concentrated.

Across all outcome dimensions and columns in the full sample, we again find no robust evidence of the synergistic effect. The estimated aggregate ATETs for subsidy & ETS firms are generally small and statistically insignificant when compared to those of subsidy-only firms. Interestingly, in the energy and transport sector subsample, the estimated aggregate ATETs for subsidy & ETS firms are somewhat

Table 1
Descriptive statistics: firms with different policy mixes.

	ETS and subsidy firms			Subsidy firms only			ETS firms only			Non-ETS and non-subsidy firms		
	Mean	Std. dev.	N	Mean	Std. dev.	N	Mean	Std. dev.	N	Mean	Std. dev.	N
Treatment variables												
Total subsidies	1.457	8.497	1606	0.128	1.101	61 131	0	0	3532	0	0	740 399
Innovation subsidies	0.990	8.157	1606	0.069	0.892	61 131	0	0	3532	0	0	740 399
ETS dummy	1	1	1606	0.000	0.000	61 131	1	0	3532	0	0	740 399
Outcome variables												
Green patents	0.473	4.538	1606	0.009	0.225	61 131	0.001	0.038	3532	0.0003	0.036	740 399
Citations	2.405	19.009	1606	0.090	3.156	61 131	0.008	0.291	3532	0.0022	0.286	740 399
Technical classes	7.554	123.555	1606	0.126	4.605	61 131	0.010	0.298	3532	0.0040	0.542	740 399
Other variables												
Production value	5536.58	13 000.00	1552	164.23	1751.65	60 894	648.14	1299.30	3384	15.14	15.14	740 193
Net investment	333.48	981.51	1552	6.08	63.47	60 894	74.46	239.25	3384	0.71	0.71	740 193
Wages	485.51	1117.89	1552	23.01	208.84	60 894	61.78	117.75	3384	2.25	2.25	740 193

Notes: All monetary variables are measured in millions of SEK. The table is compiled by the authors.

larger, particularly for citations and technical classes. However, these estimates remain statistically insignificant, providing no evidence of the synergistic effect within these high-innovation sectors.

Thus, across both comparisons – ETS firms with and without subsidies, and subsidized firms with and without participation in the ETS – we find no statistically significant evidence of the synergistic effect between the EU ETS and subsidies. While there are isolated instances of large point estimates, particularly for accumulated citation-based outcomes, these effects are not robust across the different outcome variables or timing specifications. Taken together, the findings suggest that being subject to both policy instruments does not lead to greater green innovation performance than being subject to only one policy. In other words, ETS-subsidy firms and single-policy firms were driven by similar incentives to pursue green innovation activities. This conclusion holds across all three green innovation outcome measures, across all four timing specifications, and for both total and innovation-related subsidies.

6.2. The effects of the EU ETS

Table 3 presents the estimated aggregate ATETs of the EU ETS on green innovation outcomes. These estimates are based on matched samples using propensity score matching, followed by DID estimation using the approach of Callaway and Sant'Anna (2021). To ensure that ETS and non-ETS firm groups were properly balanced, we followed a common procedure for estimating the standardized bias before and after matching. The main values of the variables used in matching did not present significant differences between the treated and control groups (see Table F1 in Appendix E for the summary of matching quality). Furthermore, the dynamic synergistic ATETs confirm the absence of pre-trends across all green innovation outcome measures (see Appendix B), supporting the validity of our identification strategy.

As before, we evaluate three outcome variables and four timing specifications. Across all outcome variables and timing specifications, we find no statistically significant effect of EU ETS participation on firms' green innovation activities. For granted patents, the estimated aggregate ATETs are nearly zero and statistically insignificant in all columns. For example, in Column 1, the estimate is 0.02 with a standard error of 0.03, and in Column 3, the accumulated effect is −0.01 with a standard error of 0.25.

Similarly, we find no significant effects on patent citations or technical patent scope. The estimated aggregate ATETs for citations range from −0.44 to 0.09 across panels, with standard errors too large to draw meaningful inferences. Technical class estimates are slightly more negative, ranging from −0.13 to −0.59, but again remain statistically insignificant due to large standard errors.

Taken together, these results suggest that EU ETS participation has not led to measurable improvements in either the quantity or the quality of green patenting among Swedish firms. This aligns with earlier findings in the literature that point to limited or even negative innovation responses under cap-and-trade systems, potentially reflecting a preference among firms to comply through cost-effective adoption of existing technologies rather than through investment in new patentable innovations.

6.3. The effects of subsidies on Green innovation outcomes

Table 4 presents the estimated aggregate ATETs of receiving subsidies on firms' green innovation outcomes. Panel A of the table reports results from the full firm sample analysis, while Panel B presents estimates using the matched firm sample. As before, we also report results for the subsample of firms in the energy and transport sectors, where most Swedish green patents are concentrated. We distinguish between general subsidies and innovation-specific subsidies.

Before we delve into summarizing the aggregated ATETs, it is important to note that the dynamic ATETs support the parallel trends assumption for all green innovation outcomes during the pre-treatment period for both the full and matched samples (see Appendix C). This consistency across the samples suggests that selection into subsidies is unlikely to bias the estimated ATETs. As a result, the estimated treatment effects of subsidies based on the full sample can be interpreted as credible and robust.

In the unmatched analysis based on the full sample, we find consistent evidence that total subsidies are positively associated with green innovation (see Panel A of Table 4). The estimated aggregate ATETs are statistically significant in most columns, with the largest effects observed in Column 3, which reflects accumulated green patent outcomes. Here, the ATET reaches 0.03 for granted patents, 0.42 for citations, and 0.61 for technical classes. These results suggest that total subsidies contribute not only to increased green patenting activity but also to more impactful and technologically diverse innovations. The results are similar in the energy and transport sector subsample. For example, in Column 3, the ATET for citations is 1.21 and for technical classes 1.84, pointing to particularly strong effects in these key innovation-intensive sectors.

Innovation-related subsidies show more variable results. In the full sample, we find statistically significant ATETs for the number of accumulated citations (0.41) and the number of accumulated technical classes (0.62), while the effect on accumulated granted patents is smaller and only marginally significant. In the energy and transport subsample, the estimates of ATETs for cumulative green patent outcomes are also positive and statistically significant.

The matched sample results, reported in Panel B of Table 4, generally confirm the direction of the effects, though magnitudes are smaller and fewer estimates are statistically significant. For total subsidies, we find the positive aggregate ATETs for all outcomes in Column 3, including 0.010 for granted patents, 0.14 for citations, and 0.20 for

Table 2
The Synergistic Aggregate ATETs across Firm Groups and Green Innovation Metrics.

		1 Patents	2 Forw. Patents	3 Cum. Patents	4 Forw. Cum. Patents
A: ETS Firm Sample: ETS vs. ETS&Subsidies					
Granted Patents					
ETS & Subsidy (N = 5 138)	ATET	0.57	0.40	5.02	3.22
	s.e.	0.71	0.46	4.60	3.51
ETS & Innovation Subsidies (N = 5 138)	ATET	0.64	0.57	5.58	3.04
	s.e.	0.73	0.60	5.26	3.60
Citations					
ETS & Subsidy (N = 5 138)	ATET	0.72	1.94	20.58*	11.40
	s.e.	3.01	2.60	12.36	11.00
ETS & Innovation Subsidies (N = 5 138)	ATET	0.33	−0.98	23.34	6.02
	s.e.	4.83	2.04	16.56	12.12
Technical Classes					
ETS & Subsidy (N = 5 138)	ATET	15.06	17.75	58.30	49.68
	s.e.	18.51	18.35	53.29	51.92
ETS & Innovation Subsidies (N = 5 138)	ATET	23.52	17.66	77.12	59.18
	s.e.	25.12	17.34	72.82	63.29
B: Subsidy Firm Sample: Subsidies vs. Subsidies&ETS					
Granted Patents					
Subsidy & ETS (N = 62 737)	ATET	0.57	0.40	4.99	3.21
	s.e.	0.71	0.46	4.60	3.51
Subsidy & ETS, Energy and Transport (N = 18 371)	ATET	2.13	1.45	14.84	10.67
	s.e.	2.12	1.38	13.95	10.64
Innovation Subsidies & ETS (N = 55 332)	ATET	0.71	0.52	6.22	4.02
	s.e.	0.88	0.57	5.74	4.40
Innovation Subsidies & ETS, Energy and Transport (N = 16 978)	ATET	2.13	1.45	14.84	10.67
	s.e.	2.12	1.38	13.95	10.64
Citations					
Subsidy & ETS (N = 62 737)	ATET	0.71	1.91	20.38*	11.40
	s.e.	3.01	2.60	12.30	11.00
Subsidy & ETS, Energy and Transport (N = 18 371)	ATET	7.96	8.10	39.11	27.21
	s.e.	7.50	7.48	34.45	31.83
Innovation Subsidies & ETS (N = 55 332)	ATET	0.84	2.65	25.12	14.13
	s.e.	3.76	3.23	15.31	13.71
Innovation Subsidies & ETS, Energy and Transport (N = 16 978)	ATET	7.96	8.10	39.11	27.21
	s.e.	7.50	7.48	34.45	31.83
Technical Classes					
Subsidy & ETS (N = 62 737)	ATET	15.01	17.70	57.92	49.55
	s.e.	18.51	18.35	53.27	51.90
Subsidy & ETS, Energy and Transport (N = 18 371)	ATET	56.64	58.46	172.60	159.94
	s.e.	55.67	55.44	161.44	157.45
Innovation Subsidies & ETS (N = 55 332)	ATET	22.33	72.26	72.26	62.04
	s.e.	22.90	64.44	64.44	64.80
Innovation Subsidies & ETS, Energy and Transport (N = 16 978)	ATET	56.64	58.46	172.60	159.94
	s.e.	55.67	55.44	161.44	157.45

Notes: This table reports the aggregate ATETs estimated by using the DID approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups. We use the augmented inverse-probability weighting estimator. Panel A summarizes the aggregate ATETs from the ETS firm sample, Panel B summarizes the aggregate ATETs for subsidy firm sample. Column 1 represents results for the number of green patents granted (citations or technical classes); Column 2 for the number of green patents granted (citations or technical classes) forwarded by 2 years; Column 3 for the number of cumulative green patents granted (citations or technical classes); Column 4 for the number of cumulative green patents granted (citations or technical classes) forwarded by 2 years. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

technical classes. The estimates for the energy and transport subsample are positive but not statistically different from zero.

Innovation-related subsidies in the matched sample yield weaker results overall. Most estimates are small and not statistically significant, except for a modest effect on accumulated technical classes in Column 3 (ATET = 0.12), which is also insignificant.

Overall, the results indicate that total subsidies are positively associated with green innovation, particularly when considering cumulative outcomes. These effects are more pronounced in the full sample and the energy and transport sectors. In contrast, innovation-related subsidies appear to have slightly smaller and less significant effects, especially after accounting for selection into treatment through matching.

6.4. Heterogeneity analysis

We next examine how the estimated policy effects vary along three dimensions: the size of subsidy support, firm size, and the timing of treatment across cohorts and over time.

6.4.1. The effects of large subsidies on Green innovation outcomes

We assess whether receiving large subsidies, as opposed to no subsidies, is associated with larger green innovation outcomes. Table 5 reports the aggregate ATET across our three outcome variables and timing specifications. Results are presented separately for the full sample (see Panel A) and the matched sample (see Panel B). Appendix

Table 3
The Aggregate ATETs of the EU ETS.

		1 Patents	2 Forw. Patents	3 Cum. Patents	4 Forw. Cum. Patents
ETS vs. non-ETS					
Granted Patents					
ETS (N = 5 658)	ATET	0.02	−0.04	−0.01	−0.03
	s.e.	0.03	0.03	0.25	0.08
Citations					
ETS (N = 5 658)	ATET	−0.08	−0.41	0.09	−0.44
	s.e.	0.24	0.44	1.37	1.03
Technical Classes					
ETS (N = 5 658)	ATET	−0.32	−0.42	−0.13	−0.59
	s.e.	0.48	0.44	1.96	1.53

Notes: This table reports the aggregate ATETs of the EU ETS estimated by using the DID approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups. We use the augmented inverse-probability weighting estimator. The results are reported for the matched sample. Column 1 represents results for the number of green patents granted (citations or technical classes); Column 2 for the number of green patents granted (citations or technical classes) forwarded by 2 years; Column 3 for the number of cumulative green patents granted (citations or technical classes); Column 4 for the number of cumulative green patents granted (citations or technical classes) forwarded by 2 years. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

D summarizes the dynamic ATETs of large subsidies, which, as in the case of subsidies and innovation subsidies, lend support for the parallel trends assumption for all green innovation outcomes during the pre-treatment period for both the full and matched samples.

In the unmatched sample, we find that large total subsidies are positively and significantly associated with green innovation. The effects are most pronounced for accumulated green innovation outcomes (Column 3), where the estimated aggregate ATETs reach 0.01 for granted patents and 1.82 for technical classes. Innovation-specific subsidies yield a similar pattern, with statistically significant effects on technical classes (2.21) and a smaller effect on granted patents (0.11). These results suggest that larger subsidies are associated with more sustained and technologically diverse green innovation.

In the matched sample, the estimated effects are smaller and generally not statistically significant. For total subsidies, we observe the positive estimated aggregate ATETs across most green innovation outcomes, but they are statistically insignificant. For innovation subsidies, the only statistically significant effect is for citations (ATET = 0.05), suggesting a modest effect of large subsidies on patent quality.

Taken together, the results suggest that large subsidies compared to no subsidies helped stimulate green innovation, particularly when considering cumulative impacts. However, these effects are no longer statistically significant in the matched sample, where the analysis is limited to a smaller set of firms matched within industrial sectors. This matching strategy improves comparability but also reduces sample size and restricts variation in subsidy levels, which may attenuate the estimated effects due to lower statistical power.

6.4.2. The effects of subsidies across firms of different sizes

Further, we investigate whether the impacts of subsidies differ by firm size.[5] The results are presented separately for the full sample (Table 6) and the matched sample (Table 7). The dynamic ATETs for small, medium, and large firms, shown in Figures S1–S12 in the Supplementary Material, support the absence of pre-trends across all size categories and outcome measures.

In the unmatched sample, we find that total subsidies are positively and significantly associated with green innovation outcomes for the sample of large firms. The estimated aggregate ATETs reach 0.10 for granted patents, 1.85 for citations, and 2.90 for technical classes (Table 6, Panel A, Column 1). Innovation-specific subsidies yield a similar pattern (Table 6, Panel B, Column 1), with larger statistically significant effects; 0.22 for granted patents, 3.47 for citations, and 5.83 for technical classes. In general, these findings indicate that large companies benefited more from total and innovation subsidies in terms of green innovation outcomes than medium and small companies. This result may reflect large firms' stronger ability to absorb and apply new knowledge, better access to complementary resources, and greater administrative capacity to obtain and manage public funding, allowing them to translate subsidies into more substantial innovation outcomes.

In the matched sample, where treated and control firms are more comparable, the estimated effects are smaller. For total subsidies (Table 7, Panel A, Column 1), we find positive and statistically significant aggregate ATETs for large firms in terms of granted patents (0.06) and technical classes (1.44). In contrast, the estimated effects of innovation subsidies are smaller and generally not statistically significant (Table 7, Panel B, Column 1).

Overall, the results suggest that total subsidies are more effective for large firms, likely due to scale economies, stronger innovation capabilities, and administrative advantages in obtaining and managing public support.

6.4.3. The synergistic effects and subsidy effects across time and different cohorts

Finally, we also explore whether the effectiveness of subsidies and their potential interaction with the EU ETS vary across time and across treatment cohorts. Treatment cohorts are defined as groups of firms that first received subsidies in different years, resulting in twelve cohorts (2007–2018). Cohort t thus includes firms that were first subsidized in year t. We estimate separate average treatment effects on the treated for each cohort and over calendar years to capture possible differences in the timing and persistence of policy impacts.

This analysis is motivated by the possibility that policy effects are state-dependent, meaning that the effectiveness of subsidies and environmental regulation may vary with macroeconomic conditions at the time of subsidy receipt. For instance, during recessions, firms tend to be more credit-constrained, risk-averse, and less inclined to invest in long-term R&D, which may dampen their responsiveness to policy incentives; see, e.g., Wilson (2012), and Chodorow-Reich (2019). Conversely, in more favorable economic environments, firms may be better positioned to leverage public support for innovation.

Several features of our empirical design mitigate the risk that different macroeconomic conditions at the time of subsidy receipt drive our results. Year fixed effects capture shocks common to all firms in a given year, while our within-sector matching ensures that treated and control firms are compared within the same industries. Consequently,

[5] We did not perform a comparable analysis for the interaction between subsidies and the EU ETS, since most ETS firms fall into the large-firm category according to our classification.

Table 4
The Aggregate ATETs of Subsidies across Firm Groups and Green Innovation Metrics.

		1 Patents	2 Forw. Patents	3 Cum. Patents	4 Forw. Cum. Patents
A: Full Sample: Subsidies vs. Non Subsidies					
Granted Patents					
Subsidy (N = 801 329)	ATET	0.003*	0.005*	0.03*	0.002
	s.e.	0.002	0.003	0.02	0.001
Subsidy, Energy and Transport (N = 249 964)	ATET	0.008*	0.02	0.10	0.04
	s.e.	0.004	0.01	0.06	0.03
Innovation Subsidies (N = 794 099)	ATET	0.005	0.000	0.03*	−0.01
	s.e.	0.004	0.002	0.02	0.01
Innovation Subsidies, Energy and Transport (N = 248 571)	ATET	0.015	−0.003	0.089*	0.009
	s.e.	0.012	0.004	0.052	0.019
Citations					
Subsidy (N = 801 329)	ATET	0.06**	0.08*	0.42*	0.13
	s.e.	0.03	0.04	0.22	0.15
Subsidy, Energy and Transport (N = 249 964)	ATET	0.14**	0.21	1.21	0.72
	s.e.	0.06	0.13	0.73	0.47
Innovation Subsidies (N = 794 099)	ATET	0.10*	−0.02	0.41**	0.01
	s.e.	0.05	0.04	0.20	0.12
Innovation Subsidies, Energy and Transport (N = 248 571)	ATET	0.24	−0.11	1.11*	0.37
	s.e.	0.15	0.09	0.67	0.33
Technical Classes					
Subsidy (N = 801 329)	ATET	0.10**	0.14*	0.61*	0.28
	s.e.	0.05	0.08	0.31	0.21
Subsidy, Energy and Transport (N = 249 964)	ATET	0.28*	0.42	1.84*	1.09
	s.e.	0.14	0.27	1.06	0.71
Innovation Subsidies (N = 794 099)	ATET	0.16	−0.01	0.62**	0.14
	s.e.	0.10	0.05	0.30	0.15
Innovation Subsidies, Energy and Transport (N = 248 571)	ATET	0.44	−0.09	1.81*	0.63
	s.e.	0.31	0.15	0.99	0.47
B: Matched Sample: Subsidies vs. Non Subsidies					
Granted Patents					
Subsidy (N = 139 043)	ATET	0.001	0.001	0.010**	0.003
	s.e.	0.001	0.001	0.004	0.003
Subsidy, Energy and Transport (N = 39 693)	ATET	0.003	0.003	0.022	0.008
	s.e.	0.003	0.002	0.014	0.009
Innovation Subsidies (N = 124 137)	ATET	0.000	−0.002	0.005	−0.002
	s.e.	0.001	0.001	0.004	0.000
Innovation Subsidies, Energy and Transport (N = 29 339)	ATET	0.02	0.00	0.01	−0.003
	s.e.	0.02	0.00	0.01	0.007
Citations					
Subsidy (N = 139 043)	ATET	0.03**	0.01	0.14*	0.07
	s.e.	0.01	0.02	0.08	0.05
Subsidy, Energy and Transport (N = 39 693)	ATET	0.07	0.04*	0.36	0.22
	s.e.	0.04	0.02	0.26	0.18
Innovation Subsidies (N = 124 137)	ATET	0.02	−0.01	0.12	0.04
	s.e.	0.01	0.02	0.09	0.06
Innovation Subsidies, Energy and Transport (N = 29 339)	ATET	0.05	0.02*	0.19	0.01
	s.e.	0.04	0.01	0.28	0.18
Technical Classes					
Subsidy (N = 139 043)	ATET	0.03*	0.02	0.20*	0.10
	s.e.	0.02	0.02	0.11	0.08
Subsidy, Energy and Transport (N = 39 693)	ATET	0.10*	0.08	0.56	0.31
	s.e.	0.06	0.05	0.36	0.29
Innovation Subsidies (N = 124 137)	ATET	0.01	−0.02	0.12	0.002
	s.e.	0.02	0.02	0.09	0.05
Innovation Subsidies, Energy and Transport (N = 29 339)	ATET	0.04	0.001	0.27	0.02
	s.e.	0.05	0.04	0.30	0.18

Notes: This table reports the aggregate ATETs of subsidies and innovation subsidies estimated by using the DID approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups. We use the augmented inverse-probability weighting estimator. Panel A summarizes the aggregate ATETs from the full firm sample, Panel B summarizes the aggregate ATETs for the matched firm sample. Column 1 represents results for the number of green patents granted (citations or technical classes); Column 2 for the number of green patents granted (citations or technical classes) forwarded by 2 years; Column 3 for the number of cumulative green patents granted (citations or technical classes); Column 4 for the number of cumulative green patents granted (citations or technical classes) forwarded by 2 years. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5
The Aggregate ATETs of Large Subsidies across Firm Groups and Green Innovation Metrics.

		1 Patents	2 Forw. Patents	3 Cum. Patents	4 Forw. Cum. Patents
A: Full Sample: Large Subsidies vs. No Subsidies					
Granted Patents					
Subsidy (N = 755 108)	ATET	0.01*	0.01	0.01*	0.04
	s.e.	0.004	0.009	0.06	0.03
Innovation Subsidies (N = 751 499)	ATET	0.02	−0.004	0.11*	0.02
	s.e.	0.01	0.005	0.06	0.02
Citations					
Subsidy (N = 755 108)	ATET	0.14*	0.01	0.17	0.69
	s.e.	0.06	0.009	0.13	0.45
Innovation Subsidies (N = 751 499)	ATET	0.30	−0.004	−0.18	0.50
	s.e.	0.19	0.005	0.13	0.41
Technical Classes					
Subsidy (N = 755 108)	ATET	0.25*	0.36	1.82*	1.04
	s.e.	0.13	0.25	1.01	0.67
Innovation Subsidies (N = 751 499)	ATET	0.52	−0.16	2.21*	0.82
	s.e.	0.38	0.18	1.21	0.57
B: Matched Sample: Large subsidies vs. No Subsidies					
Granted Patents					
Subsidy (N = 35 139)	ATET	0.001	−0.002	0.02	0.002
	s.e.	0.002	0.002	0.01	0.001
Innovation Subsidies (N = 26 902)	ATET	−0.003	−0.002	0.01	0.001
	s.e.	0.003	0.004	0.09	0.007
Citations					
Subsidy (N = 35 139)	ATET	0.06	−0.002	−0.01	0.17
	s.e.	0.04	0.002	0.05	0.15
Innovation Subsidies (N = 26 902)	ATET	0.05*	−0.002	−0.02	0.09
	s.e.	0.03	0.004	0.07	0.09
Technical Classes					
Subsidy (N = 35 139)	ATET	0.05	−0.02	0.36	0.09
	s.e.	0.04	0.04	0.25	0.14
Innovation Subsidies (N = 26 902)	ATET	−0.04	−0.05	0.21	0.005
	s.e.	0.05	0.07	0.13	0.11

Notes: This table reports the aggregate ATETs of large subsidies and large innovation subsidies estimated by using the DID approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups. We use the augmented inverse-probability weighting estimator. Panel A summarizes the aggregate ATETs from the full firm sample, Panel B summarizes the aggregate ATETs for the matched firm sample. Column 1 represents results for the number of green patents granted (citations or technical classes); Column 2 for the number of green patents granted (citations or technical classes) forwarded by 2 years; Column 3 for the number of cumulative green patents granted (citations or technical classes); Column 4 for the number of cumulative green patents granted (citations or technical classes) forwarded by 2 years. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

any residual bias would require that downturns differentially affected treated versus control firms within sectors, which represents a narrower potential channel for bias. However, we cannot entirely rule out such effects.

To examine this issue empirically, we estimate cohort-specific and time-specific ATETs. Figures E1–E8 in Appendix E present the results. Figures E1–E4 compare firms subject to the EU ETS with and without subsidies, distinguishing between total subsidies and innovation-specific subsidies, while Figures E5–E8 contrast subsidized and non-subsidized firms, both with and without matching. Each set of figures reports estimated ATETs for granted patents, patent citations, and technological scope, showing the evolution of effects across treatment cohorts and over time.

Across all specifications, the estimated effects are small and statistically insignificant, with no systematic differences across cohorts or years. In particular, firms that received innovation subsidies during the financial crisis years (2007–2009) exhibit treatment effects comparable to those first treated in later, more stable periods.

Overall, these results indicate that the effectiveness of innovation subsidies – and their potential interaction with the EU ETS – was largely stable across cohorts and over time. Despite theoretical reasons to expect state-dependent policy effects, our empirical design mitigates potential biases arising from broad macroeconomic conditions by comparing firms within sectors and controlling for year-specific factors. Together with Sweden's stable public R&D funding and resilient innovation system, this likely contributed to the observed stability in firms' innovation responses.

6.5. Robustness test

As a robustness test to check that firms with high patenting activity do not influence the main results, we dropped from the analysis three firms that represent a distinctive level of green patenting. Together, they accounted for 53% of the number of green patents during the period 2000–2018. They all belong to the manufacturing of machinery and transport equipment. One of them is regulated by the EU ETS, one of them did not receive any subsidies, and two were large subsidy recipients during the period 2007–2018. The aggregate ATET estimates of this exercise are summarized in Tables S1–S4 in the Supplementary Material.

Consistent with our main results, we do not find that the policy mix increased firms' green patenting activity (see Table S1). This result holds regardless of whether we use the ETS firm sample or the subsidy firm sample. The only notable difference is that the cumulative patent measures (number of patents granted, citations, and technical classes) are higher for firms covered by both the ETS and subsidies than for those receiving subsidies alone.

Table 6
The Aggregate ATETs of Subsidies and Innovations Subsidies Across Firms of Different Sizes: Full Sample.

		1 Patents	2 Forw. Patents	3 Cum. Patents	4 Forw. Cum. Patents
A: Subsidies vs. Non Subsidies					
Granted Patents					
Large Firms with Subsidy (N = 4 775)	ATET	0.10**	0.14*	0.78	0.14
	s.e.	0.04	0.08	0.48	0.32
Medium Firms with Subsidy (N = 22 949)	ATET	0.001	−0.003	0.01	−0.01
	s.e.	0.002	0.01	0.01	0.01
Small Firms with Subsidy (N = 773 515)	ATET	−0.001	0.001***	0.002	−0.002
	s.e.	0.001	0.0002	0.001	0.001
Citations					
Large Firms with Subsidy (N = 4 775)	ATET	1.85**	2.22*	10.90*	4.96
	s.e.	0.72	1.19	6.08	4.06
Medium Firms with Subsidy (N = 22 949)	ATET	0.02	−0.08	0.07	−0.13
	s.e.	0.02	0.12	0.11	0.09
Small Firms with Subsidy (N = 773 515)	ATET	0.003	0.01*	0.02	−0.02
	s.e.	0.01	0.01	0.02	0.03
Technical Classes					
Large Firms with Subsidy (N = 4 775)	ATET	2.90**	4.11*	15.84*	8.76
	s.e.	1.30	2.27	8.75	5.85
Medium Firms with Subsidy (N = 22 949)	ATET	0.02	−0.09	0.10	−0.14
	s.e.	0.02	0.10	0.10	0.12
Small Firms with Subsidy (N = 773 515)	ATET	−0.01	0.01**	0.02	−0.02
	s.e.	0.01	0.004	0.02	0.02
B: Innovation Subsidies vs. Non Subsidies					
Granted Patents					
Large Firms with Subsidy (N = 4 272)	ATET	0.22*	0.003	0.98*	−0.15
	s.e.	0.13	0.06	0.58	0.34
Medium Firms with Subsidy (N = 21 535)	ATET	0.001	−0.01	0.01	−0.02
	s.e.	0.003	0.01	0.01	0.01
Small Firms with Subsidy (N = 768 292)	ATET	−0.001	0.0002	0.002	−0.003*
	s.e.	0.001	0.001	0.001	0.001
Citations					
Large Firms with Subsidy (N = 4 272)	ATET	3.47*	−0.45	13.67*	2.61
	s.e.	1.86	1.32	7.43	4.21
Medium Firms with Subsidy (N = 21 535)	ATET	0.03	−0.14	0.11	−0.18
	s.e.	0.03	0.15	0.14	0.12
Small Firms with Subsidy (N = 768 292)	ATET	0.003	0.002	0.03	−0.03
	s.e.	0.01	0.01	0.02	0.03
Technical Classes					
Large Firms with Subsidy (N = 4 272)	ATET	5.83*	−0.03	20.87*	6.89
	s.e.	3.51	1.91	10.92	5.39
Medium Firms with Subsidy (N = 21 535)	ATET	0.02	−0.15	0.10	−0.23
	s.e.	0.03	0.13	0.12	0.14
Small Firms with Subsidy (N = 768 292)	ATET	−0.01	0.005	0.03	−0.03
	s.e.	0.01	0.01	0.02	0.02

Notes: This table reports the aggregate ATETs of subsidies and innovation subsidies across firms of different sizes estimated by using the DID approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups. We use the augmented inverse-probability weighting estimator. Panel A summarizes the aggregate ATETs of subsidies from the full firm sample, Panel B summarizes the aggregate ATETs of innovation subsidies from the full firm sample. Column 1 represents results for the number of green patents granted (citations or technical classes); Column 2 for the number of green patents granted (citations or technical classes) forwarded by 2 years; Column 3 for the number of cumulative green patents granted (citations or technical classes); Column 4 for the number of cumulative green patents granted (citations or technical classes) forwarded by 2 years. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Similar results are observed in the analysis of EU ETS effects (see Table S2). Although the EU ETS did not influence the number of patents granted, patent citations and patent technical classes—whether forwarded or non-forwarded—it had a positive effect on cumulative patent measures (both forwarded and non-forwarded).

Furthermore, consistent with our main results, we find that firms that received general subsidies or innovation subsidies patented more green inventions than firms that received no subsidies (see Table S3). In the energy and transport firm subsample, the estimates of aggregate ATETs for all cumulative green patent outcomes are also positive and statistically significant, supporting our main results.

Finally, we assess the effects of large general subsidies and large innovation subsidies, as opposed to no subsidies (see Table S4). In line with our main results, we find that large subsidies (general and innovation) are positively and significantly associated with green innovation outcomes. The effects are most pronounced for accumulated green innovation outcomes, as in the main analysis.

It is worth noticing that while cumulative outcomes are not commonly used in DID analysis due to concerns about selection bias and difficulties in attributing causality, we use them given the specific nature of innovation processes. Patentable innovations may take time to materialize in observable outputs such as granted patents or patent citations. Therefore, cumulative measures can offer additional insight into whether policy impacts unfold gradually over time. However, because these outcomes also reflect the preexisting characteristics and long-term innovation capacity of firms, any observed effects must be interpreted cautiously and not taken as conclusive evidence of a causal policy interaction, particularly in the absence of corresponding effects in contemporaneous or lagged outcomes.

Table 7
The Aggregate ATETs of Subsidies and Innovations Subsidies Across Firms of Different Sizes: Matched Sample.

		1 Patents	2 Forw. Patents	3 Cum. Patents	4 Forw. Cum. Patents
A: Subsidies vs. Non Subsidies					
Granted Patents					
Large Firms with Subsidy (N = 2 171)	ATET	0.06*	0.05	0.28	0.19
	s.e.	0.04	0.03	0.18	0.12
Medium Firms with Subsidy (N = 14 230)	ATET	0.0003	−0.005	0.01	0.003
	s.e.	0.002	0.01	0.01	0.01
Small Firms with Subsidy (N = 122 642)	ATET	−0.001	0.0004*	0.001	−0.001
	s.e.	0.001	0.0002	0.01	0.001
Citations					
Large Firms with Subsidy (N = 2 171)	ATET	0.86	0.45*	5.35	3.87*
	s.e.	0.54	0.24	3.47	2.29
Medium Firms with Subsidy (N = 14 230)	ATET	0.01	−0.11	0.09	−0.07
	s.e.	0.02	0.12	0.12	0.06
Small Firms with Subsidy (N = 122 642)	ATET	0.01	0.010*	0.02	−0.004
	s.e.	0.01	0.01	0.02	0.02
Technical Classes					
Large Firms with Subsidy (N = 2 171)	ATET	1.44*	1.28*	7.53	5.28
	s.e.	0.80	0.68	4.71	3.73
Medium Firms with Subsidy (N = 14 230)	ATET	0.01	−0.11	0.13	−0.03
	s.e.	0.02	0.11	0.11	0.08
Small Firms with Subsidy (N = 122 642)	ATET	−0.001	0.004	0.02	−0.02
	s.e.	0.01	0.004	0.02	0.02
B: Innovation Subsidies vs. Non Subsidies					
Granted Patents					
Large Firms with Subsidy (N = 1 588)	ATET	−0.01	−0.07	0.18	−0.01
	s.e.	0.05	0.05	0.24	0.16
Medium Firms with Subsidy (N = 11 979)	ATET	0.00	−0.01	0.01	0.001
	s.e.	0.003	0.01	0.01	0.01
Small Firms with Subsidy (N = 110 570)	ATET	−0.0001	−0.0001	0.001	−0.001
	s.e.	0.0005	0.0005	0.001	0.001
Citations					
Large Firms with Subsidy (N = 1 588)	ATET	0.78	0.17	5.82	3.41
	s.e.	0.86	0.16	5.39	3.41
Medium Firms with Subsidy (N = 11 979)	ATET	0.05	−0.14	0.09	−0.02
	s.e1	0.01	0.16	0.15	0.08
Small Firms with Subsidy (N = 110 570)	ATET	0.01	0.0004	0.024	−0.004
	s.e.	0.01	0.01	0.02	0.02
Technical Classes					
Large Firms with Subsidy (N = 1 588)	ATET	0.41	−0.34	5.81	1.91
	s.e.	1.00	0.77	5.75	3.42
Medium Firms with Subsidy (N = 11 979)	ATET	0.03	−0.15	0.12	−0.07
	s.e.	0.03	0.14	0.13	0.08
Small Firms with Subsidy (N = 110 570)	ATET	−0.01	−0.0005	0.02	−0.02
	s.e.	0.01	0.01	0.02	0.02

Notes: This table reports the aggregate ATETs of subsidies and innovation subsidies across firms of different sizes estimated by using the DID approach of Callaway and Sant'Anna (2021), which allows for treatment effect heterogeneity and staggered treatment timing across firm groups. We use the augmented inverse-probability weighting estimator. Panel A summarizes the aggregate ATETs of subsidies from the full firm sample, Panel B summarizes the aggregate ATETs of innovation subsidies from the full firm sample. Column 1 represents results for the number of green patents granted (citations or technical classes); Column 2 for the number of green patents granted (citations or technical classes) forwarded by 2 years; Column 3 for the number of cumulative green patents granted (citations or technical classes); Column 4 for the number of cumulative green patents granted (citations or technical classes) forwarded by 2 years. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7. Conclusions

This paper investigates the combined effect of public innovation subsidies and the European Union's Emission Trading Scheme on green innovation activities among industrial firms in Sweden. The aim is to evaluate whether there is a synergistic effect of these two policies at the level of the firm.

We measure green innovation through patents granted to technologies for climate change mitigation and adaptation. Subsidies are quantified based on allocations to industrial firms by various Swedish governmental agencies, where we distinguish between total direct subsidies and innovation-related subsidies. To address potential selection biases from non-random participation in subsidy programs and the varying effects of policies, we apply staggered difference-in-differences estimation and matching techniques. This allows us to evaluate the influence of different policy combinations on three key outcome variables: the number of granted patents, patent citations, and technical patent classes.

We begin by assessing whether the combination of the EU ETS and public subsidies – both total direct subsidies and those specifically aimed at innovation – generates synergistic effects on firm-level green innovation. We find no evidence of such effects, even after controlling for selection into the EU ETS and into subsidy programs. We address selection in two ways. First, we restrict our analysis to firms subject to the EU ETS, distinguishing between those that have received subsidies and those that have not. Our identification strategy leverages variation in the timing of firms' first subsidy receipt, enabling us to implement a staggered difference-in-differences approach. We find no strong evidence of a synergistic effect: firms that were part of the ETS and received subsidies did not show larger innovation output –

measured by granted patents, citations, or patent scope – compared to firms only subject to the ETS. This result holds for both total subsidies and innovation-related subsidies.

Second, we analyze the sample of firms that received subsidies at least once during the period under consideration. Within this group, we compare the innovation activity of firms that received only subsidies with those that received both subsidies and were subject to the EU ETS. We again exploit the staggered timing of firms' first subsidy receipt and interact it with an indicator for EU ETS participation. To further explore potential synergies, we conduct a sectoral analysis, focusing on energy and transport, where green patenting and ETS coverage are concentrated. The results indicate that even among these firms, those subject to both policies do not exhibit significantly different green patenting behavior compared to firms receiving only subsidies. This holds again for both total subsidies and innovation-related subsidies.

Why do we not observe any synergistic effects? One possible explanation is that the two policies affect different types of firms. In particular, the limited overlap between the firms influenced by each policy may play a key role. The EU ETS primarily covers high-emitting firms, many of which operate in sectors characterized by path dependency and technological lock-in. These firms may face structural barriers to green innovation, even when financial support is available. In contrast, innovation subsidies often go to firms with established R&D capacity, typically in less emission-intensive sectors. As shown in our sectoral analysis, the firms receiving the most innovation subsidies and producing the most green patents are generally not those with the highest emissions under the EU ETS. This suggests that the two policies tend to influence different groups of firms, which may help explain the absence of firm-level synergies.

Another possible explanation is that the effects of the policies may be heterogeneous, concentrated in certain types of firms or contexts, making complementarities harder to detect in aggregate data. We cannot assess heterogeneity in the effects of the EU ETS due to data limitations, but we explore this aspect for subsidies.

Indeed, to better understand the effects of the EU ETS and innovation subsidies on green innovation, we estimate their individual impacts using matching techniques. We find no evidence that participation in the EU ETS significantly increases the number of granted patents, their citations, or their technological scope. This result aligns with previous findings for Sweden and suggests that, in this context, the EU ETS has not been a strong driver of patentable green innovation.

In contrast, both total direct and innovation-related subsidies are positively associated with green innovation outcomes. Firms receiving subsidies tend to produce more patents, which receive more citations and span a broader range of technical classes. These effects are strongest when outcomes are measured cumulatively and in the full sample—that is, before matching is applied to construct a counterfactual group of more comparable firms. For total direct subsidies, the results are robust across both the full and matched samples, while for innovation-related subsidies, statistical significance is concentrated in the full sample.

We also examine the effects of subsidy size by categorizing firms into large-subsidy recipients versus no-subsidy recipients. In the full sample, firms receiving large subsidies show significantly higher patenting activity, particularly in terms of citations and technological scope. In the matched sample, the effects are smaller and less often statistically significant, likely due to more restrictive within-sector matching and reduced statistical power. Furthermore, when distinguishing by firm size, we find that larger firms respond more strongly to subsidy support than medium-sized and small firms. These findings support the idea that the effects of subsidies are heterogeneous, with stronger impacts observed among firms receiving larger amounts of support and among larger firms.

In summary, we find no evidence of a synergistic effect between the EU ETS and innovation subsidies. While emissions trading may shape firms' environmental behavior, it does not, in this context, stimulate green patenting. In contrast, subsidies – especially when substantial – are positively associated with both the quantity and quality of green technological development. These findings suggest that environmental policies like the EU ETS may need to be complemented by strong financial support to foster green innovation. Subsidy programs remain a key tool for overcoming market failures and accelerating the transition to environmentally sustainable technologies.

A caveat of our analysis is that, due to data limitations, we are unable to control for firms' energy use or actual carbon dioxide emissions. In other words, we measure the effect of EU ETS participation but not the compliance costs faced by individual firms. This limits our ability to assess whether the interaction between emissions pricing and innovation subsidies differs for firms with high versus low compliance costs. Nonetheless, this limitation is unlikely to substantially affect our findings. As shown in our descriptive analysis, green patenting is not concentrated among the most emission-intensive firms within the EU ETS. Moreover, many firms have historically received free emissions allowances, which significantly reduced their compliance costs. That said, this remains an important avenue for future research, particularly in studies covering more recent years, as the free allocation of allowances is gradually phased out.

Another limitation of our study, which also points to fruitful directions for future research, concerns the choice of outcome variables. While patents are widely used as indicators of technological change in the induced innovation literature – and their strengths and limitations are well documented (see, e.g., (OECD, 2009) – they capture only part of firms' innovation responses. Future research could explore a broader range of technological activities. For instance, similar analyses could be replicated using alternative indicators such as R&D expenditures or other innovation-related investments. In addition, future studies might consider examining both green and non-green patents, as spillover effects may occur in both directions—that is, innovations in other domains may contribute to green patenting, and vice versa. It would also be valuable to examine whether firms subject to more stringent environmental regulation are more likely to generate green patents, or whether their innovation activity, potentially shaped by state dependency, is directed toward other technological domains instead.

CRediT authorship contribution statement

Jessica Coria: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jūratė Jaraitė:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jessica Coria and Jurate Jaraite reports financial support was provided by Swedish Research Council Formas. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.respol.2025.105378.

Data availability

The authors do not have permission to share data.

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