FINANCING THE TRANSITION:

Empirical Evidence on Green Bonds and Sustainable Innovation in the European Union's Utilities Sector

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AUTHOR’S DECLARATION

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ABSTRACT

Green bonds have emerged as a powerful financing tool for the green transition. By easing capital constraints and steering firms toward green R&D, they can accelerate the development of climate mitigation and adaptation technologies. Yet, most existing studies rely on cross-sectoral Chinese data, leaving sector and region-specific dynamics unexplored. This paper addresses that gap by examining the effect of green bond issuance on green innovation, proxied by green patents, using an annual panel of utilities firms domiciled in the European Union (EU) from December 2015 through May 2025. The core empirical strategy employs one-to-one nearest-neighbor propensity-score matching (PSM) to construct a credible counterfactual and to more precisely isolate the causal impact of green bonds on technological innovation. The study finds that the effect of green bonds is context-dependent. Issuance spurs innovation in Austrian utilities firms, but is associated with lower patenting probability and application counts in Denmark and Italy and within electric utilities firms more broadly. Overall, the effects underscore the role of regulatory and institutional environments as well as industry-level dynamics in shaping the innovation outputs of utilities firms in the EU.

Key words: sustainable finance, green finance, green bonds, green technology innovation

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CHAPTER I: INTRODUCTION

Under the Paris Agreement, over 190 nation states recognized the role of technological development in decarbonizing the global economy, emphasizing the need to accelerate and foster innovation through investments in clean energy, sustainable infrastructure, and transport (United Nations Framework Convention on Climate Change [UNFCCC], 2015). However, a substantial increase in investment is required to meet the estimated annual green finance need of USD 7.2 trillion by 2030 to successfully decarbonize the global economy (Lee et al., 2024). To help close the green finance gap, green bonds have emerged as key instruments for mobilizing capital toward sustainability-oriented projects, representing the most prominent form of green finance and a significant share of climate investment (Adisa et al., 2024; Shah et al., 2024).

Green bonds can foster innovation in climate mitigation and adaptation technologies by alleviating financial constraints and enabling investment in green R&D projects, which typically require long-term funding, involve high risks, and yield uncertain returns (Dong et al., 2024; Ren et al., 2024). Firstly, green bond proceeds help reduce information asymmetry between issuers and investors since their proceeds are earmarked for environmentally sustainable projects (Ji & Zhang, 2023). This increased transparency can attract both sustainability-oriented investors and those seeking the reputational benefits of green investments, ultimately enabling issuers to raise more capital for their projects (Dong & Yu, 2024). Secondly, firms can issue green bonds at a lower cost than conventional bonds as investors are often willing to accept lower yields in exchange for their environmental and reputational value, resulting in a reduced cost of debt for issuers (Zerbib, 2019; Rao et al., 2022). Finally, green bonds tend to have longer debt maturities than conventional bonds, which align with the long-term funding needs of green innovation projects (Rao et al., 2022).

As societal pressure to decarbonize the global economy intensifies, utilities firms are expected to accelerate their own transition, given that they are among the highest greenhouse gas emitting sectors and play a pivotal role in enabling the decarbonization of other industries. By transitioning to renewable energy sources and improving the efficiency of electricity generation, transmission, and distribution, the decarbonization of the utilities sector can drive the electrification of transport and industry (Porter et al., 2020; D'Amore et al., 2024; Karlsson, 2024). However, utilities firms must develop and adopt technological innovations, such as advanced machinery and sustainable infrastructure, to successfully transition to greener operations (Eaton, 2013).

While previous studies have investigated the relationship between green bond issuance and green technological innovation, researchers have predominantly focused on China (Wang et al., 2022; Wu et al., 2022; Ji & Zhang, 2023; Dong et al., 2024; Wan et al., 2025; Zhang et al., 2024). In addition to overlooking dynamics in other countries and regions, existing literature has often relied on cross-sectoral samples, limiting the ability to analyze industry specific drivers, barriers, and outcomes. This study seeks to fill that gap by investigating whether corporate green bond issuance fosters the green innovation performance of utilities firms in the European Union (EU).

The objective of this paper is to apply causal inference econometric methods to examine the effect of green bond issuance on innovation activity and intensity, proxied by patent applications in climate mitigation and adaptation technologies. Using a sample of utilities firms domiciled in the EU that issued either conventional or green corporate bonds between 2015 and 2025, this study employs Propensity Score Matching (PSM) to pair green bond issuers with non-issuers sharing similar firm-level financial characteristics, thereby creating a balanced sample that better isolates the effect of green bond issuance on innovation.

The study finds that the effect of green bond issuance on green innovation is not universal, but varies by both country and industry. While issuance is associated with a higher likelihood of patenting and greater innovation output among Austrian utilities firms, it corresponds to a lower probability of patenting in Danish firms and reduced innovation output in Italy. At the sectoral level, green bond issuance is also linked to a decreased probability of innovation among electric utilities firms. These findings underscore the critical role of governments in shaping the regulatory and institutional environments in which green bond markets operate, and they highlight the importance of sector-specific policy approaches when evaluating the effectiveness of green financial instruments in supporting the green transition.

The remainder of the study is structured as follows: Chapter II provides a comprehensive review of the existing literature on green bonds and green innovation, situating the study within the broader academic discourse; Chapter III covers the theoretical framework that underpins the study and presents the research hypotheses; Chapter IV outlines the sample selection process, data sources, and variable definitions, establishing the empirical scope of the analysis; Chapter V details the empirical methodology, presenting the econometric models designed to address endogeneity concerns and strengthen causal inference; Chapter VI presents and discusses the results of the empirical analysis; Chapter VII provides policy recommendations based on the findings; and Chapter VIII concludes the study, summarizing key insights and suggesting avenues for future research.

CHAPTER II: LITERATURE REVIEW

In 2007, the European Investment Bank (EIB) pioneered the green bond market by launching the first green bond to finance renewable energy projects (Hu & Gan, 2025; Flammer, 2020). The issuance was driven by the EU's policy agenda at the time, which aimed to position the region as a global leader in climate action and energy, alongside growing investor demand for opportunities to support green projects (Wilkinson et al., 2021). By 2024, green bonds dominated the green, social, sustainability, and sustainability-linked (GSS+) debt market, accounting for 65% of annual issuance (USD 535.3 billion) and 62% of total cumulative issuance since the market's inception (USD 3.37 trillion) (Harrison et al., 2024).

2.1. Differentiating Green and Conventional Bonds

While green bonds share many characteristics with conventional bonds, their fundamental distinction lies in the "use of proceeds" clause, which mandates that green bond proceeds be allocated exclusively to environmentally sustainable projects (Flammer, 2020; Maltaisa & Nykvist, 2020; Sobik, 2023; Huang et al., 2024). One key explanation for the rapid growth and global adoption of green bonds is their compatibility with existing financial systems, which allows them to be integrated without requiring major structural changes (Monk & Perkins, 2020).

Firstly, green bonds are structurally similar to conventional bonds, with comparable terms of maturity and coupon rates. This made them easy to adopt for market participants, as their introduction did not require an overhaul of existing institutional frameworks. Their market comparability, combined with low transaction costs and reduced barriers to entry, facilitated widespread adoption and broad uptake (Monk & Perkins, 2020). Secondly, green bonds preserve traditional financial logic by applying an environmental label to a familiar instrument, enabling issuers and investors to align with environmental objectives without significantly altering their investment processes (Monk & Perkins, 2020).

2.2. Governance and Certification Landscape

In the absence of a universally recognized classification system for determining a bond's green status, the market predominantly relies on private governance through independent third parties that certify bonds in accordance with international standards (Baker et al., 2018; Flammer, 2020; Fatica & Panzica, 2021). The process is typically carried out by either organizations that develop global standards, such as the Climate Bonds Initiative (CBI) through its Climate Bond Standard and Certification Scheme or the International Capital Market Association (ICMA) via its Green Bond Principles (GBP); or by data providers like Bloomberg (Baker et al., 2018). Some regions and international bodies, such as the EU, mandate third-party certification for green bonds, while others, including China, adopt a voluntary approach in which bonds may be either self-labeled as green by issuers or formally certified (Baker et al., 2018; Lin & Hong, 2022; Huang et al., 2024).

2.3. Investor Motivations and Demand Dynamics

Several scholars argue that the primary drivers of increasing investor participation in green bond markets are non-pecuniary rather than purely financial in nature. Green bonds, which attract approximately 42% to 55% higher demand than conventional bonds, appeal to investors seeking reputational benefits and those who are driven by a preference for pro-social and pro-environmental norms (Zerbib, 2019; Maltais & Nykvist, 2020). Risal et al. (2023) find that green bonds issued by firms with stronger environmental, social, and governance (ESG) performance and lower perceived ESG reputation risk attract greater interest from investors, emphasizing their socially responsible nature. Furthermore, the green bond premium, which refers to the lower yield to maturity (YTM) of green bonds compared to conventional bonds, suggests that investors are willing to accept lower financial returns to hold green assets (Baker et al., 2018; Zerbib, 2019).

2.4. Green Bonds as Catalysts for Green Technology Innovation

As argued by Eaton (2013), a successful long-term green transition requires the development and adoption of hard and soft technologies. Hard technologies, such as energy-efficient machinery and infrastructure, are essential for advancing the technical capacity of clean energy systems, while soft technologies, including organizational practices, are equally necessary to enable the systemic transformation required for a greener economy (Eaton, 2013). Notably, Paramati et al. (2022) find that green technologies positively impact energy efficiency and significantly reduce both per capita and total energy consumption in Organization for Economic Cooperation and Development (OECD) economies. Similarly, Salman et al. (2022) highlight that environmental efficiency, which is defined as the ability of a country to utilize economic inputs to produce outputs with minimal environmental harm, is primarily driven by technological progress in developed countries. These findings underscore the critical role of green technologies in achieving the global emissions reduction targets set under the Paris Agreement.

2.4.1. Barriers to Green Innovation

While the development of green technologies that reduce environmental harm and promote sustainability is essential, such innovation faces several challenges (Zhang et al., 2023; Matviienko & Kucherkova, 2024). First, the innovation process is inherently resource-intensive, requiring long-term financial investment and substantial research and development (R&D) efforts to create new products and technologies (Moshirian et al., 2021; Ji & Zhang, 2023). Second, innovation is characterized by considerable risk as both outcomes and returns are often uncertain, discouraging firms from engaging in innovation activities (Eaton, 2013; Moshirian et al., 2021). Finally, and most importantly, financial constraints are the most critical barrier to successful innovation, as such constraints increase the failure rate of innovation projects (García-Quevedo et al., 2018; Moshirian et al., 2021).

The financial constraints faced by firms seeking to finance innovation can be either internal or external. Internal constraints arise from insufficient funds within the firm, while external ones stem from limited access to capital such as bank loans or outside investors (García-Quevedo et al., 2018). Firms often prefer to finance innovation using internal funds, particularly relying on retained earnings, to avoid the challenges associated with external financing (Myers, 1984). When firms seek external funds by issuing debt or equity, they face obstacles related to information asymmetry, as investors often lack complete knowledge about the firm's projects, and investment risk, since innovative ventures may fail to deliver returns (Ji & Zhang, 2023).

For firms engaged in green innovation, the high-risk and capital-intensive nature of these investments makes external financing essential to boost innovation capacity (Aiello et al., 2020; Bacchiocchi et al., 2024). Notably, over 50% of EU firms operating in the field of clean and sustainable technologies actively seek external financing to support their innovation efforts, with larger firms showing a preference for debt over equity financing (Delanote et al., 2024).

2.4.2. Green Bonds as a Financial Solution

To overcome the financial constraints that often hinder green innovation, firms are increasingly turning to green bonds as a source of external financing. A key feature of green bonds is the "use of proceeds" clause, which legally requires issuers to allocate the raised funds specifically to environmentally sustainable projects. This targeted structure enhances transparency and ensures that capital is directed toward green initiatives, helping firms overcome internal and external funding limitations.

Empirical evidence from China supports this mechanism, showing that green bond issuance significantly reduces firms' financial constraints, thereby enhancing their capacity to engage in green innovation (Wang et al., 2022). Green bonds also improve access to affordable and flexible capital by typically trading at a price premium, resulting in lower yields for investors and reduced borrowing costs for issuers (Zhang et al., 2024). Beyond lowering the cost of capital, green bonds provide stable, long-term financing that is well-suited for R&D projects, which often involve high upfront costs, long payback periods, and substantial uncertainty (Dong et al., 2024). Their longer maturities offer firms greater flexibility, enabling them to secure long-term capital for environmentally beneficial projects that might otherwise be too costly or risky to finance (Zheng et al., 2023). With more accessible and affordable financing, firms are better positioned to initiate or accelerate green innovation efforts.

Using Chinese firm-level data on listed companies and listed non-financial firms, respectively, Wang et al. (2022) and Wu et al. (2022) find that the issuance of corporate green bonds significantly enhances green innovation among issuing firms. Zhang et al. (2024) and

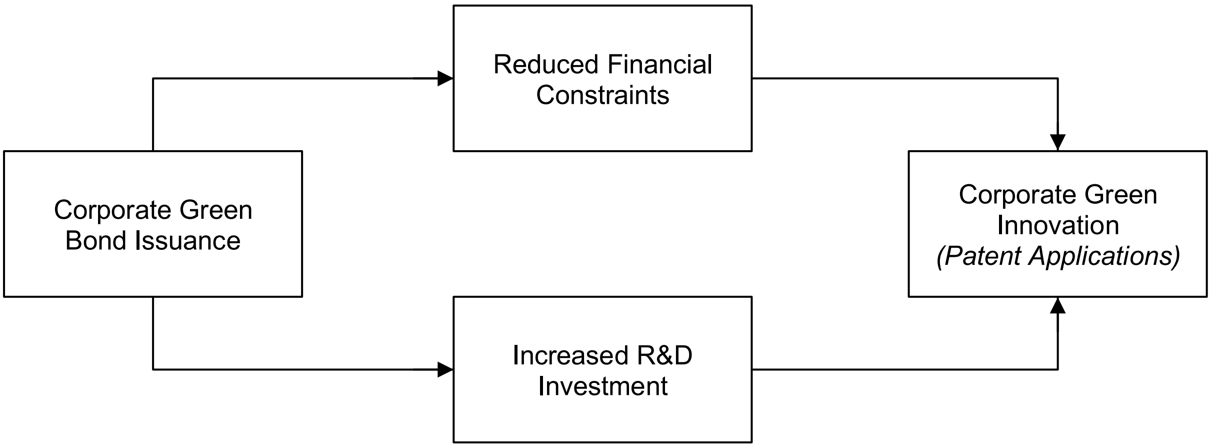
Wan et al. (2024) also find that issuance contributes to increased R&D in green technologies by improving a firm's debt structure and lowering financing costs, respectively. This argument is further supported by Dong et al.'s (2024) findings, which suggest that green bonds directly stimulate R&D spending and ease financial constraints, hence fostering innovation.

Analyzing country-level data from Europe, Nemeth-Durko (2024) finds that green bonds positively correlate with green patent growth. Similarly, Aghion et al. (2022) find a positive association between green bond issuance and green innovation, as EU countries and sectors that issue green bonds exhibit higher levels of green patenting. The paper also highlights that the EU remains behind other developed countries in green innovation, with significantly lower green patenting rates and substantial variation across member states (Aghion et al., 2022).

CHAPTER III: THEORETICAL FRAMEWORK AND HYPOTHESES

This thesis draws on Dong et al.'s (2024) theoretical framework to develop and empirically test three hypotheses. The mechanism through which green bond issuances are expected to impact green technological innovation is illustrated in Figure 1.

Figure 1. Conceptual framework linking green bond issuance to corporate green innovation.



Note(s): The directed acyclic graph (DAG) was developed by the author based on the theoretical underpinnings outlined in Dong et al. (2024).

First, proceeds raised through green bond issuances may ease capital constraints by providing funding specifically earmarked for green projects, enabling firms to undertake longer-term and riskier initiatives they might otherwise forgo. Second, the lower borrowing costs and improved access to capital associated with green bonds can incentivize firms to allocate more resources to R&D activities. In addition to the reputational benefits of engaging in environmentally sustainable practices, firms can also derive economic returns from developing green technologies, as patenting such innovations grants exclusive rights over products or processes, which can potentially boost profitability and enhance market competitiveness (Dong et al., 2024). Hence, green bonds can lower financing costs and mitigate perceived investment risks, thereby incentivizing firms to increase their R&D spending on green technologies, ultimately fostering greater innovation (Ren et al., 2024).

Although the study acknowledges the theoretical channels through which green bonds may influence green innovation, proxied by green technology patent applications, its primary objective is to isolate the effect of green bond issuance on green innovation. This entails that the empirical models do not include variables related to financial constraints or R&D investment, as the paper does not aim to test the mechanisms depicted in Figure 1. Drawing on the mechanisms outlined by scholars such as Dong et al. (2024), this study proposes the following research hypotheses:

Hypothesis 1 (H1): Firms that issued a green bond in the previous year are more likely to submit at least one patent application in the current year.

Hypothesis 2 (H2): Firms that have issued a green bond at any point in time are more likely to submit patent applications compared to firms that have never issued a green bond.

Hypothesis 3 (H3): Firms that issued a green bond in the previous year submit a higher number of patent applications in the current year.

CHAPTER IV: DATA

To quantitatively assess the impact of corporate green bond issuance on green innovation, a dataset with firm-year observations drawn from Refinitiv Eikon and the European Patent Office's (EPO) Espacenet is constructed. The study uses yearly panel data combining both cross-sectional and time-series information to compare innovation across firms and time. It spans the period between 2015 and 2025.[1]

4.1. Sample

4.1.1. Corporate Green Bonds

The sample analyzed is restricted to corporate green bonds for two reasons. First, the significance of corporate green bond issuance within the broader corporate bond market is increasing. The volume of green bonds outstanding surged from representing 3.3% of the conventional bond market to over 11% by 2024 (Lewis & Joshi, 2024). While sovereign and supranational issuers pioneered the global green bond market, corporates have dominated issuance since the mid-2010s. In 2024, corporate green bonds constituted over 50% of annual issuances, with a substantial amount of proceeds earmarked for renewable energy and energy efficiency projects (Lewis & Joshi, 2024). Second, corporate green bonds are expected to have a more direct and measurable effect on technological innovation compared to those issued by governments and supranational entities. Although sovereign and supranational green bonds support the development of markets and policies that influence innovation, their effect on the development of green technologies is understudied and likely indirect.

[1] Detailed instructions for accessing the dataset appear in Appendix VI.

4.1.2. Corporates within the EU-27

The analysis focuses on firms domiciled in the EU-27. The principal advantage of studying a sample of firms operating within the same legal and regulatory framework is that a more cohesive market environment reduces variability arising from legislative and policy differences, thereby facilitating clearer attribution of observed effects to the variables under investigation.

At the EU level, the Fit for 55 Package comprises a set of legislative proposals aimed at implementing the goals of the European Green Deal, including the target of reducing continental emissions by 55% by 2030 (Smeets Křístková et al., 2025; European Commission, 2019). More importantly, the European Green Bonds Regulation, which entered into force in 2023 and applied from 2024, constitutes a binding piece of legislation that establishes a standardized framework for the issuance of green bonds within the EU-27 (Smeets Křístková et al., 2025; European Commission, 2021). Although the regulatory framework governing the EU green bond market is not yet fully harmonized across states, existing initiatives have established a more consistent classification system for green-labelled bonds and helped reduce fragmentation in ESG reporting.

4.1.3. The Utilities Sector

The sample retains issuer firms in the utilities sector, which comprises companies that provide essential services such as electricity, natural gas, and water, for two reasons (D'Amore et al., 2024). First, the utilities sector remains the second largest greenhouse gas emitter in the EU, but holds great potential to accelerate the clean energy transition. Notably, the sector reduced emissions by 46% by decreasing its reliance on coal power and increasing its use of renewable technologies between 1990 and 2020, which highlights its commitment to decarbonization (Karlsson, 2024). By transforming how Europe generates, transmits, and distributes energy, utilities firms can play a pivotal role in accelerating the electrification of transportation and industry, shifting them from fossil-fuel-reliance to clean energy sources (Karlsson, 2024; Porter et al., 2020; D'Amore et al., 2024).

Second, the analysis focuses on utilities firms due to their predominance within the EU's green bond market. In 2024, the sector accounted for almost 30% of the market, making it the second largest issuing sector after banking (Lewis & Joshi, 2024). This trend is unsurprising, given that corporate green bonds are particularly prevalent in sectors where environmental considerations are integral to business operations (Flammer, 2021). It also reflects a broader pattern within the utilities sector, whereby firms increasingly access financial markets to develop or expand infrastructure for renewable energy production and energy efficiency projects (Sebastiani, 2019). As pressure from shareholders and stakeholders to decarbonize intensifies, utilities, particularly those with a strong sustainability orientation, are increasingly investing in R&D and adopting green technologies to drive innovation (Loredo et al., 2019).

Although utilities firms are not typically viewed as highly innovative, many are increasingly embracing the development and adoption of green technologies in response to the evolving energy landscape. This is exemplified by several European utilities companies that have prioritized innovation, particularly in energy services and efficiency, through the establishment of innovation labs, partnerships with academic institutions, and the organization of hackathons (Bigliani et al., 2017). Accordingly, this study sets itself apart from others by focusing on the utilities sector as a whole, largely overlooked in existing literature on green bonds and green innovation.

4.1.4. The Post-Paris Agreement Era

The temporal scope of the paper spans from 2015 to 2025. Although the first corporate green bonds were issued by French company Électricité de France (EDF) in November 2013, the market's expansion began in 2015 (Monk & Perkins, 2020). The Paris Agreement emphasized the urgent need for investment in environmentally beneficial projects and served as a catalyst for growth and geographic scaling (Berensmann et al., 2016). This is evidenced by the surge in green bond issuance between 2015 and 2016, with the market expanding by 92%, rising from just over $40 billion to $92 billion (Climate Bonds Initiative, 2017). Hence, the study examines the effect of green bonds on green innovation from the adoption of the Paris Agreement in December 2015 to May 2025.

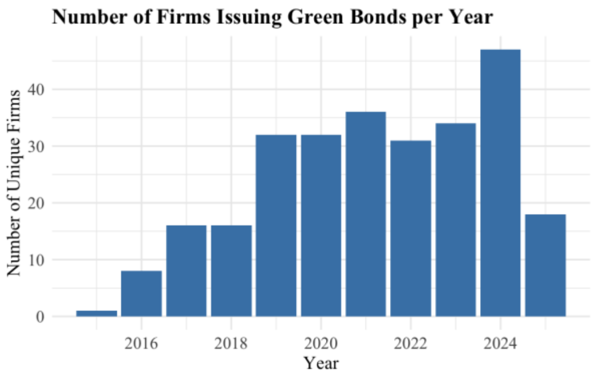
4.2. Variables

4.2.1. Green Bond Issuance

The main independent variable in this study is green bond issuance. This study uses a dummy variable, where $GreenBondDummy$ equals one if a firm issued at least one green bond in a given year, and zero otherwise, which is standard practice in the literature (Rao et al., 2022; Makpotche et al., 2023; Dong & Yu, 2024; Ren, et al., 2024). The dataset includes both green and conventional corporate bonds to ensure a comprehensive assessment of green innovation across issuer types.

Data on all corporate bonds issued by firms domiciled in the EU between December 17th, 2015, and May 26th, 2025, were collected from Refinitiv Eikon. The sample was filtered to include only companies classified under the Refinitiv Business Classification (TRBC) ‘Utilities’ sector, encompassing renewable independent power producers and electric utilities, such as those involved in solar, natural gas, water, wind, hydroelectric, tidal, nuclear, biomass, and waste-to-energy. The final sample consists of 948 conventional bonds and 465 green bonds, which were either self-labeled or aligned with Climate Bonds Initiative (CBI) criteria, totaling 1413 bond issuances across 285 firms in 25 countries during the specified period.

Figure 2. Number of firms issuing green bonds per year.



Source: Author’s own illustration based on green bond issuance data from Refinitiv Eikon.

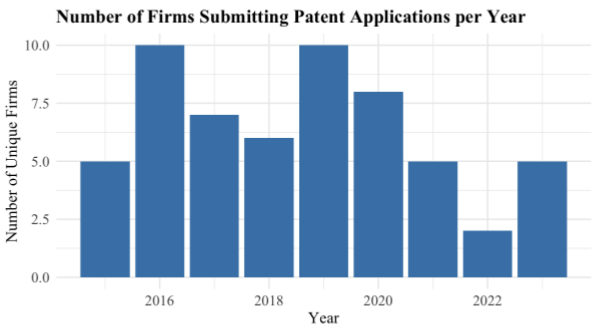
4.2.2. Green Innovation

The main dependent variable is green innovation. Following Ma et al. (2023), the focus is on patent application dates rather than authorization dates, as it more accurately reflects the timing of innovation activity and avoids distortions caused by the administrative review process of patent offices.

Green patent data were manually collected from the European Patent Office (EPO) by searching the Espacenet database for applications filed by bond issuers and filtering for patents classified under the Cooperative Patent Classification (CPC) as climate change mitigation and adaptation technologies. Specifically, all patents under the Y02 class were included, covering subclasses such as energy production, distribution, and transport (Y02E), capture and storage of greenhouse gases (Y02C), and waste management (Y02W) among others (EPO, 2019). The number of green patent applications filed by each firm was aggregated annually at the parent company level.

This study uses two different measures of green innovation. First, patenting activity is captured using the binary variable $PatentsDummy$, which equals one if a firm submitted at least one green patent application in a given year, and zero otherwise. Second, patenting intensity is measured by the natural logarithm of one plus the total number of green patent applications submitted by a firm in a given year. This transformation, following Ma et al. (2023) and Dong et al. (2024), mitigates the effects of skewness and enhances the interpretability of the regression coefficients. Given the considerable variation in patent counts across firms in the dataset, which range from zero to over twenty per year, the transformation using $[ln(PatentCount + 1)]$ improves the statistical robustness of the analysis by reducing skewness and appropriately accounting for zero values in the logarithmic transformation.

Figure 3. Number of EU utilities firms submitting green patent applications per year.



Source: Author's own illustration based on green bond issuance data from the EPO's Espacenet.

4.2.3. Control Variables

Building on previous research, this study includes controls for key firm characteristics and financial performance indicators: firm size, profitability, revenue growth rate, leverage, and liquidity. All control variables are lagged by one year, consistent with the findings of Zhang et al. (2024), which indicate that the impact of green bond issuance on innovation tends to materialize from the second year onward. To address skewness and enhance the interpretability of the regression coefficients, the control variables are log-transformed. Appendix I presents histograms that illustrate the improvements in data distribution following the transformation.

First, this study controls for firm size, measured by total assets, as larger firms face lower transaction costs in issuing green bonds, possess greater internal capacity to manage certification processes, and have more resources to invest in innovation (Rao et al., 2022; Wang et al., 2022; Chen et al., 2023; Ma et al., 2023; Dong & Yu, 2024). Second, profitability is included as a control, measured by Return on Average Total Assets (ROA), since more profitable firms are generally more capable of financing and engaging in innovation activities (Rao et al., 2022; Chen et al., 2023; Zhang et al., 2024). Third, the business growth rate, captured as the year-over-year change in revenue from business activities, is included to account for cross-sectional variation in operational performance and market-based growth expectations that may influence R&D investment (Rao et al., 2022; Wang et al., 2022).[2] Fourth, leverage is included as a control, measured by the debt-to-equity ratio, to reflect a firm's financial constraints and access to external financing, both of which may affect its ability to issue green bonds and engage in innovation (Makpotche et al., 2023). Fifth, liquidity is

[2] The natural logarithm of business revenue growth rate is transformed using ln(RevenueGrowth + 1) to account for values close to zero or negative growth rates, ensuring that the transformation is defined across the full range of the variable.

measured using the quick ratio, which represents the proportion of quick assets to current liabilities, to control for a firm's capacity to meet short-term obligations without incurring additional debt, thereby allowing greater flexibility to allocate resources to innovation (Wan et al., 2024).

Additionally, the study includes prior green bond issuance as a control using a binary variable that equals one if the firm has issued any green bond in any year preceding the current year, and zero otherwise. Firms with prior issuance experience may face lower transaction costs, have established certification processes, and be more familiar with investor expectations, which affects their likelihood of issuing green bonds and their innovation outcomes. This variable allows the study to test Hypothesis 2, which posits that firms that have issued a green bond at any point in time are more likely to submit patent applications compared to firms that have never issued a green bond.

4.2.3.1. Diagnostic Analysis of Control Variables

In line with Békés and Kézdi (2021), models aiming to identify causal effects should restrict the inclusion of control variables to those that act as endogenous sources of variation, which are referred to as confounders. While there are theoretical justifications for including the selected control variables in this study, an empirical assessment was conducted using Pearson pairwise correlations to evaluate their relationship with both the independent and dependent variables. The resulting correlation matrix is presented in Appendix II. The analysis indicates that firm size and profitability are potential common cause confounders, as they exhibit statistically significant correlations with both green bond issuance and patenting outcomes. In contrast, leverage is only correlated with patenting, while liquidity and revenue growth do not show meaningful associations with either variable. Despite this, the study retains growth, leverage, and liquidity as control variables to maintain consistency with prior literature, which frequently includes them in both regression models and as covariates in one-to-one nearest neighbor propensity score matching.[3]

Table 1. Description of variables.

Type	Variable	Measurement	Source
Dependent Variable	Patent Count	Natural logarithm of annual count of green patent applications per firm-year plus one *(ln(PatentCount+1))*	EPO
	Patents Dummy	Dummy variable that equals one if a firm submitted at least one green patent application in a given year, and zero otherwise	EPO
Independent Variable	Green Bond Dummy	Dummy variable that equals one if a firm issued at least one green bond in a given year, and zero otherwise	Refinitiv Eikon
Control Variable	Prior Issuance	Dummy variable that equals one if a firm submitted at least one green patent application in the years prior to the a current given year, and zero otherwise	
	Firm Size	Natural logarithm of total assets *(ln(TotalAssetS))*	Refinitiv Eikon
	Profitability	Natural logarithm of return on average total assets (ROA) *(ln(ROA))*	Refinitiv Eikon
	Business Growth Rate	Natural logarithm of change rate of total revenue from business activities plus one *(ln(RevenueGrowth+1))*	Refinitiv Eikon
	Leverage	Natural logarithm of total debt percentage of total equity *(ln(Debt-To-EquityRatio))*	Refinitiv Eikon
	Liquidity	Natural logarithm of quick ratio *(ln(QuickRatio))*	Refinitiv Eikon

[3] A sensitivity analysis analyzing the role of profitability as a control variable is presented in Appendix I.

4.3. Descriptive Statistics

Table 2 and Table 3 report summary statistics of the variables included in the analysis. Table 2 captures the annual total number of green bonds issued by the firms in the dataset. Issuance shows a strong upward trend throughout the sample period, increasing steadily from just two issuances in 2015 to a peak of 97 in 2024. This trend indicates a sustained and significant rise in the use of green bonds by firms over time. The table also shows the total number of green patent applications submitted by firms in each year. While the number of patent applications peaks in 2016 and 2020, with 20 applications each, it declines sharply to seven in both 2022 and 2023 and falls further to zero in 2024 and 2025.

Table 2. Annual descriptive statistics of green bond issuance and green patent applications.

Year	Number of Companies	Number of Green Bond Issued	Number of Green Patent Applications
2015	285	2	21
2016	285	14	25
2017	285	29	20
2018	285	20	12
2019	285	47	16
2020	285	52	25
2021	285	55	14
2022	285	56	7
2023	285	62	7
2024	285	97	0
2025	285	31	0

Table 3 presents summary statistics for the dependent variable (number of patent applications per company), the main independent variable (number of green bond issues per issuer), and a set of time-varying firm-level control variables. For each of the 285 issuers, the table reports the cross-sectional averages of firm-level summary statistics, including the mean, standard deviation, minimum, median, and maximum over the studied period (2015-2025).

Table 3. Cross-sectional averages of firm-level summary statistics.

Variable	Measurement	Mean	Std. Dev.	Min	Median	Max.
Number of green bonds issued per issuer		0.148	0.236	0	0.0632	0.695
Number of patent applications per company		0.0469	0.0674	0	0.0281	0.200
Prior Issuance		0.153	0.152	0	0.158	0.326
Firm Size	Natural logarithm of total assets (ln)	6.197	0.543	5.460	6.287	6.720
Profitability	Natural logarithm of return on average total assets (ROA)	-4.192	0.813	-5.225	-4.144	-3.350
Growth	Natural logarithm of change rate of total revenue from business activities	0.172	0.470	-0.305	0.128	0.764
Leverage	Natural logarithm of total debt percentage of total equity	-0.0621	0.644	-0.793	-0.0659	0.623
Liquidity	Natural logarithm of quick ratio	0.134	0.406	-0.356	0.132	0.634

Note(s): In the original dataset, all monetary variables were denominated in USD, ensuring a uniform currency basis across firms. Firm size, profitability, growth, leverage, and liquidity are log-transformed to ease interpretation.

Several trends emerge from the summary statistics in Table 3. First, green bond issuance remains relatively uncommon among firms in the sample. Of the 1413 total bond issuances recorded in the dataset, only 465 are labeled as green. On average, firms issue 0.148 green bonds per year, indicating that bond issuance is relatively rare and likely concentrated among a small number of firms. The median number of green bonds issued per firm per year is 0.0632, which is substantially lower than the mean, confirming that a few firms are responsible for a disproportionate share of green bond activity. While many firms never issue green bonds, the most active issuers average 0.695 green bonds per year. The leading issuers in the dataset are the French multiline utilities firms Engie SA and Électricité de France SA, with 34 and 27 green bond issuances, respectively, between 2015 and 2025.

Second, firms in the dataset display very low levels of innovation activity over the analyzed period, as measured by green patent applications. On average, a firm files just 0.0469 green patent applications per year, with some firms not submitting any during the study period. Even among the most active innovators, the average is only about 0.2 patent applications per year, which is roughly one every five years. The most active firm, Engie SA, submitted only 30 patent applications between 2015 and 2025, while the second most active, Orsted Wind Power TW Holding A/S, submitted just 28 over the same period.

Third, over 15% of firms are repeat green bond issuers, indicating that the majority of firms are relatively new to the green bond market. Most firms either entered the market in the later years of the observation period or issued only a single green bond throughout the entire analyzed period.

CHAPTER V: EMPIRICAL APPROACH

5.1. Propensity Score Matching (PSM)

Isolating the effect of corporate green bond issuance on green innovation is challenged by self-selection bias, as green bond issuance is inherently non-random and firms self-select into the market (Ren et al., 2024). Self-selection arises when firms choose whether to participate in the treatment (e.g. green bond issuance) or remain in the control group of non-issuers (Békés & Kézdi, 2021). For example, firms operating in environmental protection industries are more likely to issue green bonds to finance sustainability-related projects. As a result, directly comparing issuers and non-issuers can lead to biased estimates, since the decision to issue a green bond is influenced by pre-existing firm-level characteristics. Issuers may systematically differ from non-issuers in both observable and unobservable dimensions, complicating causal inference.

As green bond issuance is endogenous among the 285 EU utilities in our sample, meaning likely driven by pre-existing firm characteristics, the analysis employs propensity score matching (PSM) to mitigate non-random selection bias (Rao et al., 2022; Dong et al., 2024; Ren et al., 2024; Dong & Yu, 2024). In this framework, green bond issuance constitutes the "treatment". Firms that issued at least one green bond during the study period (2015-2025) are classified as treated, while those issuing only conventional bonds serve as controls. First, the paper estimates each firm's propensity score, defined as the probability of issuing a green bond conditional on observable covariates (Békés & Kézdi, 2021). Next, a one-to-one nearest-neighbour matching is performed, pairing each treated issuer with a non-issuer that closely aligns on the following pre-issuance characteristics: firm size, growth, profitability, leverage, and liquidity.

Using the matched sample, the study then estimates two models. First, it estimates a linear probability model (LPM), in which the dependent variable is a dummy variable that indicates whether firm i filed at least one green patent application in year t, to analyze the effect of green bond issuance on subsequent patenting. Second, it estimates a log-linear model to capture patenting intensity, with the natural logarithm of the number of patent applications plus one as the outcome.

The main specifications include year fixed effects to absorb common shocks affecting all firms in a given year. As robustness checks, the models are also estimated (a) without fixed effects, which are better suited to smaller subsamples, and (b) with both country and year fixed effects to control for time-varying, country-level confounders. Because matching already balances observed firm-level attributes between treated and control firms, incorporating firm fixed effects would eliminate much of the cross-sectional variation needed to identify the treatment effect. Hence, firm fixed effects are only included in the naïve benchmark regressions using the unmatched sample to control for all time-invariant characteristics specific to each firm.

5.1.1. Linear Probability Model (LPM) with Fixed Effects

To estimate the effect of green bond issuance on the likelihood of subsequent patenting, the study employs a linear probability model (LPM) with year fixed effects, constructed as follows:

(1) $$PatentsDummy_{i,t} = \beta_0 + \beta_1\, GB_{i,t-1} + \beta_{\,2} PI_{i,t-1} + \gamma X_{i,t-1} + \lambda_t + \varepsilon_{i,t}$$

Among them, i is a firm and t is the year. $PatentsDummy$ is a dummy variable that equals 1 if firm i filed at least one green patent application in year t and 0 otherwise. GB is a dummy variable that equals 1 if firm i issued at least one green bond in year $t-1$ and 0 otherwise. $X_{i,t-1}$ denotes all controls for firm i in year $t-1$. One of the controls is PI, which equals 1 if firm i had ever issued at least one green bond before year $t-1$ and 0 otherwise. The remaining control variables are log-transformed firm characteristics, including: $FirmSize$ (proxied by total assets), $Growth$ (proxied by the rate of change in total revenue), $Profitability$ (proxied by ROA), $Leverage$ (proxied by the debt-to-equity ratio), and $Liquidity$ (proxied by the quick ratio). λ_t is year fixed effects and $\varepsilon_{i,t}$ is the random error term.

The LPM estimates the probability of submitting a patent application as a function of green bond issuance ($Pr(Application) = 1$). It is therefore estimated to test Hypothesis 1, which posits that firms that issued a green bond in the previous year are more likely to submit at least one patent application in the current year, and Hypothesis 2, which states that firms that have issued a green bond at any point in time are more likely to submit patent applications compared to firms that have never issued a green bond.

5.1.2. Log-Linear Regression Model with Fixed Effects

To estimate the effect of green bond issuance on patenting intensity, the study employs a log-linear regression model with year fixed effects, constructed as follows:

$$ln(PatentCount_{i,t} + 1) = \beta_0 + \beta_1 \, GB_{i,t-1} + \beta_{\,2} PI_{i,t-1} + \gamma X_{i,t-1} + \lambda_t + \varepsilon_{i,t} \quad (2)$$

Among them, $ln(PatentCount + 1)$ is the log-transformed patent count for firm i filed in year t. GB is a dummy variable that equals 1 if firm i issued at least one green bond in year $t-1$ and 0 otherwise. $X_{i,t-1}$ denotes all controls for firm i in year $t-1$. The controls included are the same as those in the LPM described in the previous section. λ_t is year fixed effects and $\varepsilon_{i,t}$ is the random error term.

The log-linear model estimates the effect of green bond issuance on patenting activity. This means that, for instance, if firm i issued a green bond in year $t-1$, the number of patent applications it is expected to file changes by approximately $100 \times \beta_1\%$. The model helps test Hypothesis 3, which predicts that firms that issued a green bond in the previous year submit a higher number of patent applications in the current year.

5.1.3. Addressing Endogeneity

Empirical studies that seek to identify the impact of green bond issuance on green innovation frequently face endogeneity concerns (Wan et al., 2024). Specifically, issues such as omitted variable bias, reverse causality, and self-selection bias can threaten the validity of causal inference. While PSM mitigates selection bias as described above, the study addresses omitted variable bias and reverse causality by including additional control variables, fixed effects, and lagged covariates.

5.2.3.1. Omitted Variable Bias

To alleviate the impact of covariates, the study includes a set of time-varying potential confounders as controls. These firm-level controls ensure that differences in green innovation outcomes between green bond issuers and non-issuers are not driven by pre-existing differences in firm characteristics. By including control variables employed in prior research, namely firm size, profitability, growth, leverage, and liquidity, the results drawn from the study are expected to be more directly comparable (Rao et al., 2022; Wang et al., 2022; Chen et al., 2023; Ma et al., 2023; Dong & Yu, 2024; Chen et al., 2023; Makpotche et al., 2023; Wan et al., 2024; Zhang et al., 2024). Additionally, the analysis employs year fixed effects models to absorb economy-wide shocks that vary over time but are common to all firms in a given year to further mitigate omitted variable bias.

5.2.3.2. Reverse Causality

Firms already engaged in green innovation may be more likely to issue green bonds, making it difficult to conduct causal inference. Some firms issue bonds to finance new projects, while others do so after already scaling up their R&D efforts. To address reverse causality, all independent variables are lagged by one period, ensuring that green bond issuance precedes innovation outcomes (Wan et al., 2024; Zhang et al., 2024).

CHAPTER VI: EMPIRICAL ANALYSIS

Before propensity score matching (PSM), this study conducts naïve benchmark regressions using the full dataset and standard controls on the unmatched sample to study the raw relationship between green bonds and green innovation. Linear probability models (LPMs) are estimated to analyze the effect of green bond issuance on subsequent patenting with a dummy variable as the outcome, while log-linear models are estimated to assess the effect on patenting intensity with a log-transformed continuous variable as the outcome. Each model is estimated using four alternative specifications for robustness: (1) no fixed effects, (2) firm and year fixed effects, (3) country and year fixed effects, and (4) year fixed effects.

The benchmark regression results using the unmatched sample, which consists of 691 firm-year observations, show that larger firms are more likely to innovate and innovate more. This result is consistent with previous research that suggests that firm size is positively associated with innovation due to their greater access to financial and human capital as well as their established R&D infrastructure (Koo & Cozzarin, 2021). However, the coefficients do not show a statistically significant relationship between green bonds and patenting. Table E in Appendix III displays the estimated coefficients.

6.1. Propensity Score Matching (PSM)

6.1.1. Pre-Matching Unconditional Mean Comparison (Welch t-Test)

The Welch t-test compares the likelihood of submitting a green patent application between green bond issuers (treated firms) and non-issuers (control firms) before matching. Table 4 indicates that treated firms have an average patenting probability of 8.33% whereas control firms have a 3.11% probability in the unmatched sample. This entails that green bond issuers are more than twice as likely to innovate compared to non-issuers even before adjusting for observed and unobserved differences. As the difference in patenting probability between issuers and non-issuers is statistically significant before matching, the next step is to conduct PSM to correct for this pre-existing imbalance in the sample and address selection bias.

Table 4. Welch Two-Sample t-Test of unconditional green patenting probability by treatment status.

Group	Mean Patent Probability	Observations	df	Statistic (t)	P-value	95% CI Lower	95% CI Upper
Control	0.0311	643	152.74	-2.081	0.039	-0.1018	-0.0026
Treated	0.0833	132					

Note(s): Alternative hypothesis: true difference in means between control and treated is not equal to 0.

6.1.2. Matching Procedure

To construct a matched sample of comparable treated and control firms, this study employs one to one nearest neighbor PSM. While raw variables are used for matching to maintain data integrity, log-transformed variables are applied in regression models. After matching, the resulting sample includes 224 observations, which comprise 112 treated and 112 control observations and correspond to 82 unique firms.

As reported in Table 5, the matched panel demonstrates that the matching substantially improved covariate balance, with all covariates exhibiting standardized mean differences (|SMD|) below 0.10 for five covariates and below 0.25 for the sixth. Figure 4 visualizes the same covariate balance before and after matching. As the propensity score distance is close to

|SMD|=0, the plot confirms that observable differences between issuers and non-issuers were minimized, reducing the effect of selection bias on future estimates.

Table 5. Covariate balance before and after matching.

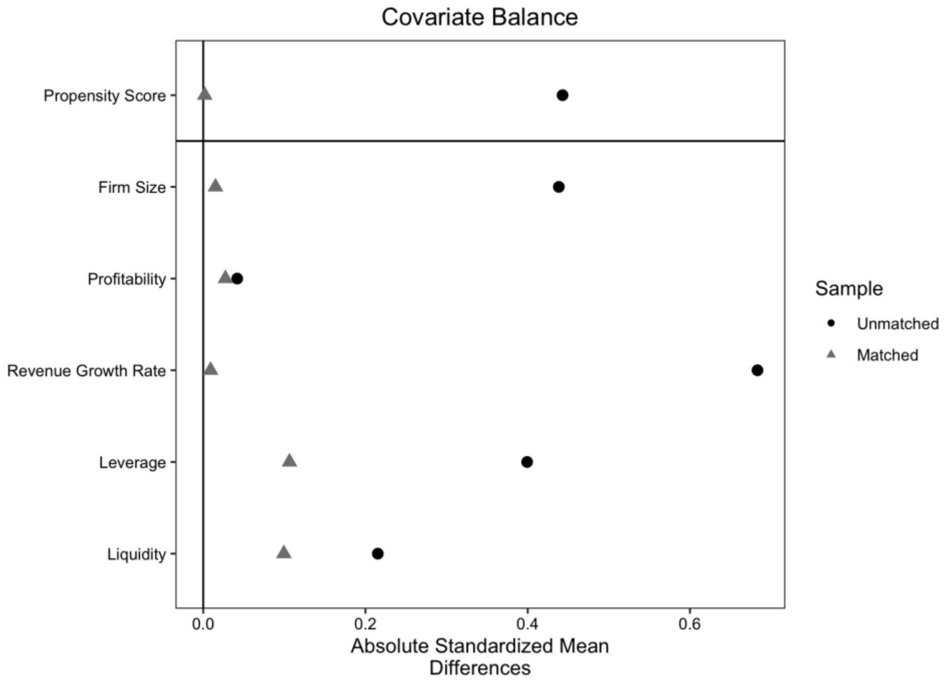
Variables	Unmatched or Matched	Mean Value		Std. Mean Diff.
		Control	Treatment	
Firm Size	Unmatched	13054.13	52241.57	0.44
	Matched	21533.37	22879.06	0.02
Profitability	Unmatched	0.03	0.03	0.04
	Matched	0.03	0.03	-0.03
Growth	Unmatched	0.48	0.17	-0.68
	Matched	0.18	0.18	0.01
Leverage	Unmatched	17.93	4.41	-0.40
	Matched	1.37	4.97	0.11
Liquidity	Unmatched	1.31	1.15	-0.22
	Matched	1.10	1.17	0.10

Note(s): The table displays the covariate balance of the sample before and after performing one-to-one nearest neighbor propensity score matching (PSM) using raw variables with a 0.10 caliper on the logit score.

6.1.3. Regression Analysis Using the Propensity Score Matched Sample

After PSM, this study estimates LPMs and log-linear models with year fixed effects as the main specification to examine the effect of green bond issuance on subsequent green patenting and patenting intensity using the matched sample. Consistent with the naïve benchmark regressions on the unmatched sample, the matched sample models suggest that larger firms are more likely to innovate and submit more green patent applications even without green bond issuances.

Figure 4. Variation of standardization deviation.



Note(s): The love plot illustrates the covariate balance before and after one-to-one nearest neighbor propensity score matching (PSM).

The coefficients in Table F of Appendix IV indicate that a one-unit increase in log firm size (total assets) is associated with a 1.9 to 3.2 percentage point increase in the likelihood of submitting at least one green patent application and a 2% to 2.8% increase in the number of green patents submitted annually. These findings imply that firm size is a statistically significant predictor of both the likelihood and intensity of patenting, providing robust evidence of its importance for green innovation. However, the regressions reveal no statistically significant relationship between green bond issuance and patenting.

These results raise the question of whether the lack of a significant effect in the matched sample is related to the one-year lag structure employed in the analysis. Prior studies suggest that the impact of green bond issuance is not immediate. For instance, Flammer (2021), Fatica and Panzica (2021), and Makpotche et al. (2023) find that green bonds do not produce measurable effects in the short term. Instead, firm-level greenhouse gas emissions tend to decline three years after issuance, and improvements in environmental performance typically emerge after five years, which is consistent with the notion that green projects require longer time horizons to generate tangible outcomes. Specifically for green technological innovation, the effects of green bond financing often materialize two to three years post-issuance, a period marked by a rise in green patent applications. However, this effect subsides after the third year (Rao et al., 2022).

To assess whether the impact of green bond issuance on innovation emerges only over a longer time horizon, this study extends the analysis by incorporating two-, three-, four-, and five-year lags. All previously specified models were re-estimated using these lag structures to evaluate whether delayed effects on green patenting activity and intensity become statistically significant over time across utilities firms in the dataset. Nevertheless, these models did not produce any statistically significant coefficients either, which is the reason why they are not presented in this section. Another possible explanation for the absence of an observed effect is greenwashing, wherein issuers allocate the proceeds from green bonds to projects that are not genuinely environmentally beneficial, but this exploration is outside the scope of this study.

Given the lack of a statistically significant average effect of green bond issuance, this study examines potential heterogeneity in treatment effects. Exploring variation across factors such as sector, country, firm size, and leverage can help identify whether green bonds affect innovation under specific conditions. The following sections investigate these differential impacts to uncover context-specific drivers of green innovation and identify potential dynamics that may be obscured in aggregate analyses.

6.2. Heterogeneity Analysis

6.2.1. Sub-Sector Heterogeneity

Sectoral heterogeneity has been identified in the literature as a key mediating factor in the link between green finance and innovation outcomes. This intuition is supported by empirical evidence showing that non-high-polluting firms show a stronger increase in green technological innovation compared to high-polluting enterprises after issuing green bonds (Ren et al., 2024; Zhang et al., 2024). For high-polluting firms, the effect of green bonds may be attenuated due to the structural and financial challenges they encounter when transitioning toward greener practices. These firms face heightened environmental pressure and regulatory scrutiny when issuing green bonds and typically require more capital-intensive investments to implement environmentally sustainable projects (Chen et al., 2024). Furthermore, investor skepticism and greenwashing concerns can reduce the credibility and perceived impact of green bond financing in such firms, thereby limiting its effectiveness in driving genuine innovation and environmental performance improvements (Zhang et al., 2022).

In line with the literature, this study expects that the effect of green bond issuance will be more pronounced among non-high-polluting firms. These firms typically face fewer structural barriers and lower transition costs, making them better positioned to translate green financing into innovation outcomes. Non-high-polluting firms in the dataset include those operating in alternative electric utilities, biomass and waste to energy utilities, geothermal utilities, hydroelectric and tidal utilities, independent power producers (IPPs), power charging stations, renewable IPPs, solar electric utilities, sewage utilities, wind electric utilities, water supply and irrigation systems, and other water-related utilities. High-polluting firms comprise those engaged in fossil fuel-based electric utilities, fossil fuel IPPs, natural gas distribution, and natural gas utilities. The pollution intensity of firms categorized as electric utilities, multiline utilities, and nuclear utilities can vary significantly depending on their specific energy mix and operational practices, which presents classification ambiguity. Table 6 displays a list of the sub-sectors included in the dataset.

Table 6. Number of utilities firms by sub-sector.

Sub-sector	Number of Firms	Number of Patent Applications	Sub-sector	Number of Firms	Number of Patent Applications
Alternative Electric Utilities	3	0	Natural Gas Utilities (NEC)	5	0
Biomass & Waste to Energy Electric Utilities	3	0	Nuclear Utilities	1	0
Electric Utilities (NEC)	120	37	Power Charging Stations	1	0
Fossil Fuel Electric Utilities	2	0	Renewable IPPs	31	1
Fossil Fuel IPPs	2	0	Solar Electric Utilities	20	2
Geothermal Electric Utilities	1	2	Sewage Treatment Facilities	3	0
Hydroelectric & Tidal Utilities	4	0	Wind Electric Utilities	13	30
Independent Power Producers (NEC)	6	0	Water Supply & Irrigation Systems	17	0
Multiline Utilities	30	75	Water & Related Utilities (NEC)	7	0
Natural Gas Distribution	17	0			

To assess sectoral heterogeneity, the analysis includes interaction terms between green bond issuance and industry dummies, allowing the effect of green bond issuance on innovation to vary across different sub-sectors. Table 6 displays the list of sub-sectors included in the dataset along with the number of patent applications submitted by each. Several sector-specific interaction terms were omitted due to collinearity, likely stemming from limited variation in green bond issuance or patenting within certain sectors. The models are constructed as follows:

(3)
$$PatentsDummy_{i,t} = \beta_0 + \beta_1\, GB_{i,t-1} + \sum_j \beta_{2j} Sector_{ij} + \sum_j \beta_{3j}(GB_{i,t-1} \times Sector_{ij}) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

(4)
$$ln(PatentCount_{i,t} + 1) = \beta_0 + \beta_1\, GB_{i,t-1} + \sum_j \beta_{2j} Sector_{ij} + \sum_j \beta_{3j}(GB_{i,t-1} \times Sector_{ij}) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

Table 7 reports the results from the heterogeneity analysis using Alternative Electric Utilities as the reference category in the interaction term analysis. Panel A presents a LPM estimating the effect of green bond issuance on subsequent patenting activity, using a binary outcome indicating whether a firm filed at least one green patent application. Panel B reports a log-linear model analyzing patenting intensity, measured as the log-transformed count of green patent applications.

Although the study's main specifications include year fixed effects, only the models that also incorporate country fixed effects yield a positive adjusted R2. Controlling for both year and country fixed effects improves model fit and enables a more accurate estimation by accounting for unobserved, time-invariant differences across countries that may influence the relationship between green bond issuance and green innovation. While the main matched-sample analysis consists of 691 observations, the regressions in Table 7 are based on a smaller subsample of 205 observations.

The results offer modest evidence that the impact of green bond issuance on innovation varies across sub-sectors. Specifically, green bond issuance is associated with a 20.5 percentage point decrease in the likelihood of filing a green patent application across electric utilities firms, on average, but no statistically significant effects on other sub-sectors are found.

6.2.2. Country-Level Heterogeneity

This section examines whether the effect of green bond issuance on innovation varies across countries, a list of which is presented in Table 8. The rationale for potential cross-country heterogeneity lies in differences in green finance infrastructure and regulatory environments. First, in countries with more developed green finance markets, issuers may benefit from lower issuance costs and stronger demand from sophisticated, sustainability-oriented investors (Lin & Hong, 2022). Second, variation in the stringency of environmental regulations and the strength of national innovation ecosystems may further influence the extent to which green bond financing translates into green technological innovation.

Zhang et al. (2024) discuss the influence of environmental regulation and highlight two main theoretical perspectives. On the one hand, stringent environmental regulation may hinder innovation by compelling firms to divert financial resources toward compliance related expenditures, such as pollution control and emission reduction. This reallocation can reduce investment in green R&D, which is often risky and requires long-term financial commitments. On the other hand, well-designed environmental regulation can stimulate innovation by encouraging firms to develop technologies that enhance operational efficiency and mitigate environmental impact, thereby offsetting regulatory compliance costs (Zhang et al., 2024).

Table 7. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, including interaction terms with industry sector.

	Panel A. Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)	**Panel B.** Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)
	Reg. (1)	Reg. (2)
Green Bond Dummy	**0.177** **(0.123)**	**0.173** **(0.119)**
Prior Issuance	**0.029** **(0.043)**	**0.058** **(0.045)**
Growth	-0.038 (0.079)	-0.004 (0.063)
Firm Size	0.039 (0.027)	0.034 (0.021)
Profitability	0.009 (0.019)	0.007 (0.020)
Leverage	-0.002 (0.024)	0.001 (0.025)
Liquidity	0.040 (0.035)	0.042 (0.033)

Electric Utilities	0.040 (0.118)	0.079 (0.113)
Hydroelectric & Tidal Utilities	0.048 (0.167)	0.123 (0.167)
Multiline Utilities	0.033 (0.138)	0.022 (0.121)
Natural Gas Distribution	-0.012 (0.159)	0.069 (0.152)
Natural Gas Utilities (NEC)	-0.022 (0.151)	0.076 (0.153)
Nuclear Utilities	0.112 (0.172)	0.146 (0.149)
Renewable IPPs	-0.055 (0.167)	-0.084 (0.207)
Electric Utilities	0.276 (0.178)	0.286 (0.182)
Water & Related Utilities (NEC)	0.064 (0.124)	0.087 (0.113)
Water Supply & Irrigation Systems	0.075 (0.130)	0.137 (0.137)
Wind Electric Utilities	0.031 (0.126)	0.081 (0.111)

Green Bond Dummy × Electric Utilities	-0.205*	-0.188
	(0.122)	(0.121)
Green Bond Dummy × Hydroelectric and Tidal Utilities	-0.348	-0.339
	(0.311)	(0.268)
Green Bond Dummy × Multiline Utilities	-0.246	-0.195
	(0.165)	(0.146)
Green Bond Dummy × Nuclear Utilities	-0.181	-0.138
	(0.161)	(0.141)
Green Bond Dummy × Renewable IPPs	-0.086	-0.019
	(0.159)	(0.163)
Green Bond Dummy × Water Supply & Irrigation Systems	-0.062	-0.117
	(0.129)	(0.154)
Green Bond Dummy × Wind Electric Utilities	0.054	-0.052
	(0.139)	(0.146)
Fixed Effects: Year	Yes	Yes
Fixed Effects: Country	Yes	Yes
Num.Obs.	205	205
R2	0.279	0.282
R2 Adj.	0.026	0.030

Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions *estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively*

To explore country-level heterogeneity, the models are constructed as follows:

(5)
$$PatentsDummy_{i,t} = \beta_0 + \beta_1\, GB_{i,t-1} + \sum_j \beta_{2j} Country_{ij} + \sum_j \beta_{3j}(GB_{i,t-1} \times Country_{ij}) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

(6)
$$ln(PatentCount_{i,t} + 1) = \beta_0 + \beta_1\, GB_{i,t-1} + \sum_j \beta_{2j} Country_{ij} + \sum_j \beta_{3j}(GB_{i,t-1} \times Country_{ij}) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

Table 8. Number of firms, patent applications, and green bond issuances per country.

Country	Number of Firms	Number of Patent Applications	Number of Green Bonds Issued	Country	Number of Firms	Number of Patent Applications	Number of Green Bonds Issued
Germany	63	47	30	Hungary	6	0	2
France	12	33	22	Ireland	3	0	6
Denmark	5	29	15	Latvia	2	0	5
Sweden	14	21	23	Lithuania	3	0	3
Italy	62	14	44	Luxembourg	2	0	1
Austria	10	1	11	Malta	2	0	1
Czech Republic	7	1	3	Netherlands	21	0	50
Portugal	7	1	10	Poland	5	0	4
Belgium	8	0	8	Romania	3	0	0
Bulgaria	2	0	0	Slovakia	3	0	0
Estonia	1	0	1	Slovenia	1	0	1
Finland	4	0	3	Spain	33	0	25
Greece	6	0	3				

Table 7 reports the results of the analysis using Austria as the reference category in the interaction term analysis. Panel C presents LPMs estimating the effect of green bond issuance on subsequent patenting activity, using a binary outcome indicating whether a firm filed at least one green patent application. Panel D reports log-linear models analyzing patenting intensity, measured as the log-transformed count of green patent applications. Regressions (4) and (6), which include year fixed effects, serve as the main specifications. Regressions (3) and (5), estimated without fixed effects, are included as robustness checks. While the main matched-sample analysis consists of 691 observations, the regressions in Table 7 are based on a smaller subsample of 205 observations.

The analysis finds that innovation varies across countries in the dataset and so does the impact of green bond issuance on patenting. Firstly, some countries display higher baseline levels of probability of innovation than the reference country, Austria, even without green bond issuance, whereas others display a lower probability of patenting. Firms in Germany (30 percentage points higher at the 10% level) and Slovenia (14.1 percentage points higher at the 10% level) have a higher baseline probability of innovating, while Denmark (11.1 percentage points lower at the 10% level), Czech Republic (9.7 percentage points lower at the 10% level), Luxembourg (9.4 percentage points lower at the 5% level), and Portugal (15 percentage points lower at the 10% level) have a lower likelihood of patenting. Secondly, baseline coefficients indicate that Denmark, Portugal, and Slovenia innovate less than Austria. The number of patent applications submitted by firms is 3.8% lower (10% level) in Denmark, 4.5% (10% level) lower in Portugal, and 5.5% (10% level) lower in Slovenia compared to Austria, on average.

Thirdly, green bonds are associated with lower patenting probability across firms in some countries and higher in others. Green bond issuance is associated with a 12 percentage point higher likelihood of patenting across Austrian firms (10% level) and a 1.7 percentage point lower patenting probability in Danish firms (10% level). Moreover, the effect of green bond issuance across Italian firms decreases subsequent patenting by 14.8 (5% level) to 16.4 (10% level) percentage points. Fourthly, green bond issuance increases innovation output in Austria and decreases it in Italy. On average, Austrian utilities firms submit 8.2% more green patent applications following green bond issuance, while Italian ones submit 12.1% less.

Table 9. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, including country interaction terms.

	Panel C. Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)		**Panel D.** Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)	
	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.213		-0.177	
	(0.166)		(0.131)	
Green Bond Dummy	**0.142**	**0.120***	**0.089**	**0.082***
	(0.122)	**(0.071)**	**(0.090)**	**(0.046)**
Prior Issuance	**0.011**	**0.050**	**0.017**	**0.059***
	(0.030)	(0.036)	(0.026)	(0.035)
Growth	0.032	0.037*	0.027*	0.032**
	(0.020)	(0.020)	(0.015)	(0.016)
Firm Size	-0.038	-0.011	-0.029	0.002
	(0.042)	(0.048)	(0.031)	(0.037)
Profitability	0.007	-0.001	0.007	-0.001
	(0.012)	(0.012)	(0.013)	(0.012)
Leverage	0.008	0.005	0.005	0.006
	(0.020)	(0.020)	(0.019)	(0.020)
Liquidity	0.013	0.038	0.012	0.034

	(0.023)	(0.026)	(0.020)	(0.024)
Belgium	-0.045	-0.032	-0.037	-0.017
	(0.060)	(0.042)	(0.050)	(0.033)
Bulgaria	-0.035	-0.020	-0.031	-0.051
	(0.072)	(0.065)	(0.065)	(0.072)
Czech Republic	-0.088	-0.097*	-0.075	-0.073
	(0.078)	(0.056)	(0.063)	(0.045)
Denmark	-0.122	-0.111*	-0.113*	-0.120*
	(0.079)	(0.063)	(0.066)	(0.067)
Estonia	-0.017	0.023	-0.018	0.043
	(0.059)	(0.044)	(0.050)	(0.046)
Finland	-0.011	-0.031	-0.012	-0.026
	(0.051)	(0.040)	(0.044)	(0.029)
France	-0.084	-0.097	-0.072	-0.076
	(0.077)	(0.061)	(0.060)	(0.046)
Germany	0.273	0.300*	0.281	0.301
	(0.192)	(0.170)	(0.209)	(0.194)
Greece	-0.014	-0.013	-0.014	-0.001
	(0.062)	(0.072)	(0.053)	(0.063)
Hungary	0.078	0.069	0.064	0.081
	(0.073)	(0.078)	(0.059)	(0.067)
Italy	0.104	0.109	0.068	0.082
	(0.090)	(0.079)	(0.067)	(0.056)

Latvia	0.271	0.289	0.217	0.247
	(0.188)	(0.202)	(0.150)	(0.159)
Lithuania	-0.055	0.046	-0.056	0.047
	(0.058)	(0.055)	(0.050)	(0.058)
Luxembourg	-0.008	-0.094**	-0.008	-0.063
	(0.050)	(0.047)	(0.044)	(0.039)
Netherlands	-0.040	-0.045	-0.036	-0.057
	(0.058)	(0.045)	(0.048)	(0.042)
Poland	-0.052	-0.009	-0.045	-0.027
	(0.066)	(0.042)	(0.055)	(0.048)
Portugal	-0.106	-0.150*	-0.090	-0.127*
	(0.085)	(0.081)	(0.066)	(0.064)
Slovenia	0.044	0.141**	0.033	0.137*
	(0.053)	(0.069)	(0.045)	(0.072)
Spain	0.016	-0.001	0.010	0.010
	(0.064)	(0.064)	(0.054)	(0.051)
Sweden	-0.075	-0.105	-0.042	-0.068
	(0.138)	(0.079)	(0.102)	(0.055)
Green Bond Dummy × Belgium	-0.125	-0.081	-0.078	-0.071
	(0.114)	(0.084)	(0.087)	(0.072)
Green Bond Dummy × Denmark	-0.116	-0.137*	-0.066	-0.075
	(0.114)	(0.073)	(0.084)	(0.054)

Green Bond Dummy × Finland	-0.164	-0.023	-0.107	-0.005
	(0.130)	(0.090)	(0.099)	(0.071)
Green Bond Dummy × France	0.004	0.033	0.073	0.081
	(0.175)	(0.138)	(0.168)	(0.139)
Green Bond Dummy × Germany	-0.234	-0.241	-0.077	-0.081
	(0.250)	(0.223)	(0.214)	(0.193)
Green Bond Dummy × Greece	-0.183	-0.078	-0.128	-0.046
	(0.131)	(0.102)	(0.098)	(0.078)
Green Bond Dummy × Italy	-0.284*	-0.268**	-0.202*	-0.203**
	(0.158)	(0.128)	(0.112)	(0.088)
Green Bond Dummy × Latvia	-0.201	-0.150	-0.137	-0.093
	(0.141)	(0.098)	(0.107)	(0.069)
Green Bond Dummy × Netherlands	-0.154	-0.119	-0.105	-0.063
	(0.122)	(0.083)	(0.088)	(0.057)
Green Bond Dummy × Poland	-0.111	-0.010	-0.064	0.054
	(0.150)	(0.115)	(0.111)	(0.112)
Green Bond Dummy × Portugal	-0.122	-0.053	-0.079	-0.022
	(0.135)	(0.114)	(0.099)	(0.080)
Green Bond Dummy × Spain	-0.135	-0.117	-0.083	-0.094
	(0.132)	(0.099)	(0.098)	(0.074)
Fixed Effects: Year	No	Yes	No	Yes
Fixed Effects: Country	No	No	No	No

Num.Obs.	205	205	205	205
R2	0.208	0.289	0.224	0.282
R2 Adj.	0.021	0.076	0.040	0.067

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

6.2.3. Firm Size–Based Heterogeneity

In this section, the interaction term between green bond issuance and firm size is used to assess the moderating role of total assets in the relationship between green bond issuance and green innovation. This analysis is motivated by prior studies suggesting that green bond issuance may have a stronger positive effect on green innovation among large firms. Given their more substantial financial resources and lower exposure to financial constraints, large firms are better positioned to allocate proceeds from green bonds toward green R&D, thereby facilitating greater engagement in green patenting activity (Dong & Yu, 2024). The models are constructed as follows:

(7) $$PatentsDummy_{i,t} = \beta_0 + \beta_1 GB_{i,t-1} + \beta_2 FirmSize_i + \beta_{3j}(GB_{i,t-1} \times Firm\ size_i) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

(8) $$ln(PatentCount_{i,t} + 1) = \beta_0 + \beta_1 GB_{i,t-1} + \beta_2 FirmSize_i + \beta_{3j}(GB_{i,t-1} \times Firm\ size_i) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

Results from this analysis suggest that, although larger firms are more likely to innovate and submit more patent applications than smaller firms, green bonds do not moderate this relationship. As shown in Table I of Appendix V, green bonds do not significantly increase innovation outcomes across the matched sample, indicating that their effect may be limited or context dependent. To further examine the moderating effect of firm size, the matched sample is divided into large and small firms based on the median value of the log-transformed total assets variable. The firm-level median size is 8.28, resulting in a large firm subsample of 45 firms and a small firm subsample of 39 firms. The results, presented in Appendix V, provide no evidence of a moderating effect of firm size on the relationship between green bond issuance and innovation.

6.2.4. Leverage-Based Heterogeneity

To assess whether the relationship between green bond issuance and green patenting varies with a firm's leverage, this section examines the moderating role of leverage by including an interaction term between green bond issuance and leverage. This approach is motivated by prior research suggesting that high financial leverage may suppress green innovation output since elevated debt levels increase financial constraints, limiting a firm's capacity and willingness to invest in long-term, high-risk activities such as R&D for green technologies. Green bonds, by offering long-term and low-cost capital, can ease these constraints and reduce pressure from existing debt (Dong & Yu, 2024). As a result, low leverage firms are expected to be more likely to channel green bond proceeds toward innovation, whereas high leverage firms may prioritize debt repayment, potentially crowding out investment in green R&D. The models are constructed as follows:

(9) $$PatentsDummy_{i,t} = \beta_0 + \beta_1\, GB_{i,t-1} + \beta_{\,2} Leverage_i + \beta_{\,3j}(GB_{i,t-1} \times Leverage_i\ ) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

(10) $$ln(PatentCount_{i,t} + 1) = \beta_0 + \beta_1\, GB_{i,t-1} + \beta_{\,2} Leverage_i + \beta_{\,3j}(GB_{i,t-1} \times Leverage_i\ ) + \gamma X_{i,t-1} + \varepsilon_{i,t} + \lambda_t$$

Results from this analysis suggest that leverage does not significantly moderate the relationship between green bonds and innovation, as shown in Table L from Appendix V. To further examine the moderating effect of leverage, the matched sample is divided into high and low leverage firms based on the median value of the log-transformed debt-to-equity ratio. The firm-level median leverage is -0.089, resulting in a high leverage subsample of 48 firms and a low leverage subsample of 44 firms. The coefficients indicate that prior green bond issuance is associated with an 11.8% increase in the number of green patent applications submitted by a low leverage firm, on average. However, this effect is only statistically significant at the 10% level in one model specification that includes both country and year fixed effects, suggesting that the relationship is not robust and may be sensitive to how unobserved heterogeneity is controlled.

6.3. Limitations

While the research design of this study offers insights, it is subject to several limitations. First, the relatively small sample size of 285 bond-issuing utilities firms in the period between 2015 and 2025 constraints the statistical power of the analysis and limits the external validity of the findings. Hence, the results of this study may not be generalizable to other sectors or regions, especially those with different financing structures or regulatory environments.

Second, green patent applications may not fully capture the scope of climate adaptation and mitigation technology development. Many firms may engage in technological advancements that contribute to the decarbonization of the utilities sector without necessarily classifying these innovations as 'green' or seeking patent protection. Moreover, firms that entered the green bond market in the later years of the study period may not have had sufficient time to allocate proceeds to R&D projects and submit corresponding patent applications. It is important to note that while the European Investment Bank (EIB) issued the first green bond in 2007 and the first corporate green bond in the EU was launched in 2013, the market only began to expand significantly following the Paris Agreement in 2015. Given that the innovation effects of green bond issuance are typically observable only after a lag of three to five years (Flammer, 2021; Fatica & Panzica, 2021; Makpotche et al., 2023), firms issuing green bonds after 2020 may not yet exhibit measurable innovation outcomes in patent data.

CHAPTER VII: CONCLUSION

The analysis covers 285 utilities firms based in the EU that issued either conventional or green corporate bonds between December 2015 and May 2025. Using annual panel data, the core empirical strategy of this study is one-to-one nearest-neighbor propensity score matching (PSM), whereby each green bond issuer is paired with a conventional bond issuer with similar observable characteristics to isolate the impact of bond type on innovation outcomes. This paper contributes to the existing literature by focusing on the utilities sector, which is the backbone of the green transition, and by drawing on a novel European sample in a context where most empirical evidence to date has been concentrated in China.

Using the number of patent applications to examine the effect of green bond issuance on the likelihood and volume of green innovation, the study finds that the impact is not uniform across utilities firms. Instead, the effect varies by country and, to some extent, by industry. The results indicate that green bond issuance fosters innovation in Austria but appears to slightly reduce innovation in Denmark, Italy, and among electric utilities firms more broadly. While the findings do not offer robust support for Hypotheses 1, 2, or 3, they underscore the role of regulatory and institutional environments as well as industry-level dynamics in shaping the climate mitigation and adaptation technology outputs of utilities firms in the EU.

Several policy implications can be drawn from these findings. First, since the effect of green bonds on green innovation is moderated by a firm's country of domicile, EU governments should ensure that environmental regulations are sufficiently stringent to incentivize the development and adoption of sustainable technologies, yet not so restrictive that they divert resources away from green R&D toward compliance costs. Second, regulators at both the EU and national levels should continue advancing the harmonization of the European Green Bonds Regulation across member states. A standardized framework for green bond issuance, which seeks to enhance the consistency and credibility of green bond classifications, is essential to ensure uniform application throughout the EU. Such harmonization is critical for fostering investor confidence and minimizing the risk of greenwashing by issuers. Third, policymakers should tailor legal and regulatory frameworks to incentivize innovation across firms with diverse characteristics, including variations in size, profitability, leverage, liquidity, and growth potential. While the evidence remains modest, this study indicates that sectoral heterogeneity moderates the relationship between green bond issuance and green innovation. In particular, high-polluting firms often face structural barriers and elevated transaction costs that hinder their transition to greener practices. Therefore, targeted policy interventions, such as tax incentives and other supportive mechanisms, should be designed to stimulate green innovation within these sectors, complementing the capital raised through green bond issuance and facilitating their effective integration into the sustainable economy.

Future research should investigate the role of EU-level legislation and regulatory frameworks in moderating the relationship between green bond issuance and the development of green technologies. A promising avenue for further studies is the impact of the European Green Bonds Regulation, which came into force in 2023 and began applying in 2024. Moreover, subsequent studies should move beyond measuring the likelihood or volume of innovation and place greater emphasis on the quality of green innovations. This is especially relevant for sectors such as utilities, where certain technologies might be more likely to accelerate the transition toward a low-carbon economy.

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APPENDIX I.

DISTRIBUTION OF KEY VARIABLES AND LOG-TRANSFORMATIONS

Firm Size

Figure 1.1. Distribution of Raw Firm Size (Total Assets)

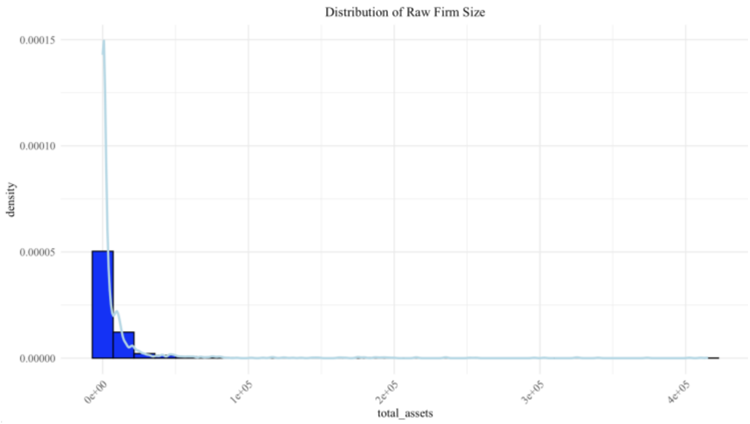
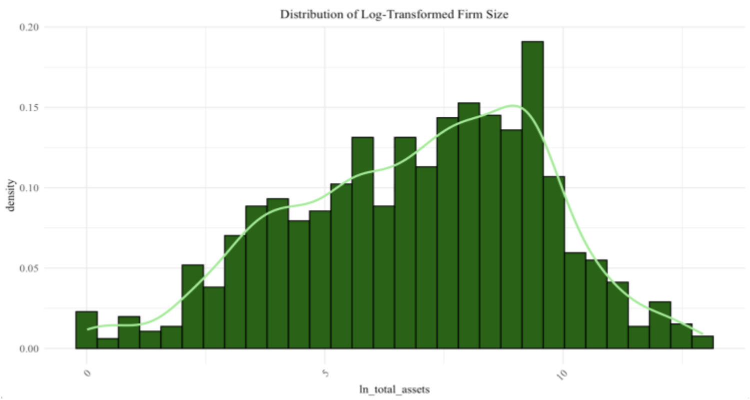


Figure 1.2. Distribution of Log-Transformed Firm Size (ln(Total Assets))



Leverage

Figure 1.3. Distribution of Raw Leverage (Debt-to-Equity Ratio)

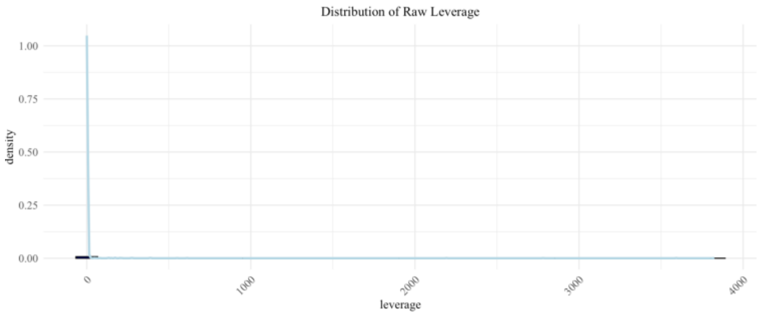
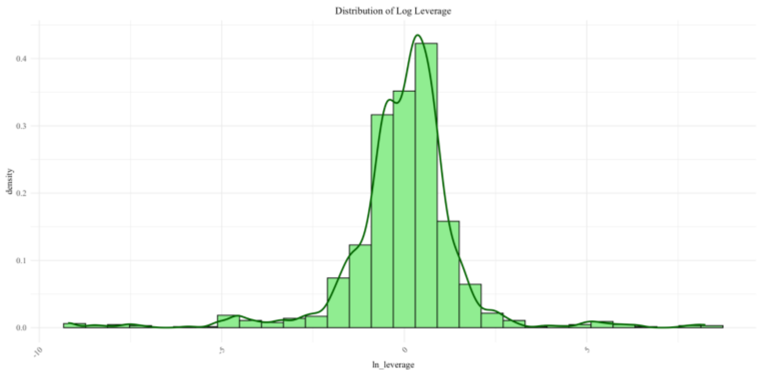


Figure 1.4. Distribution of Log-Transformed Leverage (ln(Debt-to-Equity Ratio))



Liquidity

Figure 1.5. Distribution of Raw Liquidity (Quick Ratio)

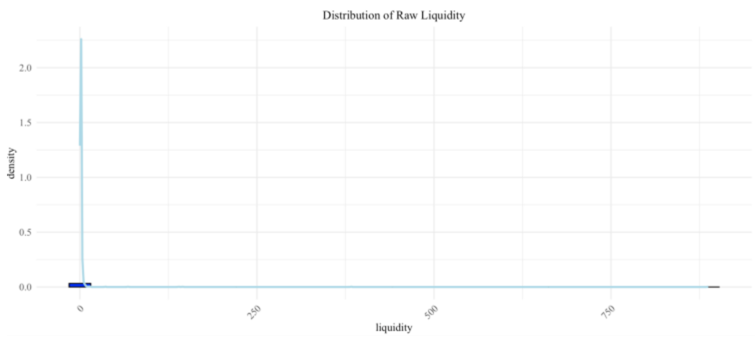
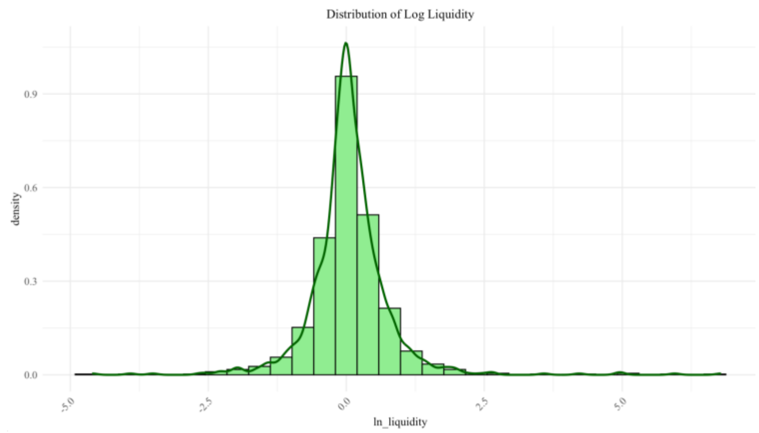


Figure 1.6. Distribution of Log-Transformed Liquidity (ln(Quick Ratio))



Business Revenue Growth Rate

Figure 1.7. Distribution of Raw Revenue Growth Rate (% Change in Revenue)

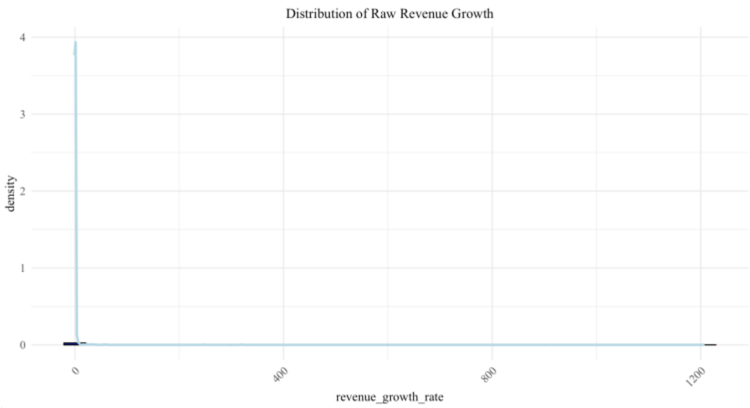
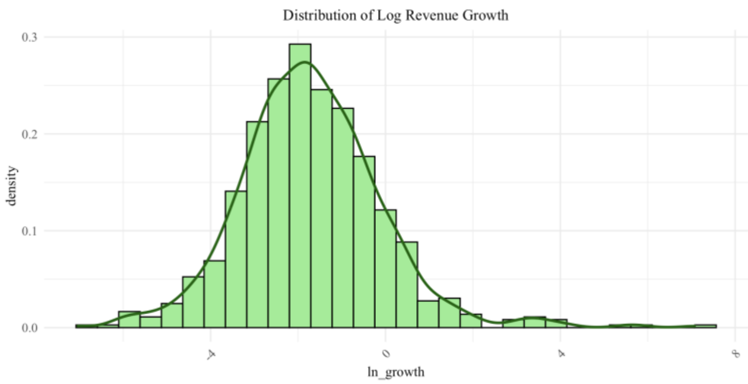


Figure 1.8. Distribution of Log-Transformed Revenue Growth Rate (ln(% Change in Revenue))



Profitability

Figure 1.9. Distribution of Raw Profitability (ROA)

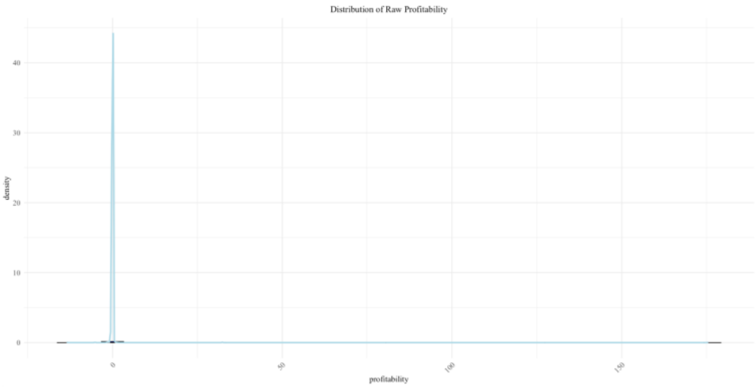


Figure 1.10. Distribution of Log-Transformed Profitability (ln(ROA))

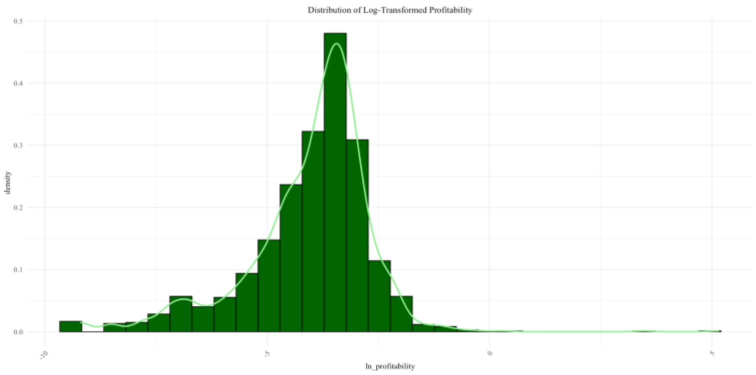


Table A. Sensitivity analysis of regression estimates with and without profitability as a control variable with matched sample.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)					
	With Profitability	Without Profitability	With Profitability	Without Profitability	With Profitability	Without Profitability
	Reg (1)	Reg (2)	Reg (3)	Reg (4)	Reg (5)	Reg (6)
(Intercept)	-0.071	-0.103				
	(0.083)	(0.066)				
Green Bond Dummy	**-0.014**	**-0.030**	**-0.018**	**-0.022**	**-0.011**	**-0.022**
	(0.029)	**(0.031)**	**(0.038)**	**(0.036)**	**(0.025)**	**(0.026)**
Prior Issuance Dummy	**-0.006**	**-0.012**	**0.028**	**0.029**	**0.024**	**0.029**
	(0.024)	(0.024)	(0.034)	(0.032)	(0.026)	(0.025)
Firm Size	0.019*	0.021**	0.032*	0.030**	0.022**	0.023**
	(0.010)	(0.010)	(0.018)	(0.015)	(0.010)	(0.010)
Revenue Growth Rate	-0.044	-0.010	-0.006	0.012	-0.026	0.007
	(0.034)	(0.041)	(0.044)	(0.046)	(0.037)	(0.045)
Profitability	0.007		-0.004		0.001	
	(0.010)		(0.012)		(0.011)	
Leverage	-0.009	0.000	-0.004	0.025	-0.013	-0.002

	(0.012)	(0.014)	(0.018)	(0.020)	(0.011)	(0.014)
Liquidity	0.014	0.016	0.035	0.049*	0.032	0.034
	(0.016)	(0.015)	(0.026)	(0.026)	(0.021)	(0.021)
FE: year			Yes	Yes	Yes	Yes
FE: country			Yes	Yes		
Num.Obs.	205	224	205	224	205	224
R2	0.045	0.050	0.249	0.273	0.110	0.120
R2 Adj.	0.011	0.024	0.094	0.142	0.040	0.061

*Note(s): OLS regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). All regressions estimate the probability of a firm submitting a green patent application in a given year, based on a dummy variable indicating green bond issuance. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Table B. Sensitivity analysis of regression estimates with and without profitability as a control variable with matched sample.

	Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)					
	With Profitability	Without Profitability	With Profitability	Without Profitability	With Profitability	Without Profitability
	Reg (1)	Reg (2)	Reg (3)	Reg (4)	Reg (5)	Reg (6)
(Intercept)	-0.098	-0.122				
	(0.086)	(0.073)				
Green Bond Dummy	**-0.006**	**-0.023**	**-0.002**	**-0.008**	**-0.003**	**-0.016**
	(0.022)	**(0.025)**	**(0.031)**	**(0.031)**	**(0.020)**	**(0.022)**
Prior Issuance Dummy	**-0.002**	**-0.010**	**0.041**	**0.043**	**0.030**	**0.035**
	(0.020)	(0.021)	(0.031)	(0.031)	(0.025)	(0.025)
Firm Size	0.020*	0.022**	0.028*	0.027**	0.021*	0.023**
	(0.011)	(0.011)	(0.015)	(0.012)	(0.011)	(0.011)
Growth	-0.029	0.016	0.007	0.041	-0.009	0.038
	(0.026)	(0.048)	(0.035)	(0.052)	(0.030)	(0.054)
Profitability	0.004		-0.004		-0.001	
	(0.011)		(0.012)		(0.011)	
Leverage	-0.009	-0.001	-0.003	0.022	-0.010	-0.002
	(0.011)	(0.012)	(0.019)	(0.019)	(0.010)	(0.013)
Liquidity	0.015	0.017	0.032	0.046**	0.031	0.034

	(0.015)	(0.015)	(0.024)	(0.022)	(0.021)	(0.021)
FE: year			Yes	Yes	Yes	Yes
FE: country			Yes	Yes		
Num.Obs.	205	224	205	224	205	224
R2	0.041	0.048	0.254	0.274	0.085	0.100
R2 Adj.	0.007	0.021	0.099	0.143	0.012	0.040

*Note(s): OLS regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). All regressions estimate the probability of a firm submitting a green patent application in a given year, based on a dummy variable indicating green bond issuance. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

APPENDIX II.

CORRELATION ANALYSES

Table C. Variable correlation analysis with variables from the unmatched sample.

	Green Bond Dummy	Patents Dummy	Patent Count	Firm Size	Profitability	Leverage	Liquidity	Revenue Growth Rate	Prior Issuance
Green Bond Dummy	1.00***								
Patents Dummy	0.11***	1.00***							
Patent Count	0.12***	0.92***	1.00***						
Firm Size	0.25***	0.14***	0.13***	1.00***					
Profitability	-0.05*	0.07**	0.08***	-0.05*	1.00***				
Leverage	0.01	0.06*	0.06**	-0.01	-0.17***	1.00***			
Liquidity	-0.02	-0.02	-0.02	-0.05*	0.03	-0.08**	1.00***		
Revenue Growth Rate	-0.04	-0.04	-0.03	-0.09***	0.12***	0.00	-0.01	1.00***	
Prior Issuance	0.42***	0.06***	0.06***	0.21***	-0.00	0.05	-0.01	0.01	1.00***

*Note(s): All coefficients are Pearson-r values. Patents Dummy denotes whether firm i filed a green patent application in year t. Number of patents denotes the actual number of patent applications filed by firm i in year t. ; stars denote two-tailed p-values: *** p ≤ 0.01, ** p ≤ 0.05, * p ≤ 0.10).*

Table D. Variable correlation analysis with variables from the matched sample.

	Green Bond Dummy	Patents Dummy	Patent Count	Firm Size	Profitability	Leverage	Liquidity	Revenue Growth Rate	Prior Issuance
Green Bond Dummy	1.00***								
Patents Dummy	-0.06	1.00***							
Patent Count	-0.04	0.93***	1.00***						
Firm Size	0.10	0.21***	0.21***	1.00***					
Profitability	-0.03	0.04	0.02	0.00	1.00***				
Leverage	0.05	0.06	0.06	0.31***	-0.05	1.00***			
Liquidity	0.01	-0.01	-0.01	-0.20***	0.23***	-0.07	1.00***		
Revenue Growth Rate	0.00	-0.03	0.01	-0.10	0.19***	0.09	0.05	1.00***	
Prior Issuance	0.53***	-0.06	-0.04	0.01	-0.03	-0.06	-0.02	-0.01	1.00***

*Note(s): All coefficients are Pearson-r values. Patents Dummy denotes whether firm i filed a green patent application in year t. Number of patents denotes the actual number of patent applications filed by firm i in year t. ; stars denote two-tailed p-values: *** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$).*

APPENDIX III.

BENCHMARK ANALYSIS

Table E. Baseline regression results for the impact of green bonds on patenting activity and intensity using the unmatched sample.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
Green Bond Dummy	**0.013**	**0.007**	**0.017**	**0.027**	**0.019**	**0.031**
	(0.024)	**(0.028)**	**(0.024)**	**(0.029)**	**(0.030)**	**(0.030)**
Prior Issuance	**-0.005**	**0.025**	**0.019**	**-0.020**	**0.009**	**0.006**
	(0.017)	**(0.021)**	**(0.017)**	**(0.021)**	**(0.018)**	**(0.016)**
Firm Size	0.021***	0.028***	0.022***	0.023**	0.030***	0.024**
	(0.008)	(0.010)	(0.008)	(0.009)	(0.011)	(0.010)
Growth	-0.018	-0.005	-0.013	-0.015	-0.004	-0.011
	(0.011)	(0.010)	(0.010)	(0.011)	(0.012)	(0.011)
Profitability	-0.005	-0.006	-0.005	-0.011	-0.012	-0.011
	(0.008)	(0.007)	(0.008)	(0.013)	(0.010)	(0.013)
Leverage	0.002	0.003	0.003	0.001	0.002	0.003

	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.006)
Liquidity	0.001	0.001	0.007	0.002	0.002	0.009
	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.012)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	691	691	691	691	691	691
R2	0.077	0.163	0.104	0.075	0.155	0.098
R2 Adj.	0.068	0.116	0.085	0.065	0.107	0.078

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

APPENDIX IV.

REGRESSION ANALYSES USING THE PROPENSITY SCORE MATCHED SAMPLE

Table F. Regression results for the impact of green bond issuance on patenting activity and intensity using the matched sample.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
Green Bond Dummy	**-0.014**	**-0.018**	**-0.011**	**-0.006**	**-0.002**	**-0.003**
	(0.029)	**(0.038)**	**(0.025)**	**(0.022)**	**(0.031)**	**(0.020)**
Prior Issuance	**-0.006**	**0.028**	**0.024**	**-0.002**	**0.041**	**0.030**
	(0.024)	**(0.034)**	**(0.026)**	**(0.020)**	**(0.031)**	**(0.025)**
Firm Size	0.019*	0.032*	0.022**	0.020*	0.028*	0.021*
	(0.010)	(0.018)	(0.010)	(0.011)	(0.015)	(0.011)
Growth	-0.044	-0.006	-0.026	-0.029	0.007	-0.009
	(0.034)	(0.044)	(0.037)	(0.026)	(0.035)	(0.030)
Profitability	0.007	-0.004	0.001	0.004	-0.004	-0.001
	(0.010)	(0.012)	(0.011)	(0.011)	(0.012)	(0.011)
Leverage	-0.009	-0.004	-0.013	-0.009	-0.003	-0.010

	(0.012)	(0.018)	(0.011)	(0.011)	(0.019)	(0.010)
Liquidity	0.014	0.035	0.032	0.015	0.032	0.031
	(0.016)	(0.026)	(0.021)	(0.015)	(0.024)	(0.021)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	205	205	205	205	205	205
R2	0.045	0.249	0.110	0.041	0.254	0.085
R2 Adj.	0.011	0.094	0.040	0.007	0.099	0.012

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

APPENDIX V.

HETEROGENEITY ANALYSES

Utilities Sub-Sectors Heterogeneity Analysis

Table G. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, including interaction terms with industry sector.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.093			-0.135		
	(0.137)			(0.136)		
Green Bond Dummy	**0.083**	**0.177**	**0.135**	**0.059**	**0.173**	**0.105**
	(0.062)	**(0.123)**	**(0.098)**	**(0.048)**	**(0.119)**	**(0.075)**
Prior Issuance	**-0.016**	**0.029**	**0.023**	**-0.009**	**0.058**	**0.034**
	(0.028)	**(0.043)**	**(0.031)**	**(0.024)**	**(0.045)**	**(0.032)**
Growth	-0.108*	-0.038	-0.085	-0.076*	-0.004	-0.050
	(0.056)	(0.079)	(0.062)	(0.042)	(0.063)	(0.047)

Firm Size	0.018	0.039	0.022	0.019	0.034	0.021*
	(0.013)	(0.027)	(0.014)	(0.013)	(0.021)	(0.013)
Profitability	0.007	0.009	0.005	0.002	0.007	-0.000
	(0.014)	(0.019)	(0.014)	(0.014)	(0.020)	(0.014)
Leverage	-0.006	-0.002	-0.012	-0.005	0.001	-0.007
	(0.016)	(0.024)	(0.016)	(0.014)	(0.025)	(0.016)
Liquidity	0.016	0.040	0.036	0.023	0.042	0.043
	(0.023)	(0.035)	(0.030)	(0.024)	(0.033)	(0.036)
Green Bond Dummy × Electric Utilities	-0.089	-0.205*	-0.141	-0.063	-0.188	-0.105
	(0.073)	(0.122)	(0.101)	(0.052)	(0.121)	(0.072)
Green Bond Dummy × Hydroelectric and Tidal Utilities	-0.351*	-0.348	-0.408	-0.255*	-0.339	-0.341
	(0.196)	(0.311)	(0.246)	(0.145)	(0.268)	(0.205)
Green Bond Dummy × Multiline Utilities	-0.159	-0.246	-0.201	-0.092	-0.195	-0.134
	(0.121)	(0.165)	(0.138)	(0.100)	(0.146)	(0.112)
Green Bond Dummy × Nuclear Utilities	-0.129	-0.181	-0.115	-0.084	-0.138	-0.038
	(0.121)	(0.161)	(0.138)	(0.107)	(0.141)	(0.116)
Green Bond Dummy × Renewable IPPs	-0.137	-0.086	-0.190	-0.113	-0.019	-0.148
	(0.088)	(0.159)	(0.120)	(0.069)	(0.163)	(0.092)
Green Bond Dummy × Water Supply & Irrigation Systems	-0.068	-0.062	-0.056	-0.040	-0.117	-0.056
	(0.059)	(0.129)	(0.079)	(0.048)	(0.154)	(0.076)
Green Bond Dummy × Wind Electric	0.132	0.054	0.044	0.083	-0.052	0.007

Utilities	(0.104)	(0.139)	(0.122)	(0.075)	(0.146)	(0.098)
Electric Utilities (NEC)	0.029	0.040	0.050	0.042	0.079	0.052
	(0.038)	(0.118)	(0.065)	(0.038)	(0.113)	(0.049)
Hydroelectric & Tidal Utilities	-0.001	0.048	0.056	0.009	0.123	0.063
	(0.043)	(0.167)	(0.073)	(0.041)	(0.167)	(0.062)
Multiline Utilities	0.092	0.033	0.100	0.061	0.022	0.061
	(0.078)	(0.138)	(0.086)	(0.060)	(0.121)	(0.066)
Natural Gas Distribution	-0.043	-0.012	-0.014	-0.017	0.069	0.005
	(0.057)	(0.159)	(0.077)	(0.051)	(0.152)	(0.063)
Natural Gas Utilities (NEC)	-0.056	-0.022	-0.002	-0.030	0.076	0.026
	(0.045)	(0.151)	(0.052)	(0.040)	(0.153)	(0.052)
Nuclear Utilities	0.019	0.112	0.087	0.010	0.146	0.038
	(0.063)	(0.172)	(0.097)	(0.054)	(0.149)	(0.076)
Renewable IPPs	0.068	-0.055	0.093	0.072	-0.084	0.066
	(0.058)	(0.167)	(0.077)	(0.055)	(0.207)	(0.066)
Electric Utilities	0.084	0.276	0.187	0.094	0.286	0.180*
	(0.075)	(0.178)	(0.113)	(0.069)	(0.182)	(0.105)
Water & Related Utilities (NEC)	-0.042	0.064	0.008	-0.037	0.087	-0.015
	(0.032)	(0.124)	(0.069)	(0.032)	(0.113)	(0.066)
Water Supply & Irrigation Systems	0.018	0.075	0.054	0.030	0.137	0.057
	(0.034)	(0.130)	(0.060)	(0.032)	(0.137)	(0.049)

Wind Electric Utilities	0.024 (0.054)	0.031 (0.126)	0.010 (0.079)	0.041 (0.052)	0.081 (0.111)	0.020 (0.060)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	205	205	205	205	205	205
R2	0.084	0.279	0.133	0.059	0.282	0.096
R2 Adj.	-0.044	0.026	-0.035	-0.073	0.030	-0.079

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Country-Level Heterogeneity Analysis

Table H. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, including country interaction terms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)		Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)	
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)
(Intercept)	-0.213		-0.177	
	(0.166)		(0.131)	
Green Bond Dummy	**0.142**	**0.120***	**0.089**	**0.082***
	(0.122)	**(0.071)**	**(0.090)**	**(0.046)**
Prior Issuance	**0.011**	**0.050**	**0.017**	**0.059***
	(0.030)	**(0.036)**	**(0.026)**	**(0.035)**
Firm Size	0.032	0.037*	0.027*	0.032**
	(0.020)	(0.020)	(0.015)	(0.016)
Growth	-0.038	-0.011	-0.029	0.002
	(0.042)	(0.048)	(0.031)	(0.037)

Profitability	0.007	-0.001	0.007	-0.001
	(0.012)	(0.012)	(0.013)	(0.012)
Leverage	0.008	0.005	0.005	0.006
	(0.020)	(0.020)	(0.019)	(0.020)
Liquidity	0.013	0.038	0.012	0.034
	(0.023)	(0.026)	(0.020)	(0.024)
Belgium	-0.045	-0.032	-0.037	-0.017
	(0.060)	(0.042)	(0.050)	(0.033)
Bulgaria	-0.035	-0.020	-0.031	-0.051
	(0.072)	(0.065)	(0.065)	(0.072)
Czech Republic	-0.088	-0.097*	-0.075	-0.073
	(0.078)	(0.056)	(0.063)	(0.045)
Denmark	-0.122	-0.111*	-0.113*	-0.120*
	(0.079)	(0.063)	(0.066)	(0.067)
Estonia	-0.017	0.023	-0.018	0.043
	(0.059)	(0.044)	(0.050)	(0.046)
Finland	-0.011	-0.031	-0.012	-0.026
	(0.051)	(0.040)	(0.044)	(0.029)

France	-0.084	-0.097	-0.072	-0.076
	(0.077)	(0.061)	(0.060)	(0.046)
Germany	0.273	0.300*	0.281	0.301
	(0.192)	(0.170)	(0.209)	(0.194)
Greece	-0.014	-0.013	-0.014	-0.001
	(0.062)	(0.072)	(0.053)	(0.063)
Hungary	0.078	0.069	0.064	0.081
	(0.073)	(0.078)	(0.059)	(0.067)
Italy	0.104	0.109	0.068	0.082
	(0.090)	(0.079)	(0.067)	(0.056)
Latvia	0.271	0.289	0.217	0.247
	(0.188)	(0.202)	(0.150)	(0.159)
Lithuania	-0.055	0.046	-0.056	0.047
	(0.058)	(0.055)	(0.050)	(0.058)
Luxembourg	-0.008	-0.094**	-0.008	-0.063
	(0.050)	(0.047)	(0.044)	(0.039)
Netherlands	-0.040	-0.045	-0.036	-0.057
	(0.058)	(0.045)	(0.048)	(0.042)
Poland	-0.052	-0.009	-0.045	-0.027

	(0.066)	(0.042)	(0.055)	(0.048)
Portugal	-0.106	-0.150*	-0.090	-0.127*
	(0.085)	(0.081)	(0.066)	(0.064)
Slovenia	0.044	0.141**	0.033	0.137*
	(0.053)	(0.069)	(0.045)	(0.072)
Spain	0.016	-0.001	0.010	0.010
	(0.064)	(0.064)	(0.054)	(0.051)
Sweden	-0.075	-0.105	-0.042	-0.068
	(0.138)	(0.079)	(0.102)	(0.055)
Green Bond Dummy × Denmark	-0.125	-0.081	-0.078	-0.071
	(0.114)	(0.084)	(0.087)	(0.072)
	-0.116	-0.137*	-0.066	-0.075
	(0.114)	(0.073)	(0.084)	(0.054)
Green Bond Dummy × Finland	-0.164	-0.023	-0.107	-0.005
	(0.130)	(0.090)	(0.099)	(0.071)
Green Bond Dummy × France	0.004	0.033	0.073	0.081
	(0.175)	(0.138)	(0.168)	(0.139)

Green Bond Dummy × Germany	-0.234	-0.241	-0.077	-0.081
	(0.250)	(0.223)	(0.214)	(0.193)
Green Bond Dummy × Greece	-0.183	-0.078	-0.128	-0.046
	(0.131)	(0.102)	(0.098)	(0.078)
Green Bond Dummy × Italy	-0.284*	-0.268**	-0.202*	-0.203**
	(0.158)	(0.128)	(0.112)	(0.088)
Green Bond Dummy × Latvia	-0.201	-0.150	-0.137	-0.093
	(0.141)	(0.098)	(0.107)	(0.069)
Green Bond Dummy × Netherlands	-0.154	-0.119	-0.105	-0.063
	(0.122)	(0.083)	(0.088)	(0.057)
Green Bond Dummy × Poland	-0.111	-0.010	-0.064	0.054
	(0.150)	(0.115)	(0.111)	(0.112)
Green Bond Dummy × Portugal	-0.122	-0.053	-0.079	-0.022
	(0.135)	(0.114)	(0.099)	(0.080)
Green Bond Dummy × Spain	-0.135	-0.117	-0.083	-0.094

	(0.132)	(0.099)	(0.098)	(0.074)
FE: year		Yes		Yes
Num.Obs.	205	205	205	205
R2	0.208	0.289	0.224	0.282
R2 Adj.	0.021	0.076	0.040	0.067

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Firm Size–Based Heterogeneity Analysis

Table I. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, including firm size interaction terms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.114			-0.112		
	(0.096)			(0.079)		
Green Bond Dummy	**0.086**	**0.081**	**0.071**	**0.028**	**0.025**	**0.012**
	(0.112)	**(0.113)**	**(0.101)**	**(0.085)**	**(0.094)**	**(0.087)**
Firm Size	0.025*	0.036*	0.027**	0.021*	0.029*	0.022**
	(0.014)	(0.021)	(0.013)	(0.011)	(0.017)	(0.011)
Prior Issuance	**-0.002**	**0.031**	**0.027**	**-0.001**	**0.042**	**0.031**
	(0.024)	**(0.032)**	**(0.025)**	**(0.020)**	**(0.029)**	**(0.024)**
Leverage	-0.009	-0.006	-0.013	-0.009	-0.003	-0.010
	(0.011)	(0.018)	(0.011)	(0.010)	(0.019)	(0.010)
Growth	-0.043	-0.003	-0.026	-0.029	0.008	-0.008

	(0.034)	(0.045)	(0.037)	(0.026)	(0.035)	(0.030)
Profitability	0.008	-0.004	0.002	0.004	-0.004	-0.001
	(0.011)	(0.012)	(0.011)	(0.011)	(0.013)	(0.012)
Liquidity	0.014	0.033	0.032	0.015	0.031	0.031
	(0.016)	(0.026)	(0.021)	(0.015)	(0.024)	(0.021)
Green Bond Dummy	-0.012	-0.012	-0.010	-0.004	-0.003	-0.002
× Firm Size	(0.015)	(0.016)	(0.014)	(0.012)	(0.013)	(0.012)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	205	205	205	205	205	205
R2	0.049	0.252	0.113	0.041	0.254	0.085
R2 Adj.	0.010	0.092	0.037	0.002	0.094	0.007

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Table J. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample of small firms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.055			-0.038		
	(0.048)			(0.033)		
Green Bond Dummy	**-0.006**	**0.054**	**-0.004**	**-0.004**	**0.037**	**-0.003**
	(0.013)	**(0.076)**	**(0.064)**	**(0.009)**	**(0.053)**	**(0.044)**
Prior Issuance	**0.033**	**0.023**	**0.036**	**0.023**	**0.016**	**0.025**
	(0.029)	**(0.034)**	**(0.036)**	**(0.020)**	**(0.023)**	**(0.025)**
Firm Size	0.007	0.011	0.009	0.005	0.008	0.006
	(0.006)	(0.013)	(0.011)	(0.004)	(0.009)	(0.008)
Leverage	-0.012	-0.023	-0.015	-0.008	-0.016	-0.010
	(0.010)	(0.017)	(0.012)	(0.007)	(0.011)	(0.009)
Growth	0.008	-0.022	0.006	0.006	-0.015	0.004
	(0.012)	(0.048)	(0.014)	(0.008)	(0.033)	(0.010)
Profitability	-0.001	0.005	0.005	-0.001	0.003	0.003

	(0.004)	(0.012)	(0.009)	(0.003)	(0.008)	(0.006)
Liquidity	-0.008	0.014	0.015	-0.006	0.010	0.011
	(0.011)	(0.039)	(0.026)	(0.008)	(0.027)	(0.018)
Green Bond Dummy × Firm Size	0.005	-0.008	0.004	0.004	-0.006	0.003
	(0.004)	(0.014)	(0.010)	(0.003)	(0.010)	(0.007)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	65	65	65	65	65	65
R2	0.057	0.402	0.226	0.057	0.402	0.226
R2 Adj.	-0.078	-0.127	-0.032	-0.078	-0.127	-0.032

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Table K. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample of large firms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.668			-0.588		
	(0.619)			(0.444)		
Green Bond Dummy	**0.039**	**-0.009**	**0.005**	**-0.221**	**-0.065**	**-0.214**
	(0.651)	**(0.633)**	**(0.601)**	**(0.484)**	**(0.609)**	**(0.457)**
Prior Issuance	**-0.042**	**0.020**	**-0.003**	**-0.040**	**0.049**	**0.001**
	(0.039)	**(0.058)**	**(0.038)**	**(0.038)**	**(0.058)**	**(0.033)**
Firm Size	0.087	0.112	0.077	0.075	0.094	0.069
	(0.066)	(0.075)	(0.064)	(0.049)	(0.062)	(0.054)
Leverage	0.024	0.020	0.016	0.022	0.047	0.025
	(0.024)	(0.053)	(0.028)	(0.024)	(0.066)	(0.035)
Growth	-0.200*	-0.252*	-0.184	-0.143*	-0.174	-0.127
	(0.102)	(0.145)	(0.118)	(0.077)	(0.109)	(0.093)
Profitability	0.020	0.015	0.013	0.014	0.012	0.011

	(0.017)	(0.022)	(0.018)	(0.017)	(0.022)	(0.020)
Liquidity	-0.002	0.000	0.008	0.001	0.011	0.010
	(0.021)	(0.040)	(0.021)	(0.019)	(0.036)	(0.019)
Green Bond Dummy × Firm Size	-0.006	-0.002	-0.001	0.022	0.007	0.023
	(0.069)	(0.066)	(0.063)	(0.052)	(0.064)	(0.049)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	140	140	140	140	140	140
R2	0.131	0.368	0.191	0.108	0.338	0.148
R2 Adj.	0.078	0.186	0.086	0.054	0.149	0.037

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Leverage–Based Heterogeneity

Table L. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, including firm size interaction terms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.068			-0.096		
	(0.083)			(0.087)		
Green Bond Dummy	**-0.016**	**-0.020**	**-0.014**	**-0.007**	**-0.004**	**-0.006**
	(0.029)	**(0.038)**	**(0.027)**	**(0.022)**	**(0.031)**	**(0.020)**
Prior Issuance	**-0.004**	**0.032**	**0.027**	**-0.001**	**0.044**	**0.032**
	(0.025)	**(0.034)**	**(0.027)**	**(0.021)**	**(0.031)**	**(0.026)**
Leverage	0.001	0.010	-0.002	-0.002	0.008	-0.002
	(0.015)	(0.025)	(0.015)	(0.013)	(0.027)	(0.013)
Firm Size	0.019*	0.031*	0.022**	0.019*	0.027*	0.021*
	(0.010)	(0.018)	(0.010)	(0.011)	(0.015)	(0.011)
Growth	-0.045	-0.005	-0.027	-0.030	0.008	-0.009
	(0.035)	(0.045)	(0.037)	(0.026)	(0.036)	(0.031)

Profitability	0.007	-0.005	0.000	0.003	-0.005	-0.002
	(0.010)	(0.012)	(0.011)	(0.011)	(0.012)	(0.011)
Liquidy	0.015	0.035	0.034	0.015	0.032	0.033
	(0.017)	(0.026)	(0.021)	(0.015)	(0.023)	(0.021)
Green Bond Dummy × Leverage	-0.016	-0.022	-0.019	-0.010	-0.018	-0.014
	(0.017)	(0.021)	(0.018)	(0.013)	(0.019)	(0.013)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	205	205	205	205	205	205
R2	0.047	0.252	0.112	0.041	0.256	0.086
R2 Adj.	0.008	0.092	0.037	0.002	0.096	0.008

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Table M. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, filtered to only include high leverage firms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.117			-0.143		
	(0.134)			(0.137)		
Green Bond Dummy	**-0.026**	**-0.015**	**-0.020**	**-0.012**	**-0.004**	**-0.014**
	(0.042)	**(0.055)**	**(0.046)**	**(0.033)**	**(0.044)**	**(0.034)**
Prior Issuance	**-0.064**	**-0.048**	**-0.032**	**-0.056**	**-0.014**	**-0.007**
	(0.043)	**(0.042)**	**(0.038)**	**(0.039)**	**(0.036)**	**(0.037)**
Firm Size	0.036*	0.043	0.038*	0.036	0.042	0.037
	(0.021)	(0.026)	(0.022)	(0.022)	(0.026)	(0.024)
Growth	-0.096	-0.082	-0.066	-0.060	-0.055	-0.026
	(0.071)	(0.098)	(0.083)	(0.053)	(0.075)	(0.071)
Profitability	0.022*	0.003	0.017	0.020	0.004	0.016
	(0.012)	(0.019)	(0.014)	(0.012)	(0.019)	(0.014)
Leverage	0.005	-0.015	-0.005	0.004	-0.017	-0.005

	(0.027)	(0.029)	(0.024)	(0.025)	(0.029)	(0.024)
Liquidity	0.032	0.027	0.046	0.030	0.029	0.044
	(0.023)	(0.042)	(0.031)	(0.021)	(0.038)	(0.033)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	121	121	121	121	121	121
R2	0.117	0.306	0.156	0.086	0.320	0.121
R2 Adj.	0.063	0.105	0.035	0.029	0.123	-0.005

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

Table N. Regression estimates of the impact of green bond issuance on patenting activity and patenting intensity in the matched sample, filtered to only include low leverage firms.

	Linear Probability Models Estimating the Effect of Green Bond Issuance on Patenting Activity (Dependent Variable: Patents Dummy)			Log-Linear Models Estimating the Effect of Green Bond Issuance on Patenting Intensity (Dependent Variable: Log of Green Patent Count)		
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)
(Intercept)	-0.069			-0.104		
	(0.138)			(0.146)		
Green Bond Dummy	**0.001**	**0.036**	**0.001**	**0.002**	**0.040**	**0.001**
	(0.028)	**(0.057)**	**(0.036)**	**(0.021)**	**(0.047)**	**(0.027)**
Prior Issuance	**0.067**	**0.138**	**0.080**	**0.065**	**0.118***	**0.079**
	(0.053)	**(0.084)**	**(0.059)**	**(0.054)**	**(0.070)**	**(0.062)**
Firm Size	0.003	0.008	0.006	0.004	0.014	0.008
	(0.007)	(0.019)	(0.009)	(0.007)	(0.018)	(0.009)
Growth	-0.003	0.019	0.001	0.002	0.031	0.006
	(0.023)	(0.057)	(0.028)	(0.019)	(0.049)	(0.025)
Profitability	-0.023	-0.026	-0.029	-0.026	-0.028	-0.031
	(0.024)	(0.022)	(0.025)	(0.027)	(0.021)	(0.027)
Leverage	0.023	0.058	0.017	0.020	0.040	0.013

	(0.019)	(0.057)	(0.015)	(0.018)	(0.043)	(0.014)
Liquidity	0.001	0.014	0.027	0.005	0.003	0.025
	(0.029)	(0.045)	(0.035)	(0.026)	(0.035)	(0.032)
FE: year		Yes	Yes		Yes	Yes
FE: country		Yes			Yes	
Num.Obs.	84	84	84	84	84	84
R2	0.046	0.401	0.172	0.071	0.478	0.185
R2 Adj.	-0.041	0.006	-0.010	-0.015	0.133	0.005

*Note(s): LPM and log-linear regression coefficients are reported with standard errors in brackets. Standard errors are clustered at the firm level (issuer). LPM regressions estimate the probability of a firm submitting a green patent application in a given year based on a dummy variable indicating green bond issuance. Log-linear regressions estimate patenting intensity based on a log-transformed variable for number of patent applications submitted by a firm in a given year. Variables green bond dummy, prior issuance dummy, firm size, revenue growth rate, profitability, leverage, and liquidity are lagged by one period (t-1). Variables firm size, revenue growth rate, profitability, leverage, and liquidity are log-transformed. The sample covers the period 2015–2025 and includes 285 firms. ***, ** and * indicate statistical significance at the 1% , 5%, and 10% levels, respectively.*

APPENDIX VI.

DATA AVAILABILITY

All datasets used in this thesis, along with the code used for data processing, propensity score matching, and regression analysis, are available in a public GitHub repository to ensure transparency and reproducibility of results.

GitHub Repository: https://github.com/salonsovega/Thesis/tree/363aeee26d5a321e98b0de790bfd9b62e54663e1

The repository includes:

- Cleaned datasets on green bond issuance and green patent applications,
- Firm-level financial indicators used as controls,
- R scripts for all empirical analyses,
- Matching diagnostics and summary statistics, and
- Figures and visualizations included in this thesis.