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Green Bond Issuance Strategies: A Stackelberg Approach with Empirical Evidence from Europe

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Abstract:

This study investigates the strategic decision-making processes involved in green bond issuance through a Stackelberg game-theoretic framework, integrating corporate social responsibility (CSR) drivers and social preferences. The model explores the interactions between a regulator, positioned as the leader, and firms as followers. The regulator establishes policy incentives to foster green bond issuance, while firms determine their issuance strategies considering regulatory backing, reputational gains, and peer influences. The framework incorporates firm heterogeneity, accounting for varied responses influenced by environmental exposure, governance quality, and macroeconomic contexts. A dynamic feedback mechanism is included, enabling regulators to refine incentives based on observed behaviors, thereby enhancing alignment with environmental objectives and economic priorities. Empirical analysis using data from 22 European countries (2013–2024) underscores the critical influence of institutional governance, environmental policy support, and carbon taxation in advancing green finance. The findings offer a robust framework for policymakers and firms, delivering practical insights to harmonize sustainability ambitions with economic goals.

Keywords: Green bonds, Stackelberg game, Sustainable finance, Governance quality, Heckman model.

JEL Codes: C72, D21, H23, Q58.

1. Introduction

Firms are significantly shaped by their interactions with both governmental and non-governmental stakeholders (Flammer, 2021). Studies emphasize that maintaining consistent, transparent, and meaningful engagement with these stakeholders is pivotal to a firm's long-term survival and success (Tang & Zhang, 2020). Governments, through political processes, exercise formal authority and regulatory oversight over corporate operations (Hachenberg & Schiereck, 2018). Beyond governmental regulation, public, private, and hybrid public-private institutions play crucial roles in monitoring and balancing the actions of both governments and corporations (Lebelle et al., 2020). Additionally, interest groups actively influence and contribute to shaping corporate decision-making processes (Zhao et al., 2023).

While traditional bonds have gained substantial attention for their ability to reflect government policy commitments—thanks to broad public support—green bonds have received comparatively less focus (Zerbib, 2019). Nevertheless, these instruments hold significant potential for fostering stakeholder support as fiscally responsible tools that address and mitigate environmental issues (Agliardi and Agliardi, 2021).

Green bonds effectively bridge corporate and environmental goals by serving as both financial instruments and policy tools. On the financial front, these bonds enable companies to secure funding for eco-friendly projects such as renewable energy, energy efficiency, or carbon reduction initiatives. By appealing to Environmental, Social, and Governance (ESG) focused investors, green bonds lower capital costs, enhance corporate reputation, and signal a commitment to sustainability. This not only strengthens market positioning but also drives stock performance and corporate valuation, showcasing the economic viability of green initiatives.

In their policy role, green bonds support government efforts to reduce emissions and advance sustainability by addressing gaps in carbon pricing mechanisms and incentivizing greener practices. They mobilize private funding for public goods like climate change mitigation, easing reliance on public resources, and aligning corporate actions with current or anticipated environmental regulations. By seamlessly integrating financial and policy benefits, green bonds demonstrate how economic and environmental objectives can reinforce one another, making them indispensable tools in tackling global climate challenges.

Within the broader regulatory ecosystem, the effectiveness of green bonds depends on the interactions among multiple stakeholders, including governments, financial institutions, enterprises, and consumers. Game theory has proven instrumental in analyzing these complex dynamics. For example, Cui et al. (2020) developed an evolutionary game model to study the impact of regulatory parameters on the green finance market, emphasizing the importance of robust government regulation. Similarly, Zhao et al. (2021) applied the Hotelling game model to assess the efficiency of dual and integrated rating systems in the green bond market, incorporating spatial effects. These insights highlight the need for coordinated efforts and improved regulatory frameworks to maximize the potential of green bonds in achieving sustainability goals.

The Stackelberg game framework, in particular, has proven to be well-suited for scenarios where governments or regulators wield greater influence. Kourosch and Ashkan (2019) employed this model to explore government interactions with Green Supply Chains (GSC), examining the implications of various carbon regulation policies. Lu et al. (2020) applied a multi-stage Stackelberg game to sustainable production inventory, positioning the manufacturer

as the leader and the retailer as the follower. Additionally, Nielsen et al. (2019) analyzed two-period procurement decisions within a green supply chain using a manufacturer-Stackelberg model. Their findings compared greening levels, profitability, and environmental outcomes under diverse incentive structures.

Expanding on these applications, Zhao et al. (2023) utilized a two-stage Stackelberg game to examine how incentive and constraint policies influence green bond issuance in China's market. Their findings highlight the model's versatility in addressing regulatory mechanisms and corporate behaviors, aligning policy design with broader sustainability objectives. Building on this foundation, this paper adopts a game-theoretic Stackelberg framework to delve into corporate decision-making in green bond issuance. By mirroring real-world dynamics between regulators and firms, the framework captures the hierarchical interactions characteristic of green finance (Zhao et al., 2023). Here, regulators take the lead in crafting policies and incentives to foster sustainable finance, while firms respond by tailoring their issuance strategies to these regulatory conditions. This leader-follower relationship reflects common regulatory settings where policymakers aim to influence corporate actions through well-structured incentives (Agliardi and Agliardi, 2021).

The Stackelberg model's sequential structure provides a robust framework for understanding and predicting the interplay between regulatory actions and corporate behavior in green finance. Regulators design forward-looking policies to incentivize green bond issuance, anticipating that firms will weigh the associated costs and benefits. This proactive approach enables policymakers to optimize strategies that encourage firms to align with sustainability goals while addressing economic constraints like inflation and public debt (Tang and Zhang, 2020). By fostering a balance between economic imperatives and environmental responsibilities, the model ensures regulatory strategies remain effective and adaptive (Hachenberg and Schiereck, 2018).

A key strength of the Stackelberg framework is its ability to account for firm heterogeneity and competitive dynamics (Lebelle et al., 2020). Firms vary in costs, reputational incentives, and exposure to environmental risks, which influence their responses to regulatory policies (Zerbib, 2019). In competitive markets, the model highlights how companies consider both regulatory expectations and competitors' strategies. This interdependence often drives firms to strategically issue green bonds, whether to enhance their reputation or comply with regulatory mandates (Flammer, 2021; Agliardi and Agliardi, 2021).

The model also integrates dynamic feedback loops critical in green finance (Zhao et al., 2023). Regulators monitor aggregate green bond issuance and refine their policies to better meet environmental objectives (Tang and Zhang, 2020). Firms, anticipating these adjustments, adapt their strategies accordingly, resulting in a dynamic equilibrium where regulatory and corporate actions co-evolve to address environmental and economic challenges (Hachenberg and Schiereck, 2018).

This framework underscores the dual priorities of environmental and economic objectives (Zerbib, 2019). Firms respond to governance quality, environmental risks, and regulatory incentives, while policymakers adjust strategies to balance broader economic considerations. This interplay offers a comprehensive perspective on how well-designed incentives can align corporate actions with sustainability and economic goals (Agliardi and Agliardi, 2021).

Moreover, the Stackelberg model integrates social preferences and Corporate Social Responsibility (CSR) motivations (Flammer, 2021). Many firms issue green bonds not merely for financial returns but as part of their broader commitment to CSR and adherence to ESG principles (Tang and Zhang, 2020). By factoring in these behavioral elements, the framework captures the intrinsic value that firms place on sustainability initiatives beyond profit-driven motives (Zhao et al., 2023). Additionally, stakeholder expectations—including those of investors, customers, and employees—play a significant role in influencing firms' decisions. Green bond issuance often serves as a means for companies to gain reputational advantages and meet stakeholder approval (Zerbib, 2019).

Building on this conceptual foundation, a multi-stage dynamic game framework is proposed. In this model, the regulator assumes the role of the leader, crafting policy incentives to stimulate green bond issuance, while two firms (A and B) act as followers. These firms decide whether to issue green bonds and determine the issuance amounts. This approach incorporates firm-level variations, such as differences in environmental exposure and economic conditions, which shape their decision-making processes (Agliardi and Agliardi, 2021). A dynamic feedback loop is also embedded, enabling regulators to refine policies over time based on observed corporate behaviors. This adaptive mechanism ensures a responsive regulatory environment that evolves alongside firms' strategies (Zhao et al., 2023).

The remainder of this paper is structured as follows: Section 2 outlines the theoretical basis and framework of the Stackelberg game model, emphasizing the dynamics between regulators and firms concerning green bond issuance. Section 3 validates the model's predictions through empirical analysis, employing a Heckman econometric method to investigate the factors influencing corporate green bond issuance across 22 European nations. Section 4 delves into the results, discussing their significance for regulators, firms, and other participants in sustainable finance. Lastly, Section 5 concludes by summarizing the main insights, offering policy recommendations, and proposing directions for future research.

2. Model Structure

In this model, there are three players: the regulator (R), who acts as the leader, and two firms (A and B), who follow. The regulator sets a policy mechanism P that includes both incentives to encourage green bond issuance and disincentives to discourage high CO₂ emissions. Firms A and B observe this mechanism, evaluate the combined impact of the incentives and disincentives, and decide whether to issue green bonds and, if so, determine the amount to issue.

This two-firm setup is designed to capture the competitive dynamics between firms while maintaining analytical simplicity. By focusing on two players, the model allows for a clearer analysis of how firms interact with the regulator's policy mechanism. While specific to two firms, the insights from this framework can be generalized to broader scenarios involving multiple firms, assuming similar competitive conditions.

The game unfolds in multiple stages. In Stage 1, the regulator sets the policy incentive P , carefully considering macroeconomic factors and governance quality (GQ), which affects the policy's effectiveness. In Stage 2, after observing P , each firm decides probabilistically whether to issue a green bond (p_i). If a firm decides to issue, Stage 3 involves choosing the issuance amount q_i , based on both the regulatory incentive P and the associated benefits and costs. A feedback loop allows the regulator to observe the aggregate issuance from both firms, updating

P in subsequent periods to maximize social welfare while adapting to evolving environmental and economic conditions.

The players have distinct objectives. The regulator seeks to maximize social welfare by setting an optimal P that promotes green bond issuance without undue economic strain. Each firm, on the other hand, aims to maximize its expected profit by considering the financial benefits of green bond issuance as well as the reputational and regulatory incentives associated with complying with or exceeding green finance expectations.

The model includes several key elements that shape firms' decisions and the regulator's strategy in the context of green bond issuance. The primary decision variable is p_i , the probability that firm i (where $i=A, B$) issues a green bond, which ranges from 0 to 1. This probability reflects the firm's decision-making process, influenced by factors such as regulatory incentives, CSR motivations, peer effects, and environmental exposure, as it considers whether or not to participate in green finance initiatives.

Behavioral factors play an important role in firms' decision-making processes. CSR Motivation (θ_i) reflects each firm's sensitivity to corporate social responsibility and the reputational gains associated with sustainable practices. This factor affects how strongly a firm values the reputational benefits of green bond issuance. The peer effect (ϕ_i) measures the influence of the competitor firm's issuance decision on firm i 's own decision, capturing the tendency of firms to follow industry trends or match competitors' actions in sustainability efforts.

Macroeconomic and environmental conditions play a significant role in influencing both firms' and the regulator's decisions. The inflation rate (INF) affects the cost of issuing bonds, potentially impacting the amount firms are willing to issue. The unemployment rate (U) influences investor demand for green bonds, as economic downturns or high unemployment may reduce investor appetite for these financial instruments, thereby lowering the probability of green bond issuance. Public debt (D) constrains the regulator's flexibility in offering incentives, as higher debt levels may limit fiscal options. Additionally, each firm's pollution exposure (E_i) influences its green bond issuance decision, as issuing green bonds can be a way to manage reputational risk associated with environmental impact.

Governance Quality (GQ) at the macro level affects the effectiveness of reputational incentives for green bond issuance. High governance quality enhances the reputational benefits linked to sustainable finance, potentially making green bonds more attractive to firms aiming to boost their public image.

Policy incentives and firm-specific parameters further shape the strategic decisions of both firms and the regulator. The incentive level (P), set by the regulator, adjusts based on the aggregate level of green bond issuance across firms, aiming to optimize social welfare. Firms' decision-making is influenced by the reputational benefit coefficient (β), which is linked to governance quality and represents the reputational gain from issuing green bonds. Each firm incurs an issuance cost (α_i), comprising both stable, inherent expenses and variable costs sensitive to inflation, which makes green bond issuance more or less attractive depending on macroeconomic conditions. Lastly, an environmental penalty (γ_i) applies if a firm decides not to issue green bonds, reflecting the reputational risk tied to its pollution exposure E_i . This penalty incentivizes firms to consider the reputational costs of not participating in sustainable finance.

Regulator's Policy Decision

The regulator sets the incentive level P to maximize social welfare. The welfare function includes traditional economic considerations as well as a component that reflects the aggregate social and environmental impact of green bond issuance¹:

$$W(P) = \rho(\sum_{i=A,B} p_i q_i) - \sigma D - \tau \left(\frac{\sum_{i=A,B} E_i(1-p_i)}{2} \right) - \varphi(\sum_{i=A,B} T \cdot C_i) \quad (1)$$

In this function, ρ represents a parameter that amplifies the welfare benefit derived from the aggregate issuance of green bonds. The term $\sigma \cdot D$ reflects the social cost associated with public debt, imposing a constraint on the regulator's capacity to offer incentives. Additionally, $\tau \cdot E_i$ serves as a penalty for environmental exposure when firms choose not to issue green bonds, thereby incentivizing corporate social responsibility (CSR) and promoting the reputational benefits linked to green bond issuance.

The objective function $W(P)$ reflects the regulator's goal of maximizing social welfare by encouraging green bond issuance while managing economic and environmental costs. The first component captures the welfare benefit from the total amount of green bonds issued by the firms, where each issuance positively contributes to social welfare. This part is weighted by a parameter ρ that indicates the regulator's valuation of green financing, with a higher weight reflecting the greater importance placed on sustainable financial practices.

The second component represents the social cost associated with public debt, acknowledging that higher debt levels impose fiscal constraints on the regulator. This cost limits the regulator's flexibility in providing incentives, as allocating resources for green finance may be challenging when public debt is high. By incorporating this cost, the model recognizes the trade-off between promoting green bond issuance and maintaining sustainable public finances.

The third component introduces a penalty for firms' environmental exposure when they choose not to issue green bonds. This penalty considers each firm's pollution or environmental risk, with the regulator incentivizing green bond issuance as a way for firms to manage reputational and environmental risks. By weighting the environmental exposure, the model aligns with the regulator's aim to mitigate pollution and encourage corporate responsibility, promoting a cleaner and more sustainable environment.

The last component represents the impact of carbon taxation on emissions and social welfare. It incorporates the carbon tax rate (T), which imposes a cost per unit of emissions, directly discouraging pollution. The emissions level (C_i), or carbon footprint, of each firm determines the total tax burden, with higher issuers facing greater costs. A weighting factor (φ) reflects how carbon tax revenues are utilized to enhance social welfare, such as by funding green projects, subsidizing green bond issuance, or reducing public fiscal burdens. This term underscores the dual purpose of carbon taxation: incentivizing emissions reductions while generating resources to support sustainability initiatives and economic stability.

¹ By dividing by 2, the model reflects the average environmental impact from firms that chose not to issue green bonds, rather than the total impact. This approach allows the regulator's welfare function to weigh pollution exposure more realistically, by considering the mean pollution impact per non-issuing firm rather than the aggregate effect. It emphasizes that the regulator is concerned with the average level of pollution exposure from firms that opt out of green financing, which could impact social welfare.

The regulator maximizes this welfare function by selecting an optimal P , anticipating that firms will respond based on financial and behavioral motivations.

Firms' Decision to Issue Green Bonds

Each firm i decides whether to issue a green bond based on a probabilistic approach that incorporates both financial and behavioral factors. This approach goes beyond traditional models by including elements such as reputational benefits, regulatory incentives, corporate social responsibility (CSR) motivations, and peer influences.

The expected payoff of issuing a green bond for firm i includes several components. First, there is a reputational benefit, represented by $\beta \cdot GQ$, which is scaled by the governance quality; this reflects the idea that stronger governance enhances the reputational advantages of sustainable financing. Second, the regulatory incentive is captured by $\rho \cdot P$, where P is the incentive level set by the regulator, encouraging firms to participate in green bond issuance.

In addition to these financial incentives, CSR utility plays a role, represented by $\theta_i \cdot CSR_i$, where CSR_i reflects the specific value that firm i places on aligning its actions with corporate social responsibility goals. This CSR factor reflects the intrinsic motivation of firms to engage in sustainable practices.

Finally, peer effects influence each firm's decision, as firms are responsive to their competitor's actions. The term ϕp_j represents the peer effect, where $0 < \phi < 1$ implies that while a competitor's decision influences firm i 's likelihood of issuing a green bond, the decision remains primarily driven by the firm's own incentives, such as regulatory support, CSR goals, and costs. This assumption ensures model stability, avoiding excessive feedback loops and reflecting realistic market behavior where firms balance peer influence with independent strategic priorities.

The quadratic term ($\frac{1}{2} p_i^2$) in the expected payoff function reflects increasing marginal costs and diminishing returns as firms raise their probability of issuing green bonds, representing the added transparency, reporting, and due diligence burdens that grow with commitment; it also captures the diminishing reputational returns, as early green finance actions provide more impact than subsequent ones. Additionally, this term models risk aversion, limiting p_i below 1 by penalizing high issuance probabilities due to uncertainty and potential market volatility, ensuring that firms balance marginal benefits with rising costs and remain aligned with regulatory incentives for sustainable finance.

Overall, the expected payoff function for issuing a green bond for firm i combines these factors, providing a comprehensive framework that accounts for both financial and social motivations in the firm's decision-making process:

$$E[\Pi_i^{issue}] = p_i \left(\beta \cdot GQ + \rho \cdot P - \frac{(\alpha_{i,0} + \alpha_{i,INF} \cdot INF)}{\tilde{\alpha}_i} + \theta_i \cdot CSR_i + \phi p_j - T \cdot C_i \right) - \frac{1}{2} p_i^2 \quad (2)$$

If firm i does not issue, it faces an environmental penalty due to its pollution exposure and loss of reputational gain:

$$E[\Pi_i^{no\ issue}] = (1 - p_i)(\gamma_i \cdot E_i + T \cdot C_i) \quad (3)$$

Combining the two expected payoffs, the total expected payoff (Π_i^{total}) is:

$$E[\Pi_i^{total}] = p_i(\beta \cdot GQ + \rho \cdot P - \alpha_i + \theta_i \cdot CSR_i + \phi p_j - T \cdot C_i) - \frac{1}{2} c_i p_i^2 \\ + (1 - p_i)(\gamma_i \cdot E_i + T \cdot C_i) \quad (4)$$

Each firm maximizes this total expected payoff with respect to p_i , reflecting its social, financial, and competitive motivations.

Taking the derivative of $E[\Pi_i^{total}]$ with respect to p_i and setting it to zero:

$$\frac{\partial E[\Pi_i^{total}]}{\partial p_i} = \beta \cdot GQ + \rho \cdot P - \alpha_i + \theta_i \cdot CSR_i + \phi p_j - p_i + \gamma_i \cdot E_i - T \cdot C_i = 0$$

Solving for p_i , we get:

$$p_i^* = \beta \cdot GQ + \rho \cdot P - \alpha_i + \theta_i \cdot CSR_i + \phi p_j + \gamma_i \cdot E_i - T \cdot C_i \quad (5)$$

This is Firm i 's best-response function, which gives p_i as a function of p_j and other parameters.

Now we have a similar best-response function for Firm j :

$$p_j^* = \beta \cdot GQ + \rho \cdot P - \alpha_j + \theta_j \cdot CSR_j + \phi p_i + \gamma_j \cdot E_j - T \cdot C_j \quad (6)$$

To solve for p_i in terms of the parameters, let's substitute the expression for p_j from (6) into (5):

$$p_i^* = \frac{\beta(1+\phi) \cdot GQ + \rho(1+\phi) \cdot P - (\alpha_i + \phi \alpha_j) + \theta_i \cdot CSR_i + \phi \theta_j \cdot CSR_j + \gamma_i \cdot E_i + \phi \gamma_j \cdot E_j - T(C_i + \phi C_j)}{1 - \phi^2} \quad (7)$$

The optimal issuance probability p_i^* illustrates how firm i decides to issue green bonds based on multiple factors including governance, regulatory support, costs, CSR motivations, environmental exposure, and competitive dynamics. Governance quality (GQ) and policy incentives (P) positively influence the likelihood of issuance by enhancing the perceived reputational and financial benefits of green bonds. The terms $\beta(1 + \phi) \cdot GQ$ and $\rho(1 + \phi) \cdot P$ indicate that governance quality and regulatory incentives not only affect firm i but also create indirect benefits for its competitor. This amplifies the effect of these factors, showing how the actions of one firm can increase green bond issuance probability for both firms, reflecting a mutually reinforcing dynamic.

The cost structure is captured by $(\alpha_i + \phi \alpha_j)$, which include both fixed issuance costs and inflation-linked costs. Higher inflation increases these costs, thus lowering the probability of issuance for firm i . The peer effect term ϕ implies that firm i is strategically sensitive to the cost pressures faced by its competitor, indicating that firms consider their competitors' financial conditions in their own issuance decisions. This competitive response suggests that firms aim

to maintain financial positioning in green bond issuance even under varying economic conditions.

CSR also plays an important role, with $\theta_i \cdot CSR_i + \phi \theta_j \cdot CSR_j$ capturing the direct and indirect influence of CSR motivations. Firm i is directly motivated by its own CSR goals, and peer influence means that a strong CSR commitment by firm j can increase pressure on firm i to issue green bonds. This mechanism highlights the competitive or reputational aspect of CSR , where firms seek to maintain alignment with industry standards and avoid reputational disadvantages relative to competitors.

The inclusion of $T(C_i + \phi C_j)$ highlights the role of the carbon tax in driving firms toward green bond issuance, especially those with high emissions, where ϕC_j reflects the competitive influence of firm j 's emissions.

The denominator term $(1 - \phi^2)$ serves as a stabilizing factor, ensuring that the peer effect ϕ influences each firm's decision without allowing it to be overly dominated by competitor actions. By keeping ϕ below 1, the model maintains a balanced equilibrium where firms' decisions are primarily driven by their own incentives rather than excessive reactions to their competitors. This structure captures the strategic balance firms must strike between internal motivations, such as governance quality, regulatory incentives, CSR goals, and carbon tax considerations, and the competitive dynamics of the market. The peer effect ϕ amplifies these factors, fostering a dynamic where firms' decisions reinforce each other's sustainability efforts, promoting a mutually beneficial trajectory for green bond issuance.

Feedback Loop and Dynamic Adjustments

After firms make their issuance decisions, the regulator observes the aggregate outcome and adjusts P in the next rounds. If the regulator's environmental or social targets—such as the desired level of green financing—are not met, it may modify P to either increase or decrease the attractiveness of green bond issuance. For example, if firms issue fewer green bonds than expected, the regulator may raise P to provide stronger financial support. Conversely, if green bond issuance exceeds desired levels or risks becoming unsustainable, the regulator might lower P to stabilize the market or address broader economic concerns like inflation.

The Nash equilibrium in this model is reached when firms make issuance decisions that maximize their individual payoffs, given the regulatory incentive P . Simultaneously, the regulator's policy P is dynamically adjusted to align observed green bond issuance levels with the targeted levels, ensuring that the overall system achieves a balance between corporate and regulatory objectives. This equilibrium reflects the point at which neither the firms nor the regulator can unilaterally improve their outcomes by changing their strategies.

The regulator updates P dynamically:

$$P_{t+1} = P_t + \eta(\text{Target Green Bonds} - \text{Observed Green Bonds}) \quad (8)$$

where η represents the adjustment rate for policy incentives.

In each new round, firms take note of the updated incentives and re-evaluate their probability and quantity of green bond issuance. As firms also consider factors such as peer influence,

adjustments in the regulatory incentive P affect not only their own strategies but also the competitive landscape. This interaction fosters a setting of strategic interdependence, where each firm's decisions are influenced by the potential reactions of others. Furthermore, firms anticipate that the regulator's policies will respond to their collective actions, incorporating this feedback loop into their strategic choices.

The feedback loop and dynamic adjustments enable a responsive and adaptive system, where firms' decisions on green bond issuance and the regulator's policy incentives mutually influence each other. This ongoing interaction leads to a stable yet adaptable equilibrium, allowing the market to align with changing policy objectives, economic conditions, and environmental goals. The regulator and firms each adjust based on observed behaviors, ensuring that green bond issuance remains strategically balanced, economically viable, and aligned with broader sustainability goals.

3. Empirical Evidence on the Determinants of Corporate Green Bond Issuance in European Countries

In this section, we evaluate our model's primary prediction by analyzing the determinants of corporate green bond issuance and associated issuance volumes, focusing on factors such as institutional governance quality, CO₂ emission exposure, environmental policy support, and carbon tax dynamics. Using a Heckman econometric specification model, we assess both the likelihood of firms issuing green bonds and the determinants of issuance volumes in 22 European countries. The Heckman model's two-step structure addresses selection bias by concentrating on countries and firms that have already issued green bonds, ensuring a precise evaluation of issuance dynamics. This approach provides a nuanced understanding of how governance, environmental pressures, and regulatory frameworks collectively influence corporate green bond issuance and scale.

The study highlights institutional governance quality as a key determinant, focusing on the macroeconomic institutional framework, which includes elements such as the rule of law, regulatory effectiveness, and corruption control. High-quality governance increases reputational incentives for firms to issue green bonds, positioning it as a critical factor in green bond activity (Obobisa et al., 2022). Similarly, exposure to CO₂ emissions plays a significant role, as firms with higher emissions are often driven to issue green bonds to mitigate reputational risks, using the instrument as a signaling strategy (García et al., 2023). Furthermore, environmental policy support, defined by the comprehensiveness and stringency of regulations across sectors and international dimensions, emerges as a crucial driver of green bond issuance decisions (Cotugno et al., 2022).

The characteristics of green bond issuances, such as coupon rates, maturities, convertibility features, and issuance currencies, are central to understanding variations in issuance volumes across countries. These features reflect firm-level strategies and preferences, shedding light on how specific financial terms shape the scale of green bond issuance (Glavas, 2023). Additionally, macroeconomic variables are pivotal in influencing green bond issuance patterns. For instance, inflation impacts the cost structure of bond issuance, while unemployment levels signal broader economic conditions that shape investor demand for green financial instruments. Public debt underscores fiscal constraints that may limit policy support for green bonds, highlighting challenges in advancing sustainable finance (García et al., 2023). Carbon taxes also play a significant role, as they create cost pressures on high-emission firms, incentivizing the adoption of green bonds as a strategic response to mitigate financial and reputational risks

associated with carbon-intensive activities (Daubanes et al., 2021; Heine et al., 2019; Li et al., 2023). Finally, environmental innovations, measured on a per-person basis, demonstrate how technological advancements promote green financial practices, linking innovation with the adoption and success of green bond initiatives (Obobisa et al., 2022).

Through this comprehensive framework, the analysis elucidates the interplay of institutional, firm-specific, and macroeconomic factors that shape corporate green bond issuance in Europe, offering a robust understanding of the dynamics underlying this growing financial instrument.

Data and specification

This study focuses on a panel dataset of 22 European countries, selected based on the availability of precise data for the most critical dimensions analyzed. The dataset includes yearly information on corporate green bond issuance and prevailing carbon pricing mechanisms over the period 2013–2024, ensuring robust empirical insights. The dataset is constructed from Bloomberg's records of all corporate non-financial green bonds issued between January 2013 and October 2024, including details on the issuer, amount, yield, maturity, and announcement and issuance dates. The dataset also accounts for instances where no corporate green bonds were issued in a given year for the 22 European countries under review. Each country is matched with its prevailing carbon tax or ETS (Emissions Trading System) price for the corresponding year, sourced from the Carbon Pricing Dashboard of the World Bank. Additionally, annual macroeconomic data, institutional governance indicators, CO₂ emission exposure, and climate action metrics are incorporated, extracted respectively from the International Monetary Fund (IMF), World Bank Worldwide Governance Indicators, and OECD Climate Action Dashboard. This comprehensive dataset enables an in-depth analysis of the determinants of corporate green bond issuance across Europe.

The final dataset of non-financial corporate bonds comprises 802 bonds, with a statistical summary presented in Table 1. It presents an overview of the non-financial corporate green bond dataset, providing key statistics for each country, including the number of bonds issued, the total issued amount (in USD millions), the average maturity (in years), and the coupon rate (minimum, maximum, and average).

The summary statistics of non-financial corporate green bonds issued between 2013 and 2024 highlight significant variation in market activity across 17 European countries, out of the 22 included in the broader analysis. These 17 countries collectively issued 802 green bonds, amounting to a total issuance of \$261.38 billion. France led in both the number of bonds issued (108) and total issuance amount (\$61.25 billion), followed by Germany (\$48.31 billion from 84 bonds) and Sweden (\$20.48 billion from 260 bonds). The average maturity of green bonds varied widely, with Iceland reporting the longest at 18 years and Switzerland the shortest at 7.3 years. Coupon rates also ranged significantly, with minimum values as low as 0% in several countries (e.g., Austria, Finland, Germany, Sweden) and a maximum of 13.168% in France. The average coupon rate across all countries was 3.349%, with Norway reporting the highest average (5.584%) and Switzerland the lowest (1.177%).

These statistics underscore disparities in non-financial corporate green bond issuance across Europe, reflecting differences in market development, regulatory frameworks, and economic conditions. The remaining five countries in the dataset did not issue any non-financial corporate green bonds during the analyzed period.

Table 1: Summary Statistics of Non-Financial Corporate Green Bonds Issued in European Countries (2013–2024)

Country	# Corporate green bonds	Issued amount (\$ US Million)	Average maturity (years)	Coupon		
				Min	Max	Average
AUSTRIA	18	4 658,4	8,9	0,000	7,000	2,674
BELGIUM	16	4 310,3	5,9	0,750	5,306	3,261
DENMARK	26	15 311,9	276,8	0,375	7,240	3,432
FINLAND	40	12 131,7	39,0	0,000	10,988	3,908
FRANCE	108	61 248,2	26,9	0,000	13,168	2,341
GERMANY	84	48 309,3	12,4	0,000	9,500	2,432
GREECE	5	2 136,9	6,3	2,250	4,700	3,180
ICELAND	2	91,0	18,0	1,250	2,477	1,864
IRELAND	1	861,3	12,0	4,250	4,250	4,250
ITALY	50	27 366,4	24,0	0,000	6,750	2,613
LUXEMBOURG	7	3 987,7	6,4	1,625	7,000	3,768
NETHERLANDS	25	14 802,1	29,0	0,500	7,750	3,130
NORWAY	62	8 151,2	6,2	0,000	11,340	5,584
PORTUGAL	13	9 377,1	34,8	1,500	5,943	3,441
SPAIN	43	21 582,4	13,6	0,375	5,483	2,609
SWEDEN	260	20 483,3	8,8	0,000	13,000	4,119
SWITZERLAND	42	6 567,3	7,3	0,000	3,000	1,177
Total	802	261 376,6	23,7	0,000	13,168	3,349

The econometric analysis employs a random-effects regression with selection model to investigate the determinants of corporate non-financial green bond issuance per capita (at constant prices) across 22 European countries over the period 2013–2024. The model accounts for potential selection bias arising from differences in the likelihood of green bond issuance among countries. The dependent variable in the main equation is the logarithm of the amount of corporate green bonds issued per capita at constant prices.

The main equation models the determinants of (log) per capita green bond issuance as a function of bond characteristics, economic conditions, and institutional factors:

The outcome of interest Y_{it} , the logarithm of per capita green bond issuance at constant prices, is modeled as:

$$Y_{it} = X_{it}\beta + v_{1i} + \epsilon_{1it} \quad (9)$$

where X_{it} , the covariates (including the constant), encompass a range of factors categorized into three groups: bond characteristics, macroeconomic indicators, and environmental and institutional factors:

- **Bond Characteristics:** These include the logarithm of bond **maturity** (in years), **callable** status (a binary indicator denoting whether the bond is callable), and the **coupon rate** (percentage). These variables capture key attributes of the bonds that may influence issuance volumes. The bond characteristics are aggregated as weighted averages, with weights based on each bond's issue size to reflect their relative importance in the overall

issuance profile. For the coupon rate, the dominant status is retained if more than two-thirds of the bonds issued in the considered year for a given country share the same characteristic. This approach ensures that the bond characteristics accurately represent the issuance profile for each country-year.

- **Macroeconomic Indicators:** This category includes the **unemployment rate**, **financial market development**, and real **GDP per capita**, each lagged by one year to capture the delayed impact of macroeconomic conditions on corporate decision-making and market dynamics influencing green bond issuance. The unemployment rate is expressed as a percentage of the total labor force, including employed and unemployed individuals but excluding those not actively seeking work, such as students, retirees, and discouraged workers. Financial market development is a composite score derived from principal component analysis that integrates six components capturing the access, depth, and efficiency of financial institutions and markets, as defined by the IMF, reflecting the overall financial development of a country. Real GDP per capita, log-transformed and adjusted for purchasing power parity, represents economic prosperity and the capacity of a country's economy to support green financial initiatives. Lagging these indicators ensures that the macroeconomic environment during the planning and initiation of bond issuance is accurately represented, providing a clearer understanding of their influence.
- **Environmental and Institutional Factors:** **Environmental patents**, measured as the number of inventions per capita in environmental technologies, and **governance quality**, represented as a score derived from principal component analysis on six components of institutional governance, are also lagged by two years. This lag is justified as the influence of these factors on green bond issuance is unlikely to be immediate, reflecting a time lag in how institutional and innovation capacity affect market behavior and issuer strategies.

v_{1i} is the panel-level random effect, and ϵ_{1it} is the observation-level error. The selection process for the outcome is modeled by:

$$selection_{it} = 1(Z_{it}\alpha + v_{2i} + \epsilon_{2it} > 0) \quad (10)$$

where $selection_{it} = 1$ if we observe (an issuance) Y_{it} and 0 otherwise, Z_{it} are the covariates modeling the probability of corporate green bond issuance, which depend on factors reflecting environmental policy support, institutional governance quality, exposure to CO₂ emissions, and additional macroeconomic variables:

- **Environmental policy support:** This variable, lagged by two years, is evaluated as a score derived from principal component analysis. It is based on the number of environmental policies adopted across sectoral, intersectoral, and international domains, as well as the rigor with which these policies are implemented. The two-year lag accounts for the time required for such policies to influence market behavior and decision-making processes related to green bond issuance.
- **Institutional governance quality:** This variable is defined as in the main equation, capturing governance quality through a score derived from principal component analysis based on six components that define the institutional governance framework in the country. Its inclusion reflects the role of governance in fostering conditions conducive to green finance.
- **Exposure to CO₂ emissions:** Lagged by two years, this variable is calculated as a score derived from principal component analysis. It is based on per capita emissions (in tons

of CO₂ equivalent) of various pollutants, including carbon dioxide, greenhouse gases, hydrofluorocarbons, methane, sulfur hexafluoride, nitrous oxide, and perfluorocarbons. The lag is justified as emissions-related factors typically influence policy and market responses over time, rather than immediately.

- Macroeconomic Variables:
 - **Inflation:** Measured as the annual percentage change in the consumer price index, it reflects economic stability and directly impacts market dynamics and corporate financial strategies.
 - **Carbon tax:** Measured in U.S. dollars per ton of CO₂ and log-transformed, this variable captures the economic disincentives for carbon-intensive activities.
 - **General government debt:** This variable, measured as a percentage of GDP and lagged by one year, represents the fiscal capacity and constraints of the government. The one-year lag accounts for the immediate influence of fiscal conditions on the decision to issue green bonds as a means of financing sustainable projects.

v_{2i} is the panel-level random effect for selection, and ϵ_{2it} is the observation-level selection error. The random effects v_{1i} and v_{2i} are bivariate normal with mean 0 and variance:

$$\begin{pmatrix} \sigma_{1v}^2 & \rho\sigma_{1v}\sigma_{2v} \\ \rho\sigma_{1v}\sigma_{2v} & \sigma_{2v}^2 \end{pmatrix}$$

The observation-level errors ϵ_{1it} and ϵ_{2it} are assumed to follow a bivariate normal distribution with a mean vector of zero and a variance-covariance matrix given by:

$$\begin{pmatrix} \sigma_1^2 & \rho\sigma_1 \\ \rho\sigma_1 & 1 \end{pmatrix}$$

These errors are independent of the random effects.

The maturities, coupons, and callable status of the corporate issued green bonds are aggregated as weighted averages, with weights based on each bond's issue size.

Econometric results and discussion

The results of the random-effects regression with selection, presented in Table 2, offer valuable insights into the factors driving the issuance of corporate green bonds per capita at constant prices, while accounting for the selection process. The analysis is based on 264 observations from 22 countries over 12 periods, with 115 observations selected by the selection equation and 149 non-selected. The Wald chi-squared statistic of 117.55 confirms that the independent variables collectively and significantly explain the variation in the dependent variable.

In the main regression, the variable **Maturity** has a marginally significant positive effect, suggesting that bonds with longer maturities are associated with higher issuance levels, though this relationship warrants further investigation. The variable **Callable** is significant and positive, indicating that callable bonds are positively associated with increased green bond issuance, reflecting their appeal or flexibility for issuers. Conversely, the variable **Coupon** has

a marginally significant negative effect, suggesting that higher coupon rates may slightly deter issuance, possibly due to cost considerations.

Other significant predictors in the main equation include **Unemployment**, which has a positive effect, implying that higher unemployment rates may motivate green bond issuance, potentially due to government or corporate efforts to address economic challenges through green financing. The variable **Financial market development** has a significant negative effect, indicating that countries with more developed financial markets may see reduced reliance on green bonds, possibly due to alternative financing mechanisms. Economic prosperity, captured by **GDP per capita**, is significantly positive, highlighting that wealthier countries are more likely to issue green bonds. Lastly, **Environmental patents** has a significant negative effect, suggesting that higher levels of environmental innovation may not directly translate into higher green bond issuance.

The selection equation highlights the importance of **Environmental policy support** and **Governance quality**, both of which positively influence the likelihood of bond issuance. These findings underscore the critical role of supportive policies and governance in fostering green finance. **Inflation** negatively affects selection, indicating that higher inflation may discourage bond issuance. Meanwhile, **General government debt** is positively associated with selection, suggesting that countries with higher debt levels may be more inclined to issue green bonds, potentially as a means of diversifying funding sources.

The lack of a significant correlation between the errors of the selection and outcome equations suggests that issues like endogeneity or selection bias are minimal in this model. This means that unobserved factors affecting the likelihood of corporate green bond issuance are not systematically related to those influencing per capita issuance volume. As a result, the coefficients in the outcome equation can be interpreted more reliably without much concern for distortions due to selection effects.

Practically, this finding indicates that simpler approaches, such as random-effects or fixed-effects regressions, could produce similar results for the outcome equation. Although the selection equation still sheds light on the factors driving the likelihood of issuance, its role in refining the outcome equation is less critical. Consequently, policymakers can place greater emphasis on the determinants of per capita green bond issuance highlighted in the outcome equation, such as the influence of callable bonds, governance quality, and financial development.

However, the strong negative correlation between green bond issuance likelihood and per capita issuance highlights an inverse relationship between unobserved factors influencing these outcomes. This suggests that characteristics driving higher issuance likelihood simultaneously reduce per capita issuance or vice versa, warranting further investigation into these dynamics. One explanation is economic constraints in markets issuing green bonds. Limited financial market capacity may lead to symbolic issuance without achieving high per capita volumes. Similarly, market maturity could play a role, with nascent markets driven by policy incentives exhibiting high issuance rates but lacking the scale for substantial per capita figures. Issuers may also test market conditions with smaller issuance volumes to minimize risk or diversify funding, contributing to this dynamic.

Expanding the model to include variables like market liquidity, issuer creditworthiness, or investor demand could clarify these nuances. Subgroup analysis by region, income level, or

market maturity might reveal variations across contexts. Robustness checks, including sensitivity analyses or alternative models such as hierarchical or structural equation modeling, could further validate these findings and explore the interplay of these factors.

This relationship carries important policy implications. Capacity-building initiatives, such as technical assistance or credit enhancements, could help smaller markets scale up per capita issuance. Investor incentives, like tax benefits or sustainability-linked funding, might also boost activity in markets with lower per capita issuance.

Table 2: Econometric results of the random-effects regression with selection for corporate green bond issuance

	Heckman MLE Model	
	Outcome Equation (9)	Probit Equation (10)
Maturity	0.210*	
	(0.120)	
Callable	0.705***	
	(0.183)	
Coupon	-0.089*	
	(0.053)	
Unemployment	0.079**	
	(0.034)	
Financial market development	-3.079***	
	(0.612)	
GDP per capita	1.452***	
	(0.436)	
Environmental patents	-0.020**	
	(0.010)	
Governance quality	0.493***	0.775**
	(0.166)	(0.404)
Environmental policy support		1.920***
		(0.318)
Exposure to CO2 emissions		-0.001
		(0.400)
Inflation		-0.160**
		(0.071)
Carbon tax	3.89***	0.266**
	(1.12)	(0.136)
General government debt		0.025***
		(0.009)
Constant	-11.426**	-2.483**
	(4.830)	(1.062)
Number of observations		264
Censored observations		149
Number of clusters		22
Wald chi2(8)		120.36***
Observation-Level Error Variance		0.406***
Correlation Between Observation-Level Errors ^a		0.123
Country-Level Variance for Outcome Equation		0.304***
Country-Level Variance for Selection Equation		1.735***
Correlation Between Country-Level Random Effects ^a		-0.867***

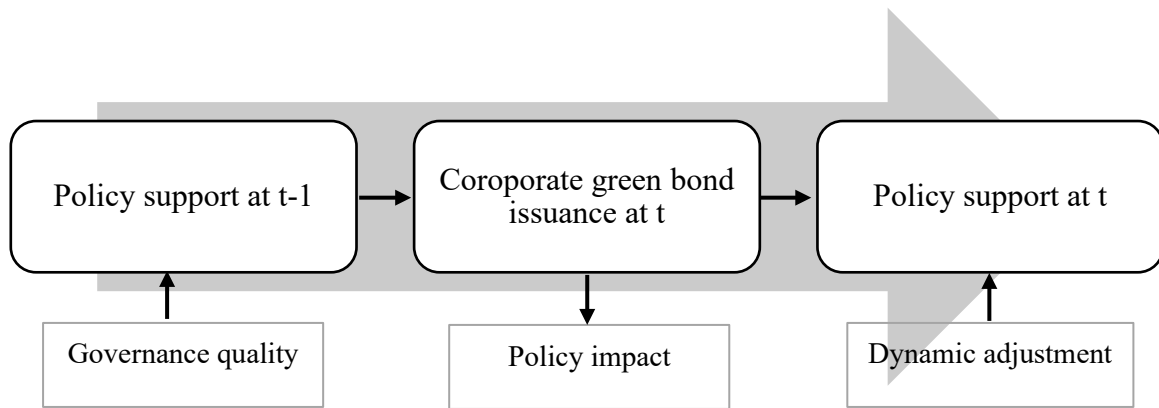
Notes: Robust-clustered (by country pair) standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.10. The interaction term is demeaned. The Heckman model is estimated by maximum likelihood procedure. Accordingly, the Probit and outcome equations are estimated simultaneously by implementing Stata's heckman command. All specifications include source and host country effects.

^a If at least one of the correlations is significantly different from zero, we can conclude that we have endogenous sample selection.

Future research should focus on understanding low per capita issuance in high-likelihood markets to align green bond financing with sustainability goals. Exploring cross-country differences in financial system maturity and green bond policy effectiveness could uncover additional drivers of this phenomenon. Addressing this imbalance is critical to improving the efficiency and equity of green bond markets, fostering broader adoption and impact.

The theoretical prediction highlights a dynamic, reciprocal relationship between green bond issuance and policy support, with governance quality acting as a crucial enabler. Supportive environmental policies and strong governance frameworks encourage firms to issue green bonds by reducing financial risks and enhancing the appeal of green finance. At the same time, increased green bond issuance signals market responsiveness and rising demand for green finance, motivating policymakers to sustain or strengthen these supportive measures (see Figure 1).

Figure 1: Feedback loop and dynamic interactions



To empirically validate the feedback loop, a dynamic panel GMM framework is employed to estimate two distinct yet interconnected equations. These equations reflect the bidirectional relationship between green bond issuance and policy support over time, with governance quality serving as a reinforcing factor. The explicit form of the estimated equations is provided below:

- The first equation models the determinants of green bond issuance by incorporating its lagged value, policy support, and governance quality. It captures how green bond issuance responds to policy incentives and the institutional environment.

$$\log(pcgbonds)_{it} = \alpha_0 + \lambda \log(pcgbonds)_{it-1} + \beta_1 P_{it} + \beta_2 GQ_{it} + \mu_i + \epsilon_{it} \quad (11)$$

where *pcgbonds* represents the per capita corporate green bond issuance at constant prices for country *i* at time *t*, with its lagged value capturing the persistence of issuance decisions over time. *P* denotes policy support, measuring the strength of environmental policies or incentives in country *i* at time *t*. *GQ* is the governance quality index, reflecting institutional stability and effectiveness. μ_i captures the unobserved country-specific effects, while ϵ_{it} represents the idiosyncratic error term.

Equation (11) tests the theoretical prediction that green bond issuance responds positively to policy support and governance quality while also exhibiting persistence over time.

- The second equation models the determinants of policy support to capture how policymakers adjust policies dynamically in response to green bond issuance and economic conditions.

$$P_{it} = \gamma_0 + \theta P_{it-1} + \alpha_1 \log(\text{pcgbonds})_{it-1} + \alpha_2 g_{it-1} + v_i + \eta_{it} \quad (12)$$

where P denotes policy support for country i at time t , with its lagged value capturing the persistence of policy measures over time. $\log(\text{pcgbonds})$ represents lagged green bond issuance, reflecting the influence of firm behavior on regulatory adjustments. g indicates lagged GDP growth, capturing the role of economic performance in shaping policy decisions for country i at time t . v_i accounts for unobserved country-specific effects, while η_{it} represents the idiosyncratic error term.

Equation (12) tests the theoretical prediction that policymakers observe green bond issuance trends and dynamically adjust policies, while GDP growth acts as an additional driver of policy changes.

The estimation results of the two equations, presented in Table 3, along with the diagnostic tests of the GMM framework, provide robust empirical evidence of the dynamic feedback loop between green bond issuance and policy support, while ensuring the model's reliability.

In equation (11), which examines the determinants of green bond issuance, the results show significant persistence over time, as the coefficient of the lagged dependent variable is positive and statistically significant. This suggests that past green bond issuance strongly influences current levels, a common dynamic feature in financial decision-making. Moreover, policy support has a strong positive effect, confirming that favorable environmental policies encourage firms to issue green bonds. Similarly, governance quality is significant and positive, highlighting the role of stable institutions in boosting investor confidence and supporting green financial activities. These findings align with theoretical predictions, showing that firms respond to both regulatory incentives and institutional stability.

In equation (12), which examines the determinants of policy support, the results reveal strong persistence in policy decisions, as the lagged dependent variable is highly significant. This highlights the gradual and inertial nature of policy adjustments over time. Furthermore, green bond issuance has a positive and statistically significant effect on policy support, indicating that policymakers adapt and reinforce policies in response to market activity and observable firm behavior. Additionally, GDP growth positively influences policy support, suggesting that economic performance enables policymakers to allocate resources and political focus toward advancing green policies.

The diagnostic tests associated with the GMM estimations confirm the reliability of the models. The Arellano-Bond test for autocorrelation identifies the expected first-order autocorrelation while showing no evidence of second-order autocorrelation, validating the moment conditions used for estimation. The Hansen test for overidentifying restrictions fails to reject the null hypothesis of instrument validity in both equations, confirming that the instruments are exogenous and appropriate. The Difference-in-Hansen tests further support the validity of the instrument subsets, particularly the GMM instruments for levels and the IV instruments for policy support, governance quality, and GDP growth. Although the Sargan test shows over-rejection in some cases due to sensitivity to heteroskedasticity, the robust Hansen test remains reliable.

Overall, these results confirm the existence of a bidirectional feedback loop: policy support and governance quality drive green bond issuance, while green bond issuance, in turn, motivates policymakers to sustain and adapt supportive policies. The strong persistence observed in both policy support and green bond issuance highlights the gradual and dynamic nature of these adjustments. The diagnostic tests validate the robustness of the GMM estimates, ensuring that the findings are not compromised by endogeneity, instrument proliferation, or serial correlation. These results reinforce the theoretical prediction that firm-level green finance decisions and regulatory responses are interdependent, with governance quality and economic growth acting as critical enablers of this feedback mechanism.

Table 3: GMM Estimation Results for the Dynamic Feedback Loop between Green Bond Issuance and Policy Support

	Equation (11)	Equation (12)
$\log(pcgbonds)_{it-1}$	0.399*** (0.134)	
P_{it}	0.489*** (0.134)	
GQ_{it}	0.269*** (0.114)	
Constant	0.942*** (0.212)	
P_{it-1}		0.840*** (0.030)
$\log(pcgbonds)_{it-1}$		0.096*** (0.021)
g_{it-1}		0.0032*** (0.005)
Number of observations	242	242
Number of instruments	21	20
Wald chi2(3)	288.84***	2446.69***
Sargan test of overid. restrictions: chi2(17)	33.66***	44.88***
Difference (null H = exogenous): chi2(9)	13.54	21.41
Arellano-Bond test for AR(1) in first differences: z	-1.96**	-3.84***
Arellano-Bond test for AR(2) in first differences: z	0.75	-1.66

Notes: Robust-clustered (by country pair) standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.10. The dependent variable in equation (11) is the logarithm of the per capita corporate green bonds issued at constant prices (using the GDP deflator in the considered country) transformed using an inverse hyperbolic sine transformation (Burbidge et al. 1988) in order to deal with country-years in which no corporate green bonds were issued.

4. Conclusion and Policy Recommendations

This paper presents a coherent and well-structured progression from theoretical concepts to empirical validation, providing valuable insights into the interplay between policy incentives, corporate strategies, and green bond issuance. The study effectively bridges theoretical predictions with real-world data, emphasizing key factors such as governance quality, environmental policy support, and carbon taxation. By empirically examining these elements, the research robustly validates the core assumptions and predictions of the proposed framework.

A significant strength of the study lies in its methodological rigor, demonstrated through the application of the Heckman econometric model, which effectively addresses selection bias. This approach aligns with the hierarchical decision-making process outlined in the framework,

allowing for a comprehensive analysis of both the likelihood and volume of green bond issuance. The methodological consistency enhances the study's relevance to policy design and market practice.

The empirical results also confirm the existence of a dynamic, bidirectional feedback loop between green bond issuance and policy support, employing a dynamic panel GMM framework. The findings demonstrate that green bond issuance responds positively to policy support, governance quality, and its own persistence over time, reflecting firms' responsiveness to regulatory incentives and institutional stability. Simultaneously, policy support dynamically adapts to green bond issuance trends and economic conditions, with strong persistence capturing the gradual nature of policy adjustments. Diagnostic tests, including the Arellano-Bond and Hansen tests, affirm the robustness and validity of the models, ensuring the reliability of the results.

The study also highlights the macroeconomic and institutional drivers of green bond issuance, particularly the role of governance quality and policy incentives. By illustrating the hierarchical interactions between regulators and firms, the paper successfully connects theory with practice, underscoring its contribution to understanding the dynamics of sustainable finance.

Policy Recommendations

Governments should prioritize the development of robust environmental policies and transparent institutional frameworks to encourage green bond issuance. Measures such as tax incentives, subsidies, and sustainability-linked standards can strengthen investor confidence and support the green finance ecosystem. Callable bond incentives, in particular, can increase flexibility and reduce financial risks for issuers.

Addressing market-specific constraints is essential for emerging and less mature markets, where smaller, symbolic issuances are common. Capacity-building initiatives, such as technical assistance, credit enhancements, and investor incentives like tax exemptions, can help scale up issuance volumes. Policymakers must also promote financial market development to ensure sufficient liquidity and infrastructure for substantial green bond issuance.

Economic growth and unemployment play critical roles in driving green finance. Policymakers should leverage economic prosperity to channel resources into green initiatives and use green bonds strategically to address unemployment and stimulate recovery during economic downturns.

To bridge the gap between innovation and finance, governments need to link technological advancements directly to green finance opportunities. Dedicated funding channels, sustainability-linked financing mechanisms, and the integration of environmental patents into green bond frameworks can ensure that innovation translates into practical financial outcomes.

Market liquidity and financial development are key enablers of large-scale green bond issuance. Policymakers should promote green financial products and enhance market infrastructure to improve liquidity and investor confidence. Supporting market maturity through regulatory clarity and creditworthiness assessments will encourage greater issuance volumes in advanced financial markets.

Finally, tailored regional strategies are critical to addressing variations across economic contexts. Subgroup analyses by region, income level, and market maturity can inform targeted policy interventions, particularly within the European context, where specific regulatory frameworks and economic conditions can be leveraged to enhance green bond issuance and foster sustainable finance growth.

However, the study acknowledges limitations in its scope, notably the exclusion of factors such as investor preferences, market liquidity, and issuer-specific challenges, which are essential determinants of green bond issuance. Addressing these gaps in future research could further enhance the model's robustness and broaden its practical relevance.

In conclusion, this study lays a strong foundation for understanding the interdependence between policy design and corporate behavior in the green finance sector. By addressing the identified shortcomings and expanding on the findings presented here, future research can offer deeper insights, fostering the development of more effective and comprehensive sustainable finance frameworks. This, in turn, will support policymakers and market stakeholders in driving the transition to a greener and more sustainable economy.

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