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Central bank policies and green bond issuance on a global scale

Charilaos Mertzanis

Abu Dhabi University, United Arab Emirates

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ABSTRACT

We employ recently released IMF data to examine the impact of central bank supervision policies on green bond issuance in sixty-six countries during 1992–2021. We introduce three novel metrics to assess central banks' supervisory authority: the breadth of their supervision mandates, the intensity of monitoring and enforcement, and the power of utilization of systemic risk tools. Countries with central banks possessing broader supervisory mandates and actively employing systemic risk tools are broadly associated with higher overall values of green bond issuance. Conversely, higher monitoring and enforcement intensity is associated with lower issuance values. These effects are pronounced in the realm of private green bond issuance and less prominent in government bond issuance where the government has a strong role. While the efficient functioning of financial institutions and the quality of ratings play crucial roles, inflation does not seem to have a significant impact on green bond issuance. Our results remain robust through sensitivity tests and endogeneity analyses. Developed countries primarily rely on central bank monitoring and enforcement intensity as the dominant policy variable, whereas developing countries lean more towards the central bank mandate as the influential policy variable.

1. Introduction

In recent years, there has been a growing acknowledgment of the significant role played by central banks in addressing the challenges of climate change and advancing sustainable finance (Campiglio et al., 2018; Brunnermeier and Landau, 2020). Central banks and financial regulators are increasingly underscoring the imperative for financial institutions to assess and transparently disclose climate-related risks (Monasterolo et al., 2017). This necessitates the integration of climate risk considerations into their risk management frameworks and information disclosure protocols. Furthermore, numerous central banks are proactively formulating guidelines and frameworks to promote green finance (Durrani et al., 2020; Dikau and Volz, 2021). Delineating criteria for categorizing investments as "green" or environmentally sustainable and offering guidance to financial institutions on incorporating these principles into their operational frameworks is a key challenge. Central banks are also concentrating on providing incentives and support (D'Orazio, 2023). Several central banks are exploring mechanisms to incentivize and bolster green finance initiatives, which may involve extending favorable terms for green investments or integrating sustainability criteria into their asset purchase programs.

Moreover, central banks are intensifying regulatory interventions and implementing rules for stress testing against climate risks (DeMenno, 2023). There is a growing trend of integrating climate-related stress testing into the assessment of financial system stability, evaluating the resilience of financial institutions under diverse climate scenarios. Additionally, central banks are incorporating environmental considerations into monetary policy (Boneva et al., 2021). Some central banks are actively exploring the incorporation of environmental factors, including climate change, into their monetary policy frameworks, signaling a broader acknowledgment of the interconnectedness between environmental sustainability and economic stability. In pursuit of these objectives, central banks are actively participating in international collaboration and partnerships to establish common standards and frameworks for sustainable finance (Gonzalez, 2021). Initiatives such as the Network for Greening the Financial System (NGFS) underscore the global scope of these endeavors. Lastly, in preparation for upcoming challenges, central banks are investing in capacity building and training programs to enhance the comprehension of climate-related risks among financial institutions, supervisors, and regulators.

Understanding the role of central banks in green finance is a central consideration for public policy. Numerous studies examine specific aspects of this role, contributing to a comprehensive understanding of the dynamics involved. Some investigations (Ferrari and Landi, 2023; Flammer, 2020a, 2020b) concentrate on the examination of specific policies and initiatives implemented by central banks and their influence on the issuance of green bonds. This line of inquiry is crucial for assessing the efficacy of these policies in fostering environmentally

E-mail address: Charilaos.mertzanis@adu.ac.ae.

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sustainable investments. Other studies (Fender et al., 2020; Giovanardi et al., 2023) focus on dissecting the mechanisms and instruments employed by central banks to incentivize green bond issuance, delving into the design of incentive programs, regulatory frameworks, and other tools that drive the adoption of green finance. Concurrently, other research (Kiliç, 2022; DiLeo, 2023) centers on the evaluation of the overall effectiveness of central bank policies in achieving environmental objectives. This involves scrutinizing the correlation between the presence of specific policies or initiatives and the actual issuance and performance of green bonds. Moreover, there is a call to extend this evaluation to assess the broader impact of central bank interventions on the entire green finance market. Collectively, these studies contribute to a nuanced comprehension of the multifaceted role of central banks in shaping and promoting sustainable financial practices.

However, there is a noticeable gap in the existing research regarding whether the impact of central bank policies on green finance exhibits variations across countries, regions, or sectors (Spyromitros, 2023). Given the unique economic, regulatory, and environmental contexts of different countries, central bank policies operate in diverse settings, presenting an opportunity for researchers to identify patterns, differences, and best practices, as noted by Steffen (2021). Consequently, green finance policies implemented within distinct policy frameworks may experience varying degrees of success in different countries (Mertzanis, 2023). Recognizing these distinctions is essential for policymakers, as it enables them to identify policies that have proven successful in specific regions and assess their potential applicability and transferability to other countries. This not only facilitates global cooperation but also fosters a collaborative learning environment, allowing nations to draw from international experiences and contribute to the development of a consistent and transparent global green finance ecosystem.

This paper contributes to the existing research agenda by leveraging recently compiled International Monetary Fund (IMF) data to examine the influence of central bank policies and monetary conditions on green bond issuance across sixty-six countries from 1992 to 2021. Introducing three innovative metrics to gauge central banks' supervisory authority, encompassing the breadth of their supervision mandates, the intensity of monitoring and enforcement, and their power of utilization of systemic risk tools, we uncover insightful findings. Our analysis reveals that countries with central banks wielding broader supervisory mandates and actively employing systemic risk tools tend to exhibit higher overall values of green bond issuance. Conversely, heightened monitoring and enforcement intensity are associated with lower issuance values. Notably, these effects are more conspicuous in the domain of private green bond issuances and less pronounced in government bond issuances. While the efficiency of financial institutions and the quality of ratings emerge as principal factors, inflation does not appear to exert a significant impact on green bond issuance. Our results withstand rigorous scrutiny through various sensitivity tests and instrumental variable analyses, addressing potential endogeneity concerns. To further discern the relative impact of a range of factors on green bond market growth, we apply dominance analysis, revealing the stronger influence of certain central bank policies compared to other factors. These findings contribute to a nuanced understanding of the interplay between central bank policies and the dynamics of green finance.

Our paper contributes to existing literature in several ways. Firstly, it advances the theoretical understanding of the design of central bank policies to effectively stimulate the growth of the green bond market, aligning with broader sustainability goals (Durrani et al., 2020; Dikau and Volz, 2021; Oberholzer, 2022). This contribution involves the conceptualization and development of frameworks for policies that not only foster sustainable finance but also integrate environmental considerations into monetary policy, providing insights into the intricate interactions between central banking, monetary policy, and sustainable finance.

Secondly, our paper contributes to the analysis of the impact of central bank policies on the dynamic of green finance markets, particularly within the realm of green finance (Boneva et al., 2021; Ferrari and Landi, 2023). By identifying incentives, regulations, and interventions that influence investor behavior and market outcomes, our research sheds light on the mechanisms driving progress towards sustainable development goals. This analysis is crucial for understanding the broader societal and economic implications of central bank actions in the context of green finance.

Lastly, our paper contributes to the analysis of the long-term effects of central bank policies on financial stability within the domain of green finance (Raberto et al., 2019; Popoyan and Galanis, 2022). This entails an assessment of the resilience of green financial markets to systemic risks originating from both economic and non-economic sources. By probing into these long-term effects, our research provides valuable insights into the sustainability and stability of financial systems under the influence of central bank policies, contributing to the broader discourse on green finance and its implications for economic stability.

The structure of the paper unfolds as follows: In Section 2, we offer an extensive summary of the associated literature concerning the correlation between central bank policies, monetary conditions, and green bond issuance. Section 3 provides a comprehensive insight into the data sources and empirical identification strategy that underpin our analysis. Section 4 discusses the results of the baseline analysis. Section 5 introduces various sensitivity tests, exploring the robustness of our findings, while Section 6 focuses specifically on addressing potential endogeneity. Further bolstering the reliability of our results, Section 7 presents additional robustness checks. Finally, Section 8 serves as the concluding segment of the paper, encapsulating the key outcomes and their broader implications.

2. Related literature

Central bank policies can influence the supply of and demand for green bonds through various channels, impacting investor behavior, market dynamics, the regulatory environment, and the provision of incentives for engaging in green finance. These policies also affect the structure of financial intermediation. We outline the operation of these channels below.

2.1. Central bank policies and the demand for green bonds

Central bank policies wield a substantial influence on the investor demand for green bonds, primarily through their impact on investor behavior and market dynamics. Notably, central banks frequently leverage interest rates and monetary policy tools as mechanisms to shape economic conditions. The strategic use of lower interest rates, for instance, can render green bonds more appealing to investors in comparison to traditional bonds, consequently fostering an upsurge in demand for green financing (Hachenberg and Schiereck, 2018). During periods of market distress, central banks adopt quantitative easing or asset purchase programs, potentially incorporating green bonds into their portfolios (Bremus et al., 2021). This dual function not only provides financial backing for green projects but also serves as a signal to the market that central banks regard environmentally sustainable investments as integral to their strategy, potentially amplifying demand.

Furthermore, central banks often collaborate with governments to directly introduce incentives and subsidies for green investments, thereby augmenting the attractiveness of green bonds to investors (Chygryn et al., 2019; Dikau and Volz, 2021). The provision of preferential interest rates, tax benefits, or other financial incentives plays a key role in enhancing the appeal of green bonds in the eyes of investors. This multifaceted approach underscores the proactive role of central banks in not only shaping market dynamics but also in directly influencing investor decisions and behaviors in favor of environmentally sustainable investments.

From a micro policy perspective, central banks exert considerable

influence on the demand for green bonds through strategic measures such as accepting these bonds as collateral in their lending operations (Fender et al., 2020; Dafermos et al., 2021). By incorporating green bonds into their collateral framework, central banks enhance the liquidity and broader acceptability of these instruments, thereby expanding their appeal to a more diverse range of investors. Additionally, central banks may institute requirements for financial institutions to assess and transparently disclose climate-related risks within their portfolios (Durrani et al., 2020; Deschryver and De Mariz, 2020). This transparency not only guides investors in making well-informed decisions but also has the potential to boost demand for green bonds by reducing perceived environmental risks. Moreover, central banks play a key role in stabilizing green bond markets and offering liquidity support. This initiative-taking involvement serves to enhance the attractiveness of green bonds by addressing concerns related to market stability and the ease of trading. As a result, the intervention of central banks in providing support and stability can contribute significantly to the sustained growth and appeal of the green bond market from a micro policy standpoint.

Furthermore, the establishment of clear regulatory frameworks and standards by central banks plays a crucial role in assuring investors about the credibility and environmental impact of green bonds (Perkins, 2021; Chen and Zhao, 2021). Such regulatory clarity not only reduces uncertainty but also enhances investor confidence, thereby stimulating demand for green bonds. Additionally, some central banks are exploring the integration of environmental considerations into their monetary policy frameworks (Krogstrup and Oman, 2019; Boneva et al., 2021). Explicitly incorporating environmental sustainability into the central bank mandate can send a robust signal to the market, potentially amplifying demand for green bonds.

Finally, central bank officials strategically use public statements and communication channels to underscore the significance of sustainable investments (Arseneau et al., 2022). This signaling effect can significantly influence investor perceptions and preferences, potentially acting as a driving force behind the increased demand for green bonds. The combination of regulatory frameworks, integration of sustainability into monetary policy, and effective communication strategies collectively contribute to shaping the market dynamics and fostering a supportive environment for the growth of the green bond market.

2.2. Central bank policies and the supply of green bonds

Central bank policies exert a notable influence on the supply of green bonds by actively shaping the regulatory environment, offering incentives, and creating conditions that encourage issuers to bring more green bonds to the market. A key strategy involves central banks establishing clear and supportive regulatory frameworks and standards for green bond issuance by financial institutions (Skinner, 2021; Dikau and Volz, 2021). This initiative involves precisely defining the criteria that qualify a bond as “green” and providing comprehensive guidelines for issuers. By implementing a well-defined framework and green finance taxonomies, central banks can streamline the issuance process, thereby enhancing the overall supply of green bonds in the market. This initiative-taking involvement underscores the significant role of central banks in fostering an environment conducive to the expansion of the green bond market.

Central banks support the supply of green bonds through various provision mechanisms. Notably, they can offer credit facilities and accept green bonds as collateral for loans (González and Núñez, 2021; Giovanardi et al., 2023). By doing so, central banks provide issuers with additional avenues for financing, simultaneously enhancing the liquidity and marketability of green bonds. Furthermore, central banks engaged in asset purchase programs (Bremus et al., 2021) and can actively include green bonds in their portfolios. This direct source of demand for green bonds not only supports the market but also encourages issuers to supply more in response to the favorable stance of the central bank. In a broader sense, central banks can introduce incentive programs and subsidies specifically tailored for issuers of green bonds (Hvammen and Fleischer, 2023; Björkqvist, 2023). These programs may encompass preferential terms, reduced financing costs, or tax benefits, collectively rendering green bonds more attractive for entities seeking to raise funds for environmentally sustainable projects. The multifaceted support provided by central banks thus contributes significantly to the bolstering of the supply of green bonds in the financial markets.

From a micro enforcement standpoint, central banks can enact policies mandating financial institutions to disclose climate-related risks within their portfolios. This requirement serves to promote transparency and may incentivize issuers to favor green bonds as a means of highlighting their commitment to environmentally sustainable practices (Steuer and Tröger, 2022). However, it is essential to acknowledge that such mandates can simultaneously elevate issuance costs, potentially acting as a deterrent to bond finance (Bonsall and Miller, 2017; Mertzanis, 2020).

Additionally, central banks may choose to enforce predetermined policy targets or quotas for green finance within the financial system (Robins et al., 2021). To address environmental systemic risk, an alternative approach involves introducing ceilings on credit extension specifically for carbon-intensive or polluting activities (Volz, 2017). This target-setting approach has the potential to motivate financial institutions to augment their issuance of green bonds to meet the established environmental targets. Balancing the regulatory push for sustainability with potential cost implications remains a critical consideration in formulating and enforcing micro-level policies for green finance.

Public statements and communication emanating from central bank officials, emphasizing the significance of green finance, plays a significant role in creating awareness and interest among bond issuers (Deyris, 2023). This advocacy has the potential to stimulate the public offering of green bonds by fostering a positive perception of these instruments within the financial community. Such statements may include explicit commitments by central banks to stabilize green bond markets, ensuring their efficient operation (Lupu and Criste, 2023). By doing so, central banks create a conducive environment for issuers, instilling confidence in the stability of the market and thereby encouraging an increased supply of green bonds. The public stance of central banks can function as a catalyst, aligning market sentiment with sustainability objectives and further propelling the growth of the green bond market.

2.3. Economic and financial conditions and green bond markets

Economic and financial conditions wield a significant impact on the markets for green finance, exerting influence over investor behavior, fund availability, and the overall growth and stability of the green finance sector. A prime example of this influence is evident in changes to monetary policy set by central banks, which directly affect inflation and subsequently shape the cost of capital and borrowing dynamics. Central banks achieve this by implementing various forms of money issuance, managing interest rates, and overseeing their balance sheets (Castillo-Martinez and Reis, 2019). Lower interest rates, an outcome of monetary policy adjustment, can render green financing attractive, stimulating investor demand for green financial instruments. Simultaneously, these lower rates incentivize issuers to tap into the green bond market. However, lower interest rates and unconventional monetary policy may contribute to inflation, potentially creating a deterrent for green bond issuance (Lhuissier and Szczerbowicz, 2022). The nuanced interplay between economic conditions, monetary policy, and the green finance sector underscores the need for a comprehensive understanding of these dynamics to foster sustainable growth within the market.

Buoyant economic growth has a profound impact on investor confidence and risk appetite (Stulz, 2000). In periods of economic uncertainty, investors often exhibit a preference for stable and sustainable investments. Robust economic conditions can foster increased

investment in green projects, driven by the perception that sustainable assets offer stability and resilience. Conversely, economic instability may compel investors to gravitate towards more sustainable and resilient assets as a means of safeguarding their portfolios (Mertzanis and Allam, 2018). On a broader scale, positive trends in global economic conditions and international cooperation can affect the expansion of the global green finance market. This is achieved by attracting green investments (Sudo, 2016). The synergistic effect of a thriving global economy and collaborative international efforts contributes to the overall growth and attractiveness of the green finance market, reflecting the interconnectedness between economic conditions, investor preferences, and the trajectory of sustainable investments.

Credit market conditions and risk perceptions also influence the availability and cost of financing for green projects (Dhruba, 2018). Financial institutions meticulously assess the creditworthiness and associated risks of green investments. When credit conditions are favorable, and there is a positive outlook on risk, it tends to result in increased lending and investment in green projects. Conversely, heightened risk aversion can impact the availability of funds for such initiatives. Moreover, the functioning of green financial markets is intricately linked to market liquidity (Raberto et al., 2019). A lack of liquidity or a decline in confidence within the market can significantly impact on the ability to buy and sell green financial instruments. Therefore, maintaining adequate market liquidity and fostering high investor confidence are essential for the smooth operation and sustained growth of the green finance market. The interplay between credit market conditions, risk perceptions, and market liquidity underscores the importance of a stable financial environment in facilitating green investments and supporting the broader objectives of sustainable finance.

The increasing awareness of environmental, social, and governance (ESG) factors within the mark*et also* plays a significant role, influencing investor preferences (Tan and Zhu, 2022). Investors are becoming more conscious of the environmental impact of their investments, driving a surge in demand for ESG-compliant investments, including green bonds and other sustainable financial instruments. This shift in investor preferences towards sustainable and responsible practices is a significant driver for the growing popularity of green finance.

Additionally, technological advancements and innovations significantly impact the development of green solutions and sustainable projects (Hughes et al., 2021). These developments not only influence the attractiveness of green finance but also contribute to a tech-driven transition towards sustainable practices. Such a transition may result in increased financing for innovative green projects, thereby contributing to the expansion of the green finance market.

Finally, the increasing frequency and severity of natural disasters and climate events draws attention to the importance of investing in resilient and sustainable projects (Dzator et al., 2021). Heightened awareness of climate-related risks becomes a driving force behind investments in green finance, as stakeholders actively seek to mitigate environmental impacts and build resilience. The convergence of investor preferences, technological innovations, and growing awareness of climate-related risks collectively propels the growth and significance of the green finance market.

2.4. Research hypothesis

Building upon the insights derived from the reviewed literature, this study frames its leading research hypothesis, positing that central bank policies exert a discernible influence on the overall value of green bonds issued in the market as a whole. This influence manifests through various demand and supply factors that, in turn, shape investor behavior, market dynamics, the regulatory environment, and the provision of incentives for active participation in green finance. Both economic and non-economic factors contribute to this multifaceted effect. In our hypothesis, the exploration of the impact of central bank policies on green bonds unfolds across diverse countries and centers on the breadth of their mandate, the monitoring and enforcement intensity, and the utilization of systemic risk tools. This approach allows for a comprehensive examination of how the nuanced aspects of central bank policies intersect with the offering of green bonds globally. The subsequent section provides detailed insights into the data and outlines the identification strategy employed to establish causal relationships between central bank policies and the offering of green bonds..

3. Data and identification strategy

3.1. Data

This study aims to establish a causal link between central bank policies, monetary conditions, and the offering of green bonds for the market as a whole. To conduct this analysis, cross-sectional data spanning multiple years is utilized, focusing on a distinctive panel dataset extracted from the IMF Climate Database. This dataset comprises 351 private and government green bond offerings, valued in USD billions, originating from sixty-six countries over the expansive period from 1992 to 2021. The choice of the IMF Climate Database is driven by its recognized status as a comprehensive repository of green bond data. Notably, a sizable portion of these green bond issuances occurred post-2011, aligning with the introduction of the Green Bond Principles by global investment banks. These principles have played a vital role in standardizing requirements, thereby bolstering market confidence in this evolving financial instrument (Cheong and Choi, 2020). To form our sample, we incorporate additional data from the World Bank's Bank Regulation and Supervision Survey, providing insights into central bank regulation and supervision policies (Cihak et al., 2012). Furthermore, economic and financial controls data from the World Development Indicators database are included in the sample. After data matching, the final baseline dataset comprises 217 annual aggregate green bond offerings from sixty-six countries. To mitigate the potential impact of outliers, the analysis utilizes the logarithmic values of certain level variables, especially those exhibiting extreme values. This methodological strategy is employed to bolster the robustness of the analysis and enhance the overall reliability of the findings.

Applying a country-year panel data estimation approach to analyze the effect of central bank policies on green bond issuance blends in-depth temporal and cross-sectional insights, enabling researchers to understand both immediate and long-term policy impacts across different national contexts (Bernanke and Boivin, 2003). This approach stands out for its ability to control for unobserved heterogeneity, enhancing the accuracy and depth of findings. Moreover, it offers more robust and efficient estimators due to the increased data variability, providing a stronger statistical basis for analysis compared to simpler models. However, this approach comes with its set of challenges, including the complexity of statistical analysis required, potential difficulties in sourcing consistent and comprehensive data across countries and over time, and the risk of model misspecification which could lead to biased outcomes. Additionally, the extensive time and resources needed for assembling quality datasets and conducting sophisticated econometric analyses can pose significant hurdles. Despite these challenges, our panel data approach presents a powerful tool for dissecting the complex impacts of central bank policies on green bond markets. This paper navigates the inherent data complexities with proper attention to data quality supported by the IMF's credibility and to proper model specification.

3.2. Key variables

In our empirical analysis, the dependent variable is the natural logarithm of the aggregate value in USD billions of green bonds offered to investors in each country, encompassing both private and sovereign issues, denoted as BNDGRN. This important data is sourced from the IMF

Climate Database. We note that analyzing green bond issuance through either aggregate country values or individual deal data offers distinct insights, each with its own set of advantages and disadvantages. Aggregate country values provide macro-level insights, simplify data analysis, enable comparative analysis between countries, and facilitate policy evaluation, making them ideal for understanding national commitments to green finance and the effectiveness of related policies. However, this approach may obscure the specifics of individual green bond deals, potentially leading to misinterpretation and overlooking detailed trends within sectors. Focusing on individual deal issuance allows for a detailed analysis of each project's environmental impact, financial returns, and risk profile, highlighting innovative practices and providing valuable insights for future investments. Yet, this approach can be complex, time-consuming to analyze, and may miss broader patterns visible only through aggregated data. Since we analyze the effect of aggregate central bank policies, our choice of aggregate green bond values might better suit broad policy concerns, country commitment to sustainability, and market trend analysis, relative to individual deal data that is more suitable for detailed investment decisions and project-specific impact assessment.

Our key predictor variables revolve around three measures of central bank supervision authority. The first measure, denoted as CBMND, is an ordinal variable ranging from 1 to 8 (strongest authority). It captures the extent of the central bank's supervisory mandates, cumulatively encompassing financial stability, market conduct, consumer protection, combatting financial crime/AML, competition/antitrust, deposit insurance, financial access/development, and bank restructuring insolvency. The second measure, denoted as CBENF, is an ordinal variable ranging from 1 to 9 (highest intensity). This measure gauges the central bank's monitoring and enforcement intensity, considering its power to cumulatively analyze and monitor the compliance of financial institutions and market trends (1–3 representing the highest); review the accuracy and regulatory compliance of reports (1–3 representing the highest); and assess risk profiles and establish strategic directions (1–3 representing the highest). The third measure, denoted as CBSYS, is an ordinal variable ranging from 1 to 5 (highest use). This measure assesses the central bank's systemic risk management tools, considering its power to cumulatively use countercyclical capital requirements, countercyclical loan/value ratios, granular capital requirements based on loan/price ratios, countercyclical provisioning requirements, and restrictions on dividend/bonus distribution. These newly constructed variables, derived from the Bank Regulation and Supervision Survey administered by the World Bank, effectively capture important aspects of central banks' supervision power.

Table 1 offers a summary of the pattern of the total value of green bonds offered and of the various supervisory powers of central banks across all sample countries. The average total country (absolute) value of green bonds offered is USD 5.10 billion, with the average value of corporate green bonds at USD 4.57 billion and government bonds at USD 5.69 billion. These values are noteworthy when compared to the average total value of conventional bonds. Leading the total offering of green bond are China (2.49), France (2.48), and the Netherlands (2.42), while countries like Iceland (−0.14), Norway (−0.2), and Mexico (−0.23) occupy middle positions. Namibia (−5.46), Morocco (−4.24), and Seychelles (−3.51) take the lowest positions in green bond offering. This suggests that lower-income and smaller countries are also riding the wave of green bond issuance market, propelled by growth opportunities despite encountering both supply and demand side barriers (see Cheong and Choi, 2020). Turning to central bank supervisory mandates, Bangladesh, Mexico, and Panama emerge among other countries too as

Table 1
Central bank policies and green bond issuance (average country values).

Country	Green bond issuance	CB mandate	CB enforcement	CB systemic risk tools	Country	Green bond issuance	CB mandate	CB enforcement	CB systemic risk tools
Argentina	−0.62	3.00	6.00	1.00	Luxembourg	0.36	7.00	3.00	0.00
Australia	0.42	3.00	6.00	2.00	Macao	−0.24	7.00	6.00	0.00
Austria	0.15	4.00	6.00	2.00	Malaysia	−1.39	6.00	6.00	2.00
Bangladesh	−1.05	8.00	6.00	1.00	Mauritius	0.61	7.00	3.00	1.00
Belgium	−0.30	4.00	6.00	1.00	Mexico	−0.23	8.00	6.00	1.00
Brazil	−0.68	6.00	6.00	0.00	Morocco	−4.24	2.00	6.00	1.00
Canada	1.18	2.00	6.00	3.00	Namibia	−5.46	5.00	4.00	1.00
Cayman Isls	0.78	5.00	3.00	0.00	Netherlands	2.42	4.00	6.00	1.00
Chile	0.61	5.00	6.00	1.00	New Zealand	−1.68	4.00	6.00	0.00
China	2.49	3.00	6.00	0.00	Nigeria	−2.59	5.00	6.00	0.00
Colombia	−1.85	4.00	6.00	2.00	Norway	−0.20	6.00	6.00	0.00
Costa Rica	0.00	4.00	6.00	0.00	Pakistan	−0.69	6.00	6.00	2.00
Denmark	0.85	6.00	6.00	1.00	Panama	−2.36	8.00	3.00	1.00
Egypt	1.10	7.00	6.00	0.00	Peru	−1.47	4.00	6.00	2.00
Estonia	−2.69	7.00	6.00	0.00	Philippines	−1.09	1.00	6.00	0.00
Fiji	−2.39	5.00	3.00	0.00	Poland	0.76	4.00	3.00	0.00
Finland	0.28	5.00	6.00	1.00	Portugal	0.54	5.00	6.00	2.00
France	2.48	4.00	6.00	2.00	Romania	−0.73	4.00	6.00	1.00
Germany	0.10	4.00	0.00	0.00	Russia	−1.53	6.00	6.00	1.00
Greece	−0.62	4.00	6.00	1.00	Serbia	1.51	6.00	6.00	1.00
Guernsey	−2.76	5.00	6.00	0.00	Seychelles	−3.51	4.00	6.00	0.00
Hong Kong	1.16	5.00	6.00	2.00	Slovak Rep.	−0.79	5.00	6.00	0.00
Hungary	0.85	6.00	6.00	0.00	Slovenia	−2.47	4.00	6.00	0.00
Iceland	−0.14	4.00	6.00	5.00	South Africa	−2.25	3.00	6.00	0.00
India	0.48	7.00	6.00	1.00	Spain	1.45	3.00	6.00	1.00
Indonesia	0.70	6.00	6.00	0.00	Switzerland	−0.90	5.00	6.00	0.00
Ireland	0.66	7.00	3.00	2.00	Thailand	−0.76	4.00	6.00	2.00
Israel	0.08	6.00	6.00	1.00	Turkey	−1.32	2.00	6.00	2.00
Italy	0.06	4.00	6.00	0.00	Ukraine	0.50	4.00	4.00	1.00
Jersey	−0.99	2.00	9.00	0.00	U.A.E.	−1.18	7.00	6.00	3.00
Korea, Rep.	0.99	5.00	0.00	3.00	U.K.	0.80	7.00	6.00	2.00
Latvia	−2.83	4.00	6.00	3.00	U.S.A.	1.44	7.00	3.00	0.00
Liechtenstein	−1.61	6.00	6.00	0.00					
Lithuania	−0.89	5.00	6.00	0.00	Total average	0.05	4.81	5.17	0.97

leaders with a score of 8.0, followed by Austria, Belgium, and Colombia with a score of 4.0. Countries such as Turkey, Jersey, and the Philippines occupy the lowest positions. Similar wide diversification is observed in the remaining central bank policy variables. This diversity underscores the global nature of green bond issuance and the varying degrees of central bank supervisory powers across nations.

3.3. Controls

Our main goal is to scrutinize the complex relationship between fluctuations in central bank supervisory policies and green finance. Acknowledging the inherent complexity of real-world scenarios, which often involve additional factors that can influence green finance and potentially complicate the comprehension of the fundamental cause-and-effect relationship, we introduce control variables. These control variables are employed to untangle and better understand the multi-faceted interplay at play in this context. The control variables in our study are as follows:

The initial control variable introduced is the inflation rate, denoted as INFL, sourced from the IMF Economic Outlook database. This variable serves as an indicator of the efficacy of monetary policy and its impact on issuer default risk. Elevated inflation rates can introduce instability in the broader economy, diminishing the creditworthiness of a state (Nickel et al., 2011). The growth of the green bond market may face obstacles in the presence of high inflation rates (Le et al., 2023). In our analysis, we gauge the influence of inflation by examining the annual percentage change in the general price level, anticipating that higher inflation rates will exert a negative impact on the issuance of green bonds..

The second control variable considered in our study is the sovereign credit rating, denoted as RATING and obtained from Moody's Corporation. This variable is assigned values ranging from 1 to 4, with higher values indicating a superior rating. Credit ratings offer comprehensive assessments of issuers' creditworthiness and probability of default, encompassing both economic and non-economic factors. These ratings wield substantial influence over various bond market activities, including the offering of green bonds (Prajapati et al., 2021) and the shaping of investor decisions. Additionally, ratings influence the green bond spreads and yields (Hachenberg and Schiereck, 2018). Lower rating scores suggest higher financing costs, reflecting the issuer's heightened ability to fulfill debt obligations and access capital markets (Wang et al., 2020). Changes in sovereign ratings can impact both debt and equity markets, as well as domestic and foreign markets (Rusike and Alagidede, 2021). In our study, we leverage Moody's sovereign debt ratings to capture these dynamics (Capelle-Blancard et al., 2019). We anticipate that higher ratings will positively influence green bond issuance.

The third control variable is the extent of financial institutions' efficiency, denoted as FIE, sourced from the IMF's Financial Development database. The variable measures the degree of efficiency in intermediating savings to investment, operational efficiency, and profitability efficiency, with higher values indicating higher efficiency. Efficient financial institutions are better equipped to conduct thorough risk assessments of green issuers and due diligence (Akomea-Frimpong et al., 2022). This is particularly crucial in the case of green bonds, where investors are often concerned about the environmental sustainability of the projects being financed. Moreover, more efficient financial processes can lead to lower transaction costs (Berger and DeYoung, 1997). Lower transaction costs make it more cost-effective for issuers to bring green bonds to market, as they can incur fewer expenses related to the issuance process. This cost-effectiveness may encourage more companies to consider green bonds as a financing option. We expect that higher financial institution efficiency will exert a positive overall effect on green bond offering.

Lastly, it is noteworthy that both the European Union (EU) and the OECD have implemented policies and guidelines for the promotion of green finance and the use of green bonds (OECD, 2021; EU, 2019). The EU has launched its Green Deal for green finance and environmental compliance that is mandatory for its member-States. Likewise, the OECD has recognized the significance of green finance in attaining sustainable development goals and has encouraged its members to embrace green bonds as a financing mechanism for sustainable projects. We factor in these policies by incorporating dummy variables on whether a country is a member of these supranational institutions.

Table 2 provides descriptive statistics for the variables, revealing substantial diversity among countries. The variables show considerable dispersion, but also small discrepancies between mean and median values suggest an approximation to normal distribution patterns. Moreover, Table 3 displays pairwise correlations among the variables employed in our empirical estimation. The table reveals that the green bond issuance values correlate with the central bank policy proxies, providing initial indication of a potential causal relationship. Additionally, the limited correlations among other predictors in the table indicate a low likelihood of collinearity.

3.4. Estimation model

Establishing a causal link between a country's central bank supervisory policies and green bond issuance is inherently complex, largely attributed to the potential presence of unobserved factors that share correlations with both central bank policy decisions and the choice to initiate green bond offerings. It is crucial to acknowledge that the relationship between green bond issuance and central bank policies is likely to be complex. Both variables are influenced by various economic, social, and political factors, and their interactions can be dynamic. For instance, a growing trend or demand for green finance and green bond investments in the market may induce central banks to adjust their supervision policies in response to this trend. Omitted economic and non-economic conditions and priorities may play a significant role. If environmental sustainability becomes a higher priority for governments and society, central banks may respond by incorporating green finance considerations into their supervisory policies. These possibilities imply that endogeneity may pose a serious potential challenge.

To tackle this challenge, we adopt alternative model specifications. Initially, we apply a pooled ordinary least squares (OLS) estimation model that incorporates country and year fixed effects to address time-invariant and time-varying heterogeneity, respectively (Greene, 2012). But OLS linear estimation has its limitations. It struggles with managing nonlinear relationships, exhibits poor extrapolation properties, is sensitive to outliers, and may be prone to attenuation bias, resulting in potentially inflated values for the outcome variable. Despite these drawbacks, OLS estimation serves as a robust starting point for constructing models of data relationships. It is favored over nonlinear estimation, which can be susceptible to incidental parameter bias (Angrist and Pischke, 2009). The inclusion of fixed effects in the analysis partly mitigates the bias associated with OLS estimation. However, to ensure the robustness of our findings, we conduct additional sensitivity and endogeneity analyses, considering only non-missing observations for the variables and employing country-clustered standard errors. The estimation model equation we utilize is as follows:

$$\mathrm{BNDGRN}_{jt} = \mathrm{a} + \mathrm{CNTRBNK}_{jt}\,\beta_1 + \mathrm{X1}_{jt}\,\beta_2 + \kappa_{jt} + \lambda_{jt} + \varepsilon_{jt} \quad (1)$$

In Eq. (1), the variables are as follows: BNDGRN_{jt} represents the value of green bonds issued in country *j* in year *t* (outcome); $\mathrm{CNTRBNK}_{jt}$ represents each of the three central bank supervisory policy proxies (CBMND, CBENF, CBSYS) considered separately in country *j* in year *t*; and $\mathrm{X1}_{jt}$ represents the vector of financial and economic controls in country *j* in year *t*. The error term λ_t accounts for year effects, the term κ_j accounts for country effects, and the term ε_{jt} represents the estimation's error term, assumed to be distributed normally and be variable across years and countries. Acknowledging the difficulties in establishing causal effects solely on observed correlations, we interpret our findings

Table 2
Summary statistics.

Variable	Obs	Mean	SD	Min	P25	P50	P75	Max
BNDGRN	217	0.07	1.90	−4.91	−1.05	0.20	1.40	4.00
CBMND	217	4.73	1.77	0.00	4.00	4.00	6.00	8.00
CBENF	217	5.17	1.80	0.00	6.00	6.00	6.00	6.00
CBSYS	217	1.00	1.03	0.00	0.00	1.00	2.00	5.00
INFL	217	2.38	4.86	−28.62	0.97	1.65	2.37	32.30
RATING	217	3.70	0.52	2.00	3.00	4.00	4.00	4.00
FIE	217	0.79	0.11	0.47	0.73	0.82	0.87	0.94
GDPG	217	1.16	3.75	−14.87	0.92	1.97	2.97	8.52
DUM9	217	0.39	0.49	0.00	0.00	0.00	1.00	1.00
DUM12	217	0.73	0.44	0.00	0.00	1.00	1.00	1.00

Note. The table reports the summary statistics of the variables.

Table 3
Correlation matrix.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
BNDGRN (1)	1									
CBMND (2)	0.06*	1								
CBENF (3)	−0.10*	−0.16***	1							
CBSYS (4)	0.07*	−0.04	0.11*	1						
INFL (5)	−0.14**	−0.00	0.03	0.01	1					
RATING (6)	0.22***	0.07	−0.16***	0.11*	−0.15***	1				
FIE (7)	0.22***	−0.33***	0.07	0.06	−0.10	0.30***	1			
GDPG (8)	−0.05	−0.09	−0.08	−0.01	0.03	0.11*	−0.02	1		
DUM_{EU} (9)	0.19***	−0.11*	−0.19***	−0.04	−0.08	0.12**	0.27***	0.02	1	
DUM_{OECD} (10)	0.23***	0.01	−0.18***	0.09	−0.06	0.38***	0.29***	0.05	0.45***	1
VIF	1.30									

Notes. The table reports the pairwise correlations between all the variables. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

as indications of the strength of association rather than causation. For simplicity, we opt to use the term "predict" to describe these relationships.

4. Baseline results

Our estimation analysis assesses the relative impact of our central bank policies on the total market issuance of green bonds, while accounting for various economic factors. Table 4 shows the outcome of the analysis, which indicates that our central bank policy proxies are significant predictors of green bond issuance values in all models with fixed effects. A broader range of central bank mandates is positively associated with increased green bond issuance. This aligns with the perspective of Dikau and Volz (2021), emphasizing the need for central banks to integrate climate-related risks into their policy frameworks. On the other hand, higher central bank monitoring and enforcement intensity appear to impede green bond issuance. It is plausible that stringent reviews of accuracy and regulatory compliance reports, along with a rigorous assessment of risk profiles, may discourage issuers of green bonds. Jackson and Roe (2009) argue that the effectiveness of enforcement depends on the quality of enforcement institutions and the level of financial development, which may not align with the conditions in some countries. Wong (2020) suggests that temporal differences across green investment projects, coupled with systemic disruptions, might discourage the issuance of green bonds, particularly when enforcement is exerted in the presence of complex networks. Additionally, a more extensive use of systemic risk tools by central banks is linked to a stronger trend in green bond issuance. This aligns with Volz's (2017) emphasis on the importance of systemic risk containment policies in green finance. As anticipated, higher credit ratings and greater efficiency of financial institutions are associated with increased green bond issuance. Notably, economic growth does not seem to exert significant effects on green bond issuance.

Table 4
Baseline effects.

Variable	(1)	(2)	(3)	(4)
CBMND	−0.017	−0.062	0.829***	0.425***
	(0.129)	(0.125)	(0.217)	(0.141)
CBENF	−0.115	−0.195***	−1.469***	−0.944***
	(0.069)	(0.072)	(0.210)	(0.165)
CBSYS	−0.001	−0.176	0.708***	0.445***
	(0.218)	(0.232)	(0.088)	(0.131)
INFL	−0.035	0.008	−0.046	0.008
	(0.038)	(0.019)	(0.044)	(0.013)
RATING	0.644	1.121**	0.769***	0.754
	(0.389)	(0.426)	(0.268)	(0.452)
FIE	2.100	−0.052	21.781***	7.918**
	(1.548)	(1.647)	(5.270)	(3.567)
GDPG	−0.054*	0.036	−0.015	0.059
	(0.031)	(0.058)	(0.027)	(0.038)
adj. R^2	0.074	0.329	0.476	0.713
RMSE	1.832	1.560	1.379	1.019
F-test	3.649			
Country FE	No	No	Yes	Yes
Year FE	No	Yes	No	Yes
Dummies	Yes	Yes	Yes	Yes
N	217	217	217	217

Notes. Notes. The table reports the baseline effects of central bank policies, and monetary conditions on the value of green bonds issued. Additional control variables include economic and financial variables. The pool sample period is 1992–2021. We use an OLS model with random and fixed effects and EU/OECD dummies. We cluster standard errors at the country level. Model (1) includes random effects only. Model (2) includes year effects only. Model (3) includes country effects only. Model (4) includes country-year effects.
*$p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Sensitivity and endogeneity analysis

Endogeneity is a common challenge in econometric estimation that arises when an explanatory variable is correlated with the error term in a regression model (Wooldridge, 2010). This correlation can lead to

biased and inefficient parameter estimates, making it difficult to draw valid conclusions from the analysis. Initially, if an important determinant of green bond issuance is omitted from the model and is correlated with both the central bank policy proxies and one or more included controls, it can lead to biased estimates. To tackle these potential challenges, our initial strategy is to integrate fixed effects, diverse country-level controls, and group dummies to alleviate this risk. Further, measurement errors in either green bond issuance value or the central bank policy proxies could result in biased and inconsistent parameter estimates if they are correlated with the error term. This concern is especially pertinent in our cross-country setting, characterized by considerable variability in measurements.. Endogeneity could further arise if change in green bond issuance cause changes in the central bank policy proxies, leading to reverse causation, which violates the assumption that these policy proxies are exogenous. Nonetheless, we contend that this concern is not substantial in our study, given that the green finance decisions of individual firms and governments are unlikely to exert influence on a country's central bank policies. The formulation of the latter policies typically involves a negotiated process, reflects broader political and other considerations, and is implemented well before the dependent variables are measured. Furthermore, the extensive cross-section of countries further reduces the potential likelihood of reverse causation. To enhance the robustness of our findings, we conduct additional sensitivity tests, employing alternative estimation methods and variable measurements, along with instrumental variable estimation methods and the novel Oster test of coefficient stability.

5.1. Sensitivity analysis

The aim of sensitivity analysis is to assess the reliability and robustness of the baseline statistical results by examining the impact of changes in data, assumptions, or methodologies on the conclusions drawn from the analysis. Table 5 provides the results of all sensitivity tests.

The initial sensitivity test adopts an alternative measure for the outcome variable, focusing solely on private sector green bonds. The data is derived from the IMF Climate database. Although central bank policies impact both private and government green bond issuance, the influence on each sector can diverge based on specific policies, economic contexts, market conditions, and the responsiveness of financial institutions and investors to sustainability initiatives (Hachenberg and Schiereck, 2018; Flammer, 2020a, 2020b). Furthermore, the efficacy of central bank policies in promoting green finance may differ between the public and private sectors depending on their implementation. In general, isolating the effect of central bank policies on corporate green bond issuance captures the unique responsiveness of the private sector to financial regulations and monetary stimuli, shedding light on the distinct dynamics of corporate financing for green projects. This analysis stresses the innovation and market development driven by the corporate sector, highlighting how public policy impacts vary across different risk profiles, pricing mechanisms, and the diverse range of projects funded. By focusing on corporate issuances, we discern how central bank policies influence investment appetite and signal market confidence. It also facilitates a more tailored assessment of policy effectiveness in encouraging corporate participation in sustainable financing. Column (1) of the results shows the findings from this alternative analysis. The impact of central bank mandates and the utilization of systemic risk tools is positive and significant, while the effect of monitoring and enforcement intensity is statistically significant and negative. Thus, the significance and direction of central bank policy effects align with those observed in the baseline results.

The second sensitivity test employs an alternative measure for the outcome variable, focusing exclusively on government green bonds with data sourced from the IMF Climate database. While central bank policies may exert influence on government green bond issuance, the latter is predominantly shaped by the broader financing needs of the

Table 5
Sensitivity tests.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
CBMND	0.423***	−1.497***	0.422***	−1.459	0.448***	−0.268
	(0.152)	(0.090)	(0.151)	(1.513)	(0.148)	(3.700)
$CBMND^2$						0.069
						(0.378)
CBENF	−0.935***	−0.593***	−0.943***	0.001	−0.945***	−3.199**
	(0.179)	(0.092)	(0.178)	(0.002)	(0.176)	(1.523)
$CBENF^2$						0.261
						(0.217)
CBSYS	0.439**	3.617***	0.444**	2.413*	0.425**	7.050***
	(0.191)	(0.083)	(0.190)	(1.411)	(0.195)	(1.758)
$CBSYS^2$						−3.372***
						(0.574)
INFL	0.008	0.104**	0.008	−0.060	0.009	0.008
	(0.012)	(0.030)	(0.012)	(0.216)	(0.012)	(0.012)
RATING	0.745	−2.052***	0.769	−8.824	0.751	0.754
	(0.725)	(0.411)	(0.720)	(8.203)	(0.734)	(0.729)
FIE	7.881**	15.214*	7.865**	26.910	8.423***	7.918**
	(3.287)	(5.785)	(3.252)	(20.718)	(2.955)	(3.272)
GDPG	0.061*	0.013	0.056	0.042	0.065*	0.059
	(0.036)	(0.030)	(0.043)	(0.034)	(0.037)	(0.037)
adj. R^2	0.725	0.986	0.706	0.913	0.726	0.713
RMSE	0.984	0.225	1.042	0.482	0.971	1.019
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Dummies	Yes	Yes	Yes	Yes	Yes	Yes
N	217	20	203	14	210	217

Notes. The table reports the baseline effects after applying alternative variable measures and sample structures. The pool sample period is 1992–2021. We use an OLS model with fixed effects and EU/OECD dummies. We cluster standard errors at the country level. Model (1) uses an alternative measure that includes only corporate green bonds (BNDGRNCR) to capture private sector effects. Model (2) uses an alternative measure that includes only government green bonds (BNDGRNGV) to capture government sector effects. Model (3) restricts the sample to include only developed countries. Model (4) restricts the sample to include only developing countries. Model (5) uses an alternative sample that excludes China (largest issuer). Model (6) uses an additional square term of each of the central bank policy variables to capture nonlinear effects.
*$p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

government. Nevertheless, the oversight of government debt obligations, encompassing green bonds, is primarily within the purview of government authorities (Fender et al., 2020). Likewise, isolating the effect of central bank policies on government-only green bond issuance allows for an in-depth exploration of how monetary policies influence government strategies for financing sustainable projects, revealing the complex relationship between fiscal policy and public investment in environmental initiatives. By examining government issuances, we assess the public sector's leadership in setting sustainability standards, its impact on risk perceptions through sovereign guarantees, and its role in developing the green bond market. Furthermore, concentrating on government green bonds facilitates a closer evaluation of public fund allocation, the measurable environmental impact of financed projects, and the transparency and accountability of public sector investments. Additionally, this approach unveils the macro-economic implications of green bond issuance on national debt, interest rates, and inflation, offering a comprehensive view of the sustainability of public financing mechanisms for green projects. Column (2) presents the outcomes of this alternative analysis. The impact of central bank utilization of systemic risk tools is notably positive and significant, while the effects of central bank mandates and monitoring and enforcement intensity are statistically significant but negative. Hence, higher central bank mandates do not necessarily correlate with increased government green bond issuance. This aligns with expectations, given that government authorities exercise greater control over government bond issuances, including those related to green bonds. This discovery adds an interesting dimension to the analysis.

In the third sensitivity test, an alternative sample structure is employed, focusing exclusively on developed countries. It is plausible that central bank policies in these nations are more sophisticated and stringent (Crowe and Meade, 2007). Distinguishing the impact of central bank policies on green bond issuance between developed and developing countries is crucial due to their different economic contexts, financial market maturity, and environmental priorities. Developed nations, with mature financial markets, might see these policies differently affecting market depth and green transitions, while in developing countries, such policies are often more critical for market creation and addressing environmental needs. Additionally, the risk-return profiles of green bonds, access to capital, and the types of projects financed vary significantly between these regions, necessitating tailored policy approaches. Moreover, in developing countries, central bank policies may also need to focus on capacity building and regulatory framework development, addressing financial inclusion and achieving social impacts alongside environmental goals. Understanding these distinctions is key to formulating effective policies that promote sustainable finance globally, ensuring they meet the unique needs of different regions and contribute to global sustainability goals. Column (3) exhibits the outcomes of this alternative analysis. The impact of central bank mandates and the use of systemic tools is notably positive and significant, while the effect of monitoring and enforcement intensity is statistically significant but negative. Thus, the findings for developed countries closely resemble those of the baseline results, largely attributed to their representation as a core component of the overall sample.

In the fourth sensitivity test, we adopt another alternative sample structure, focusing exclusively on developing countries. Central bank policies in these nations may differ from those of developed countries, primarily due to lower independence (Otek Ntsama et al., 2021). Column (4) presents the outcomes of this alternative analysis. The impact of central bank use of systemic tools remains significant, while the effects of the breadth of mandates and monitoring and enforcement intensity are insignificant. This is partly attributable to a notable reduction in the sample size. However, it underscores the significance of systemic risk considerations in the context of central bank support for green finance in developing countries.

In the fifth sensitivity test, we investigate the potential impact of large-size bias by excluding China, the largest green bond value sovereign issuer, from the estimation sample. This exclusion allows us to assess whether the presence of a large issuer affects the baseline results. Excluding extreme values from the data can enhance the assessment of central bank policies on green bond issuance by reducing skewness, improving model accuracy, enhancing statistical test robustness, and focusing on typical market responses. This practice helps in mitigating the disproportionate influence of outliers, leading to more accurate and reliable analysis of policy effects. However, the criteria for exclusion should be carefully considered to avoid losing valuable information, ensuring that the findings remain robust and relevant to policy formulation. Column (5) reveals the outcomes of this sensitivity test. The effect of central bank use of systemic risk tools remains significant and positive, while the effect of central bank monitoring and enforcement intensity is still significant but negative. The role of central bank mandates is less significant in this context.

In the final sensitivity test, we introduce a quadratic term for each of the three central bank policy variables to account for potential nonlinear effects on green bond issuance. The impact of interest rate changes on green bond issuance, for example, may exhibit nonlinearity (Bartram, 2002). There might be specific threshold levels of central bank policy measures (such as incentives, subsidies, or regulatory support) that trigger a significant increase in green bond issuance. Once these thresholds are surpassed, the positive effects may become more pronounced, indicating a non-linear relationship. Including a quadratic term of central bank policies in a regression model enables a nonlinear estimation of their effect on green bond issuance, capturing the complex, non-linear dynamics of economic behaviors. This approach acknowledges that the impact of policies might not be constant across all policy intensities, allowing for the identification of inflection points where the effectiveness of policies changes direction. It enhances the model's fit and predictive power by better reflecting the true relationship between policies and market outcomes, providing a richer, more detailed analysis. By accommodating nonlinearity, such a model acknowledges the complex mechanisms at play, offering a more nuanced understanding of policy effects. However, this complexity requires careful interpretation, emphasizing the need for a robust theoretical and statistical foundation in the analysis. Column (6) presents the findings of this new analysis. The effect of central bank mandates becomes insignificant, but the effects of monitoring and enforcement intensity and the use of systemic risk tools remain significant. Additionally, the quadratic term for the use of systemic risk tools is negative and significant, suggesting that higher use of systemic risk tools may exert a positive but successively weaker effect on green bonds.

The findings from the five sensitivity tests consistently support and affirm the significance and direction of the baseline effects of central bank policies on green bond issuance, particularly in relation to the influence of monitoring and enforcement intensity and the utilization of systemic risk tools. However, the role of central bank mandates appears less consistent across the sensitivity tests, indicating a need for further detailed analysis to unravel these effects. Additionally, the observed effects display some degree of nonlinearity and are stronger in corporate bond offering. These findings collectively underscore the strong relationship between central bank policies and the promotion of green finance. Further exploration and refinement of these effects would contribute to a more nuanced understanding of their dynamics.

5.2. *Instrumental variable estimation*

To address potential endogeneity concerns, we utilize instrumental variable (IV) methods, specifically employing the 2SLM estimator with use of an eternal instrument, to assess the robustness of our baseline results (Wooldridge, 2010). We utilize the degree of hierarchy in society (HIERARCHY) as our external IV instrument. Schwartz (2006) provides the data for the variable (1–3 highest). As a first approximation of the instrument's relevance, we observe that its pairwise correlation with BNDGRN is very low (0.014), whilst its correlation with CBMND is

considerable (−0.258), as well as with CBENF (−0.212), but somewhat lower with CBSYS (0.127).

The instrument also makes economic sense. Hierarchical structures in society can be associated with more strict financial regulation policies. Hierarchies often seek to maintain control and stability in the social and economic systems (Eskelinen, 2017). Strict financial regulations can be seen to control the activities of financial institutions, markets, and participants, reducing the likelihood of financial crises, and ensuring overall economic stability. Further, hierarchical social structures may be more risk-averse and altruistic (Mantell, 2018), which may be especially true in financial matters Strict financial regulations are often implemented to manage and mitigate risks in the financial sector, preventing excessive speculation, fraud, and other activities that could lead to economic instability. In hierarchical societies, decision-making authority is typically concentrated at the top levels of government or regulatory bodies (Romme, 2021). This centralized decision-making allows for the formulation and enforcement of comprehensive financial regulations that align with the broader economic goals of society. Hierarchical structures may prioritize the protection of investors and consumers (Hyman and Shingler, 1999). Strict financial regulations can be designed to ensure transparency, fair practices, and the safeguarding of the interests of individual investors, aligning with the hierarchical goal of protecting those lower in the social and economic hierarchy. Hierarchies often have an interest in preserving the existing economic order. Strict financial regulations can be used to shape and control economic activities, preventing excessive speculation, market manipulation, or unfair practices that could disrupt the established economic hierarchy.

Table 6
Endogeneity analysis.

Variable	(1)	(2)	(3)	(4)
CBMND	−0.601***	0.244	0.326*	0.829***
	(0.219)	(0.163)	(0.180)	(0.217)
CBENF	−0.308**	−0.739*	−0.141	−1.469***
	(0.139)	(0.412)	(0.265)	(0.210)
CBSYS	−0.201	0.069*	1.072*	0.708***
	(0.278)	(0.337)	(0.561)	(0.088)
INFL	−0.014	0.023	−0.004	−0.046
	(0.036)	(0.035)	(0.037)	(0.044)
RATING	1.056**	0.177	−0.406	0.769***
	(0.440)	(0.475)	(0.707)	(0.268)
FIE	−2.977	1.842	0.713	21.781***
	(2.591)	(2.703)	(2.654)	(5.270)
GDPG	−0.076*	−0.103***	−0.073**	−0.015
	(0.043)	(0.036)	(0.036)	(0.027)
First stage				
HIERARCHY	−2.880***	−2.794**	−0.131**	
	(0.673)	(1.205)	(0.054)	
Second stage				
Kleibergen-Paap_F_stat	9.874	5.165	6.806	
Kleibergen-Paap_LM_stat (pv)	3.720 (0.156)	3.585 (0.058)	6.660 (0.036)	
Stock-Wright_stat (pv)	7.660 (0.022)	8.652 (0.003)	5.346 (0.069)	
Delta				−0.678
Beta				−0.130*
Fixed effects	Yes	Yes	Yes	Yes
Dummies	Yes	Yes	Yes	Yes
N	178	166	140	217

Notes. The table reports the results of the endogeneity analysis. The outcome variable is the value of green bonds issued. The key independent variables are the central bank policies and the control variables. Model (1) uses the 2SLS estimator to instrument the CB mandate variable (CBMND) only. Model (2) uses the 2SLS estimator to instrument the CB enforcement variable (CBENF) only. Model (3) uses the 2SLS estimator to instrument the CB systemic risk tools variable (CBSYS) only. The external instrument used is the degree of hierarchy in society (HIERARCHY). Model (4) uses the Oster test of coefficient stability in regression.
*$p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 presents the estimation results derived from various instrumental variable (IV) regression models aimed at scrutinizing the relationship between central bank policies and green bond issuance. Columns (1) to (3) showcase the outcomes of the 2SLS estimator, individually applied to each of the three central bank policy variables (CBMND, CBENF, CBSYS) respectively. This estimator first regresses each of the central bank policy proxies on the value of the external instrument, addressing its validity. The first stage results show that the instrument is significant predictor of all central bank policy proxies, especially with respect to the first two ones. Further, the null hypothesis for the Kleibergen-Paap F statistic is that the instruments are valid, i.e., they are uncorrelated with the error term in the first-stage regression. Since the Kleibergen-Paap F statistic is small and not significantly different from zero, it suggests that the instruments are valid, supporting the null hypothesis. Moreover, the null hypothesis for the Stock-Wright test is that the instruments are uncorrelated with the error term in the first-stage regression. Likewise, since the Stock-Wright statistic is small and not significantly different from zero, it suggests that the instruments are broadly valid. Overall, the results from applying the two-stage 2SLS estimator for each policy variable indicate that all central bank policy proxies remain significant in all IV models with broadly the same sign as the baseline effects. However, the effect of the control variables varies by model. Overall, our instrumental variable approach tends to confirm the relevant validity of the central bank policy proxies in predicting the value of green bond issuance across countries.

5.3. The Oster test of coefficient stability

To enhance the reliability of our findings and mitigate the potential impact of omitted variable bias, we conduct additional tests. While we incorporate observed predictors into our model to minimize potential confounding, the inclusion of these predictors alone may not entirely control bias arising from unobserved factors. To address this concern, we employ Oster's (2019) bias-adjusted treatment test. This test examines the impact of incorporating unobserved predictors on omitted variable bias by scrutinizing variations in the stability of coefficients and the entirely explained variation of regressors when transitioning from observed to unobserved predictors.

Oster's test of coefficient stability introduces a novel approach to endogeneity analysis by focusing on the stability of estimated coefficients across different subsamples of the data or time periods. Unlike traditional tests that evaluate the validity of instruments or the overall model fit, the Oster test specifically addresses the potential endogeneity of each individual predictor variable in the entire regression. It assesses whether the coefficient remains consistent across varying subsamples or time periods.

In the presence of omitted variables, identifying the coefficient β representing the direct treatment effect becomes challenging. Instead, a range, including upper and lower bounds, of the treatment effect can be identified based on the proportionality degree, δ, between observed and unobserved predictors, as well as on the unknown overall model fit, R_{max}, which encompasses both observed and unobserved predictors. Moreover, the δ parameter plays a crucial role in interpreting the results, representing the threshold below which changes in coefficients are considered insignificant and above which they are deemed significant. It indicates the strength of correlation between unobserved predictors and the outcome variable relative to observed predictors, with larger values suggesting stronger endogeneity.

Column (4) in Table 6 presents the results of the Oster test. In this context, a small and negative δ parameter (−0.678) suggests that the inclusion of excluded instruments leads to a minor change in the potentially endogenous variable BNDGRN, indicating a low likelihood of endogeneity. The significant β coefficient (−0.130) further suggests that the instrumental variable is a reliable predictor of the allegedly endogenous variable, providing valid means to address endogeneity concerns..

6. Additional tests of robustness

6.1. New controls

Furthermore, the regulatory environment, government policies, and global climate agreements can significantly influence green bond issuance. Stringent environmental regulations and policies supporting sustainable finance can encourage total green bond offering (Berrone et al., 2023). Additionally, countries committed to achieving their climate targets under international agreements, such as the Paris Agreement, may actively promote green finance through supportive policies and incentives. The alignment of national policies with global sustainability goals contributes to a conducive environment for green bond issuance (Mertzanis and Tebourbi, 2023; Ferguson et al., 2021).

The financial market structure also plays a crucial role. A well-developed financial market with a diverse investor base, including institutional investors with a focus on ESG criteria, can provide a robust foundation for green bond issuance (Campiglio et al., 2018). Institutional investors, such as pension funds and sovereign wealth funds, increasingly incorporate sustainability considerations into their investment strategies, contributing to the demand for green bonds (Berg et al., 2022). Conversely, in markets with limited institutional investor participation or insufficient ESG awareness, the growth of the green bond market may face challenges.

While central bank policies and monetary conditions are influential factors, the landscape for green bond issuance is complex and multifaceted. It is shaped by a combination of economic, environmental, regulatory, and market-specific dynamics, as well as global trends in sustainable finance and geopolitics (Mertzanis and Tebourbi, 2024). Understanding these interconnections is essential for comprehensively assessing the drivers behind the issuance of green bonds and formulating effective strategies for fostering sustainable finance.

The inclusion of additional controls in the regression analysis aims to address potential confounding variables and enhance the robustness of the results. The analysis introduces several new factors, each representing distinct aspects of the economic, environmental, and geopolitical context. We discuss the impact of these controls on the association between green bond offering and central bank policies. In revisiting Eq. (1), we introduce additional groups of variables to encompass diverse impacts: firstly, addressing equity market and country-level risk, we incorporate information on each country's equity risk premium (RISKEQT) and country risk premium (RISKCTR) sourced from Professor Aswath Damodaran's Stern School of Business website. Secondly, to consider environmental economic conditions, we include the share of energy production from oil (ENRGOIL) and the value of environmental taxes as a percentage of GDP (ENVTAX), with data sourced from the IMF Climate Database. Thirdly, to account for global uncertainty, we introduce each country's annualized measures of geopolitical risk (GRPLOG) and the world uncertainty index (WUI), with data provided by Caldara and Iacoviello (2022) and the Economist Intelligence Unit, respectively. The updated results in Table 7 demonstrate that the positive and significant impact of central bank mandates and the use of systemic risk tools on green bond issuance remains consistent across all models, while monitoring and enforcement intensity maintains a significant and negative relationship. Notably, the inclusion of new controls amplifies the effects, with these variables emerging as significant predictors of green bond issuance. This model refinement enhances the understanding of how central bank policies influence green finance without altering their fundamental relationship.

6.2. Dominance analysis

We further employ dominance analysis (see Azen and Budescu, 2006) to discern the dominant central bank policies influencing green bond market offering. Dominant analysis goes beyond singular coefficient examination and examins the holistic impact of independent variables in the given model. Rooted in game theory's Shapley value decomposition, dominance analysis assesses the relative importance of individual predictors in determining the given model's overall predictive power. Leveraging Luchman's (2021) recent methodology for conducting dominance analysis, we calculate the average net improvement in the overall model R^2 upon introducing each independent predictor. This approach offers nuanced insights into the hierarchy of importance among central bank policy proxies, aiding in a more precise comprehension of their relationships with the outcome variable. Dominance analysis serves as a valuable tool to pinpoint the most influential predictors and enhance our understanding of their collective impact on green bond issuance.

Table 8 reveals the results of dissecting the effect on total green bond offering of each central bank policy proxy and control variable individually and in tandem. In Column (1), when considering each central bank policy proxy in isolation, monitoring and enforcement intensity emerges as the dominant factor, followed by the use of systemic risk tools and breadth of mandates. Column (2) introduces control variables, highlighting that the rating score assumes dominance, trailed by financial institutions' efficiency and the extent of monitoring and enforcement intensity. In Column (3), focusing solely on developed countries, the results align with the overall sample. Intriguingly, in Column (4), scrutinizing developing countries exclusively, the breadth of central bank mandates takes precedence, succeeded by the rating score and the inflation rate. These insights shed light on the specific variables that policy interventions should target to yield the most substantial growth effects in the green bond market.

Table 7
Additional robustness checks.

Variable	(1)	(2)	(3)
CBMND	0.922***	0.445**	0.569***
	(0.233)	(0.189)	(0.143)
CBENF	−0.724***	−0.857***	−0.802***
	(0.120)	(0.208)	(0.191)
CBSYS	0.915***	0.635***	0.424***
	(0.214)	(0.076)	(0.127)
INFL	0.006	0.021**	0.016*
	(0.013)	(0.010)	(0.008)
RATING	0.822	0.165	0.887**
	(0.494)	(1.254)	(0.366)
FIE	9.533***	8.788**	8.446**
	(3.296)	(3.546)	(3.515)
GDPG	0.061	0.008	0.037
	(0.040)	(0.050)	(0.041)
RISKEQT	−170.265***		
	(56.996)		
RISKCTR	182.415***		
	(50.274)		
ENRGOIL		0.291***	
		(0.102)	
ENVTAX		−0.340	
		(0.334)	
GPRLOG			5.239***
			(0.315)
WUI			−1.159*
			(0.583)
adj. R^2	0.714	0.754	0.717
RMSE	1.019	0.957	1.018
Fixed effects	Yes	Yes	Yes
Dummies	Yes	Yes	Yes
N	217	188	205

Notes. The table reports the baseline effects of central bank policy and monetary conditions on the value of green bonds issued. Additional control variables include macroeconomic and environmental variables. The pool sample period is 1992–2021. We use an OLS model with fixed effects and EU/OECD dummies. We cluster standard errors at the country level. Model (1) controls for the effect of additional risk premium conditions in financial markets (RISKEQT, RISKCTR). Model (2) controls for the effect of additional environmental conditions (ENRGOIL, ENVTAX). Model (3) controls for the effect of additional geopolitical uncertainty conditions (GPRLOG, WUI). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
Dominance analysis.

Variable	(1)	(2)	(3)	(4)
CBMND	0.0041	0.0014	0.0095	0.5626
CBENF	0.0126	0.0143	0.0162	0.0001
CBSYS	0.0061	0.0005	0.0004	0.0270
INFL		0.0111	0.0101	0.1135
RATING		0.0299	0.0351	0.1173
FIE		0.0205	0.0176	0.1073
GDPG		0.0078	0.0138	0.0056
Fit-stat	0.0227	0.1124	0.1304	0.9333
N	306	217	203	14

Notes. The outcome variable is the value of green bonds issued. The independent variables are the central bank policies and the controls. Model (1) shows the dominant effect of each of the central bank policy variables only on total green bond issuance value for the whole sample. Model (2) shows the dominant effect of each of central bank policy variables and the controls on total green bond issuance value for the whole sample. Model (3) shows the dominant effect of each of central bank policy variables and the controls on total green bond issuance value only for developed countries. Model (4) shows the dominant effect of each of central bank policy variables and the controls on total green bond issuance value only for developing countries.

Table 9
Central Bank enforcement effect mitigation channels.

Variable	(1)	(2)	(3)
CBMND	0.443*	0.766***	0.778***
	(0.231)	(0.164)	(0.160)
CBENF	0.422	−1.256***	−5.208**
	(0.737)	(0.169)	(2.270)
CBSYS	0.984***	0.442***	0.765***
	(0.152)	(0.082)	(0.097)
INFL	−0.017	0.012	−0.005
	(0.023)	(0.014)	(0.020)
RATING	0.645	−1.278**	−3.919***
	(0.703)	(0.560)	(0.815)
FIE	18.712***	18.822***	20.722***
	(4.358)	(4.072)	(4.019)
GDPG	0.021	0.046	0.067
	(0.027)	(0.177)	(0.175)
PRODSTR	9.613***		
	(3.109)		
CBENF * PRODSTR	−1.118*		
	(0.585)		
BIGTECH		0.004***	
		(0.001)	
CBENF * BIGTECH		0.001***	
		(0.000)	
NGAIN			0.958***
			(0.167)
CBENF * NGAIN			−0.103***
			(0.032)
adj. R^2	0.717	0.703	0.696
RMSE	1.006	1.030	1.035
Fixed effects	Yes	Yes	Yes
Dummies	Yes	Yes	Yes
N	216	197	140

Notes. The table reports the effect of mediator variables on the association between monitoring and enforcement intensity and green bond issuance. The pool sample period is 1992–2021. We use an OLS model with fixed effects and EU/OECD dummies Model (1) presents the moderating effect of a composite measure of economic activity structure (PRODSTR). Model (2) presents the moderating effect of the size of bigtech finance in the economy (BIGTECH). Model (3) presents the moderating effect of the extent of country adaptation to climate disruptions (NGAIN). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

After identifying monitoring and enforcement intensity as the dominant predictor among the three central bank policy variables, we now explore new economic variables that may mediate its impact, thereby enhancing green bond market issuance. We assess both direct and interaction effects. Table 9 shows the results. Firstly, we introduce the country's economic production structure (PRODSTR) as a potential mediator. Data from the World Development Indicators database informs this variable, which is calculated as the first principal component of the shares of agricultural value added, industrial and manufacturing value added, and services value added. We find that greater diversification in the country's production structure could stimulate green bond issuance directly and indirectly by mitigating the adverse effects of monitoring and enforcement intensity. Secondly, we consider the total value of finance expended by bigtech firms as percentage of GDP attributed (BIGTECH) as another crucial mediator. Data from Cornelli et al. (2023) is utilized for this variable. Increased bigtech financing in the economy is expected to directly encourage green bond issuance and indirectly exacerbate the adverse effects of monitoring and enforcement intensity. Thirdly, we look at the extent of a country's adaptation to climate disruption (NGAIN) as an additional mediator, using data from the NGAIN Project at the University of Notre Dame. We find that higher adaptation to climate disruption directly encourages green bond issuance and indirectly mitigates the adverse effects of monitoring and enforcement intensity. It's important to note that this is a preliminary analysis, and a more in-depth exploration is warranted in future research.

7. Conclusions

Our analysis investigated the connection between central bank policies and the global offering of green bonds, utilizing an extensive dataset from the IMF Climate Database that encompasses sixty-six countries and spans from 1992 to 2021. We create three proxies of central bank policies: the breadth of central bank mandates, the extent of monitoring and enforcement intensity, and the utilization of systemic risk tools.

We find that the effect of the breadth of central bank mandates on green bond offering is positive but rather inconclusive, exhibiting sensitivity to model conditions. This variability underscores the complex relationship between the scope of central bank responsibilities and the promotion of sustainable financial instruments. It prompts further exploration into the contextual factors that may influence the impact of central bank mandates on the offering of green bonds, acknowledging the complex interplay of economic, political, and environmental considerations. Contrary to the potential positive impact of central bank intervention, our analysis reveals a rather unexpected negative effect associated with monitoring and enforcement intensity. This intriguing finding calls for a more nuanced understanding of the mechanisms through which central banks influence the green bond market. Further research is warranted to examine the specific regulatory measures and enforcement strategies that may inadvertently hinder the offering of green bonds, despite overarching efforts to promote sustainable finance. This counterintuitive result underscores the need for a comprehensive evaluation of regulatory practices to ensure their alignment with sustainability goals. Finally, on a positive note, the significant and positive effect observed in the case of central banks utilizing systemic risk tools further emphasizes the key role these institutions play in steering financial markets towards environmentally responsible investments. The proactive use of systemic risk tools by central banks emerges as a potent driver for the offering of green bonds, providing a promising avenue for policymakers to bolster sustainable finance. This finding invites a deeper exploration of the specific tools and mechanisms employed by central banks to mitigate systemic risks and their subsequent impact on fostering a green financial landscape.

Our investigation has not only scrutinized the primary variables but has also navigated the complexities associated with potential endogeneity issues, conducted sensitivity tests, and employed dominance analysis. These rigorous methodological approaches not only enhance the robustness of our results but also underscore the reliability and validity of the observed correlation.

The findings of this research hold several implications for central

banking theory, ushering in a paradigm shift in how we conceptualize the role of central banks in the broader financial landscape. Traditionally, central banks have been primarily associated with monetary policy and financial stability. The positive correlation between central bank policies and green bond offering broadens the conventional understanding of central banking, suggesting an expanded role in promoting sustainability. This challenges traditional theories that focus solely on price stability and inflation targeting.

The uncertain impact of the breadth of central bank mandates highlights the need for a more nuanced and context-dependent understanding of central banking functions. Central banking theories may need to evolve to incorporate the idea that the effectiveness of central bank mandates in promoting sustainability is contingent on specific economic, political, and environmental conditions. This calls for a holistic regulatory approach that considers the broader implications of central bank actions. Moreover, the unexpected negative effect associated with central bank monitoring and enforcement intensity prompts a reassessment of intervention strategies. Central banking theories may need to incorporate a more thorough examination of enforcement mechanisms to ensure they do not inadvertently hinder sustainable financial practices. This challenges the assumption that increased regulatory oversight inherently supports environmental objectives. Finally, the significant and positive effect of central banks using systemic risk tools on green bonds introduces a new dimension to central banking theory. The emphasis on these tools suggests that central banks can actively contribute to sustainable finance through their risk management functions. Central banking theories may need to incorporate a deeper analysis of how systemic risk tools can be leveraged to align financial systems with environmental objectives.

The implications of our research extend beyond the immediate scope of the study. The broad positive association identified between central bank policies and green bond offering suggests that the regulatory environment established by central banks plays a significant role in fostering sustainable financial practices globally. As nations grapple with the challenges posed by climate change, our findings underscore the potential of central banks to function as influential catalysts in steering financial markets towards environmentally responsible investments. Furthermore, our research contributes to the evolving discourse on the role of central banks in addressing contemporary challenges. The strong association we have identified emphasizes the need for a comprehensive approach to financial regulation, one that recognizes the interconnectedness between monetary policies and sustainability objectives. However, the traditional boundaries of central banking functions may need to be redefined to accommodate a more comprehensive and dynamic approach that aligns with the imperatives of sustainability and environmental responsibility. The findings underscore the importance of integrating environmental considerations into central banking theories. Sustainability is becoming a critical aspect of economic and financial stability, and central banks may need to adapt their theories to acknowledge the interconnectedness of environmental factors with traditional economic indicators.

CRediT authorship contribution statement

Charilaos Mertzanis: Writing – original draft, Methodology, Formal analysis, Conceptualization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2024.107541.

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