Cureus Journal of Business and Economics

Open Access Original Article

Implications of the Relationship Between Quantitative Intervention and Green Bond Issuance for Managing Economic Cycles

Manha Sorathiya [1] , Zaara Sadh [1] , Shaunak Kulkarni [1] , Gitanjali Mohanty [2]

1. Economics and Finance, University of London, Mumbai, IND 2. Faculty of Economics, Podar World College, Mumbai, IND

Corresponding author: Manha Sorathiya, manhasorathiya3@gmail.com

Received 03/10/2025
Review began 03/20/2025
Review ended 05/31/2025
Published 06/24/2025

DOI: https://doi.org/10.7759/s44404-025-03624-4

Abstract

This study examines the effect of quantitative intervention (QI) on green bond issuance using a simple linear regression model and evaluates its significance for economic cycle management policies. The findings exhibit a conditionally positive correlation between QI and green bond investment, contingent on the extent of central bank asset expansion aspect, and a negative correlation with monetary base expansion. In a limited sense, this implies that quantitative easing diverts capital away from green bonds, whereas quantitative tightening is associated with increased activity in the sector. This study can help inform policy decisions regarding the appropriate form of monetary intervention, whether QI or more traditional rate-based measures, based on green financing priorities, and it briefly covers measures that may be taken to modify this outcome.

Categories: Climate Change, Sustainable Economic Development
Keywords: green bonds, sustainable finance, economic cycles, monetary policy, central banking, quantitative easing, quantitative tightening
JEL Classifications: E32, E52, E58, E61

Introduction

One of the most well-known uses of contemporary economics is the identification of factors that contribute to economic fluctuations and the development of strategies for mitigating their effects. With the help of constantly improving records and an expanding array of empirical tools, policymakers are well-positioned to predict economic turning points. Contemporary policy authorities often face a trade-off between overarching economic management and fostering a sustainable macroeconomic environment. Over time, international efforts have facilitated the development of standard frameworks and securities such as green bonds; however, the conflict between priorities remains a pressing issue in an increasingly interconnected global economy where even minor slowdowns have a ripple effect across economies and sectors, whether through government debt, supply chain disruptions, credit market shocks, or otherwise. Therefore, policies must account for a broad spectrum of macroeconomic consequences.

Green bonds have experienced rapid growth in recent years due to their unique green attributes. They are the most suitable sustainable investment tools for combating climate change while also supporting the financial system's stability (Zhou and Kythreotis, 2024).

The aim of this study is to evaluate the effectiveness of unconventional monetary policy, with the primary constraint being its impact on green bond issuance. We have used quantitative easing (QE) and quantitative tightening (QT), collectively referred to as quantitative intervention (QI) in this paper, that has gained traction in the 21st century, with respect to its effect on green finance, as our hypothesis. Furthermore, we delve into wider policy ramifications associated with its deployment.

The relevance of this study lies in the contribution of central bank assets in the growing discourse on the intersection of monetary policy and sustainable finance, specifically in relation to climate change, economic footprint, and boosting investment in green financial instruments. This research brings into picture the green aspect that the central bank should take into consideration while carrying out actions in investment and purchasing of assets, expanding monetary bases and making policies that directly impact green investments, bringing to light the mechanisms that promote or hinder the growth of sustainable finance. By understanding the relations between QI and green bond issuance, central bank policies can be altered and changed with respect to an overall sustainable impact through financial markets in the economy. It paves the way for policymakers to make more sustainably aligned decisions with respect to liquidity provisions in the economy. This research acts as a bridge between monetary policy and climate finance. The central bank should take into consideration the efficiency of QI's effect on the green bond market owing to the increase in the role of climate-related risk in economic stability.

How to cite this article
Sorathiya M, Sadh Z, Kulkarni S, et al. (June 24, 2025) Implications of the Relationship Between Quantitative Intervention and Green Bond Issuance for Managing Economic Cycles. Cureus J Bus Econ 2 : es44404-025-03624-4. DOI https://doi.org/10.7759/s44404-025-03624-4

Observing the correlation between QI and green bond investment, this study addresses the question that arises, which is 'how can management of economic cycle fluctuations be leveraged to stimulate higher green bond investment?'

Literature review

The growing significance of green bonds as a financing tool for addressing climate change by promoting sustainability is a widely addressed and well-established global topic. Empirical studies show that green bonds significantly reduce CO_2 emissions and increase renewable energy production (Zhang et al., 2024). Moreover, green bonds have historically been proven to be more defensive than traditional bonds, as evidenced by lower duration-adjusted volatility, and have similar duration-adjusted return's. This characteristic (lower duration volatility) provides greater stability to portfolios during economic downturns, aiding institutions and investors in protecting capital during periods of decline in riskier assets, such as stocks.

Authors in an article (Quantitative Easing for Economic Recovery Must Consider Climate Change, 2020) highlight the improvement of financial regulators in having a keener understanding of how climate change poses risks to financial and macroeconomic stability, compared to 2008. It describes the behavior of central bank and other financial regulators in encouraging financial institutions to take climate risk seriously and investors to consider climate change when making investment decisions. This gives our study incentive to incorporate a sustainable study. Therefore, it is necessary to investigate the economic effects of QE on sustainability, a tool of monetary policy, which is incorporated in our research. Using monetary policies, especially QE, central banks are essential to green finance. Authors in an article (Monetary Policy for the Green Transition, 2024) found that monetary policy contraction hurts green investments disproportionally. It was also found that the effect of shock in tightening financial conditions is negative for the green sector but not for non-green. This implies that green investment is hampered by monetary and financial shocks as it raises financing costs, limiting access to outside funding. In comparison to sectors that are established, green projects are more valuable to tightening because of their high upfront costs and long-term goals. Higher rates of interest considerably discourage green investments and innovation, which slows the green transition, according to empirical data. This highlights the crucial role of policy tools, in shielding green investment from market fluctuations and sustaining the transition to clean technology, like targeted credit support or subsidies.

In their article, (Otek Ntsama et al., 2021) point out the criticism faced by European Central Bank (ECB) and the Bank of England (BoE), for implementing traditional QE programs for disproportionately favoring high-carbon sectors due to their dominance in corporate bond markets. An article (The Climate Impact of Quantitative Easing, 2017) gives out study incentive for our research as it calls a targeted strategy that prioritizes green bonds in central bank asset purchase programs. This initiative has been driven by the misalignment with climate goals.

In their model, (Ferrari and Landi, 2023) find that a market-neutral QE raises emissions, given its positive effect on green and brown outputs. This is found under the assumptio`n that all firms issue bonds. They explain market-neutral QE as the portfolio of the central bank that replicates the capital/GDP shares of the two sectors, where QE expansionary effects raise emissions. Another finding from this study supports the idea that market-neutral QE is less effective than a green QE. Under the assumption of market-neutrality, they also find that sectors that dominate the bond market - often carbon-intensive industries like manufacturing, energy, and transportation - receive a larger share of QE investments. According to (Monasterolo and Raberto, 2017), QE that involves large-scale purchases of sovereign green bonds has a stronger effect in increasing the issuance of both green bonds and green loans compared to traditional QE. Their findings reveal that central bank's purchases of green bonds stimulate investments and decrease unemployment more than traditional QE. This is primarily due to the higher sensitivity of low-carbon sector to favorable funding conditions, unlike the carbon-intensive sector. As the cost of financing decreases for the low-carbon sector through green bond purchases, it leads to greater investment and increase in the job creation sector, accelerating the transition to a low-carbon economy.

Authors (Diluiso et al., 2021) suggest that green QE programs perform slightly better in reducing output losses and volatility due to the higher riskiness of low-carbon assets, given the higher initial spread on these assets. They conclude that the overall absorption of this risk from the banks' balance sheet is slightly higher by means of the credit policy. This highlights the importance of careful policy design to balance central banks' mandates while supporting climate action without unintended economic trade-offs. Building on these insights, our research applies statistical models to examine the quantitative relationship between traditional QE and green bond purchases, offering a more comprehensive understanding of their correlation.

We discuss other policy measures that could prove to be more effective in promoting sustainable growth in addition to looking at how QE affects green investment.

According to (Catalano and Forni, 2021), 'The conclusion from the simulations supports the view that a mix of supply-side policies (carbon pricing) and demand-side interventions (deficit financed green public investment) is necessary to achieve the Paris goals within the specified period and with a fiscally sustainable outcome.' Their work highlights how fiscal measures might enhance long-term debt dynamics in addition to hastening economic recession recovery. Our study expands on their discussion of demand-side policies by examining whether QE could produce comparable results.

Authors (Benkhodja et al., 2021) establish two-sector model to simulate the potential effects of green fiscal policies and unconventional green monetary policy on the economy during a recovery or in case of a stimulus policy. It finds that instruments such as carbon tax, implicit tax on brown loans, and subsidy for the purchase of green goods are all found to be beneficial to the green sector in contrast to green QE. It therefore suggests to combine green monetary and fiscal policy with policies that are aimed to make it easier for households to access green goods such as the development of organic shops. These findings suggest that raising consumers' awareness and ability to consume green goods reinforce the efficiency of public policies designed for low-carbon transition of the economy.

A study (Abiry et al., 2022) suggests that green QE has an additional climate-mitigating effect when it comes on top of a carbon tax policy, and thus green QE complements the green fiscal policy. This effect of carbon taxes would not be magnified when green QE is simultaneously at work. They conclude by explaining the joint effect of green QE and a carbon tax relative to a scenario where carbon taxation is used in isolation, which would imply a global temperature reduction of 0.037 degrees. Another study (Mas, 2023) has differing views and believes QE is more efficient, and 'these proposals offer essential new options because the current generation has failed to implement what some think would be the first-best solution of a global carbon tax.'

Hence, our research study helps bridge several existing gaps. The studies cited above primarily focus either on green QE or on the interaction between fiscal and monetary policies. In contrast, our study differs by exclusively examining monetary policy, specifically analyzing the impact of its conventional tool 'QE' on green bond issuance. This focused approach allows us to isolate and better understand the correlation between standard QE and its influence on sustainable financing through green bonds.

Research Method

The basis of our empirical study lies in the investigation of a substantive relationship - causal or otherwise - between the direct character of central bank/monetary authority intervention through QE (or tightening) and the issuance of green bonds, in order to ascertain the nature of impact that QI may bring about. As such, this 'direct' component of the character of intervention is not concerned so much with measuring the policy drivers of said intervention, or effectiveness thereof, as it seeks to meaningfully demonstrate the 'action' of intervention; in fact, so far, as this study seeks to investigate the joint impact (or plausibly, the side effect) on green bonds of QI towards an independent policy objective, a metric that measures intervention across assorted levels of effectiveness and goals would afford more intuitive (and likely more robust, given the limitations of this study) inferences than those gained from constructing a composite metric by controlling for effectiveness (itself a function of ex-post inputs) using measures that do not readily lend themselves to consistent interpretation in a simple comparative study. To this end, we abstract the data being investigated to its effects as below.

$$\text{Green Bond Investment} = f(\text{QI}) + g(\text{Economic Footprint}) \quad (1)$$

Such decomposition as drivers of green bond investment enables study of the ceteris paribus effect of QI relative to the overall state of an economy, as specified by functions *f* and *g*. A major limitation of employing this construction with statistics available through secondary sources is the poor predictive value it offers independent of complementary studies into the co-dependence between QI and the economic footprint; however, this is an acceptable constraint in an investigation of the overarching impact of (as opposed to a precise sensitivity to) the QI decision on green bond investment, and its implications are discussed further in this section.

Deriving from this construction, we employ an assortment of basic linear regression models to investigate the QI 'actions' treatment that takes inputs for intervention and its solely monetary outcome given an economic 'footprint' composed of macroeconomic indicators. Before proceeding with the specification of variables, it is necessary to emphasis that the monetary outcome we seek to measure will not explicitly control for pre-existing monetary conditions or shocks, as this study seeks to describe an a priori expectation of impact; it is not designed to investigate the impact of a necessarily successful intervention, so much as that of the actual administration of a QI decision. A well-composed footprint would provide implicit controls for endogenous (non-QI) drivers of monetary change, and makes an abstraction as above feasible for our study despite its limitations.

Key factors

For the purpose of this study, the value of central bank assets serves as a representative marker of action, such that the value of change (when controlled for the footprint of an economy) reflects a decision to administer QI. The specification of a sufficiently consistent measure of monetary outcomes is less straightforward, as several metrics - including composites involving real exchange rates and price indices, money supply figures, and highly involved derivatives employing the quantity theory of money - can be expected to reasonably capture key aspects of monetary outcomes. We steer clear of elaborate derivatives and composites (elaborate for the purpose of this study, as statistics involving joint operations on figures from more than two distinct data sources) due to risks inherent in the complexity of operation and combination. Upon considering the availability of credible secondary data, we find two promising metrics to choose from: gross monetary base, and percentage change in broad money. Broad money growth rate (BMNY.ZG) is a strong contender as a measure of monetary outcomes, as it is specifically sensitive to abnormal changes in money supply and is policy agnostic to the effectiveness of QI. Agnostic as it may be insofar as changes to an underlying trend are concerned, broad money growth fails to distinguish between a trend unto policy targets and a trend of shocks; although controlling for an underlying policy-driven monetary trend may address this limitation, it would also make variables sensitive to the policy outcome of QI, contrary to the goal of measure sensitivity to the a priori administration of QI.

Information-dense as it may be, the change in broad money growth rate fails to communicate a meaningful monetary outcome without controlling for overarching policy trends, which compromises the model's indifference to the expected monetary outcome of QI. In light of this, a more traditional approach to measuring monetary outcome as the upfront change in an economy's monetary base is far more practical. It is entirely possible that such reasoning overlooks corollaries to the drivers of a change in broad money growth that are not captured in the economic footprint; as such, it will be useful to investigate a BMNY.ZG treatment to guide considerations of QI factors that may otherwise be overlooked, and variables that could contribute to a more complete economic footprint.

Having established the QI treatment as a function of central bank holdings and the economy's monetary base, we now turn to the issue of controlling for a host of non-monetary (sometimes non-quantifiable) factors that have bearing on how QI transmits to green bond issuance. At the outset, GDP, population, and overall development appear to be key determinants of the footprint of an economy in this context. As is generally the case, GDP serves as an effective indicator of an economy's fundamental size, notwithstanding market structure. Population naturally emerges as a control variable for GDP, and together, the two provide a relatively stable comparative measure of an economy's dollar productivity. Although sufficient as a broad-based footprint of economic outlook, neither factor provides any real access to information regarding the maturity of an economy or its capital markets. While this study is not dependent on a maturity treatment, it is reasonable to infer that the nature of monetary transmission mechanisms is linked to the character of capital markets in an economy, and economic maturity in general; it therefore stands to reason that the footprint should capture (thus control for) financial/economic maturity. In order to control for said factors, we turn to existing literature in economic growth and development, as an entirely objective and internationally consistent metric of economic maturity is not readily available, and constructing a robust metric to that end is beyond the scope of this paper. Modern theorists posit a strong relationship between economic maturity and living standards; as Rostow describes, a 'drive to maturity' precedes widespread material security in an 'age of high mass consumption' (Rostow, 1959), which contemporary measures of development are well-suited to capture. This relationship is, however, tenuous at best; it would not be prudent to rely wholly on a continuous proxy seeking to capture an essentially binary necessary condition, which itself remains a subjective representation of transmission in markets.

The footprint is therefore reinforced with actual capital flow figures and market expectations, to which end we include portfolio, foreign direct, and gross domestic investment (GDI) flows, real interest rate records, and fiscal transfers. Foreign direct investment (FDI) and foreign portfolio investment (FPI) flows are reliable indicators of capital flows into and out of an economy, which provide unambiguous controls for capital shocks that may significantly affect the issuance of green bonds. It is, however, necessary to investigate the possibility that redundant inputs to investment data (multicollinearity, in a statistical sense) may hamper the selection of suitable controls to the QI treatment: inward FDI is entirely captured in both GDI and FDI, which can dilute the statistical significance of the remainder of factors in each indicator; although this is unlikely to directly impede or bias a study of QI treatments, overlapping inputs may interact with further terms to produce a confounding effect as the composition of an objective and modular economic footprint develops. Cumulative portfolio investment overlaps with GDI and can directly confound the effect of other treatments (including that of QI, as here) on green bond issuance, as it also shares inputs with measures of debt financing - all capital raised through marketable securities is captured in a cumulative portfolio investment metric.

Thus, we test QI treatments with unaltered FDI and portfolio investment controls to confirm whether this reasoning is consistent with empirical evidence, akin to running the broad money growth treatment, and to seek out factors that may have been overlooked. Despite the overlap, FDI retains valuable information regarding open economy capital flows; having established that inflows are captured in GDI, we instead utilize the outflow component of decomposed FDI statistics in the prototype for a footprint. The motivation for including real interest rate is self-evident, as it provides a single statistic that captures the broad-based cost of capital in an economy and growth expectations. It is prudent, however, to consider alternatives and their implications for the footprint, in which regard we also test a control for economic growth in form of national stock market indices. Fiscal transfers are similarly straightforward controls in the footprint, through statistics summarizing the character of financial participation by domestic governments. We employ net lending/borrowing figures as a primary measure of fiscal transfers, and briefly consider the possibility of an additional effect through sovereign debt.

All statistical analysis for this paper is conducted using R, employing the built-in linear regression function. The data used to evaluate the ECFFI effect primarily covers the years 2013 through 2022, excluding any incomplete entries where key data points are unavailable. A more nuanced commentary on the choice of model is included in Appendix III.

Results

With the QI treatment defined as a function of monetary base and central bank asset figures, we find a more familiar econometric construction of our study in the form of a linear regression model controlling for non-monetary factors through an early archetype of an economic footprint. Extensive definition of input data for each variable can be found in Appendix I: Input Statistics. Table *1* may be used for quick reference.

Variable	Usage (source)
ECFFI	Annual Green Bond Issuance (Climate Change Indicators Dashboard, 2023)
CBTAD	Central Bank Assets (Central Bank Total Assets Data, 2024)
BMNY.ZG	Broad Money Growth Rate (Broad Money Growth, 2024)
MBCD	Monetary Base in USD (International Financial Statistics, 2023)
USDX	Domestic Currency - USD spot rate (International Financial Statistics, 2023)
RINR	Real Interest Rate (Real Interest Rate, 2024)
INDX.ZG	Stock Market Index Growth Rate (S and P Global Equity Indices, 2024)
FDI	FDI (Foreign Direct Investment, 2024)
FDIm	FDI import/outflow (Foreign Direct Investment, 2024)
PTXL.CD	Net Portfolio Investment (Portfolio Investment, 2024)
TOTL.CD	GDI (Gross Capital Formation, 2024)
NGDP	GDP in USD (World Economic Outlook Database, 2024)
NGDP.DI	GDP deflator (World Economic Outlook Database, 2024)
WDG	Sovereign Debt in USD (World Economic Outlook Database, 2024)
CNLR	Net Lending as a Percentage of GDP (World Economic Outlook Database, 2024)
IHDI	Inequality Adjusted Human Development Index (All composite indices and components time series, 2024)
LP	Local Population (World Economic Outlook Database, 2024)

TABLE 1: Major Variables

Identifying nomenclature employs ISO alpha-3 codes (UNSD Methodology, 2024).

Extensive specification is available in Appendix I.

Model 0, the first regression we consider, is meant to inform further selection of variables, and the results are not intended to convey real economic relationships.

Model 0 - Base Treatment:

$$\mathrm{ECFFI} = \beta_0 + \beta_1 \mathrm{CBTAD} + \beta_2 \mathrm{BMNY.ZG} + \mathrm{footprint} + \epsilon \quad (2)$$

Model 0 - Footprint:

$$\begin{aligned}\mathrm{ECFFI} = \mathrm{treatment} &+ k_1\,\mathrm{USDX} + k_2\,\mathrm{RINR} + k_3\,\mathrm{INDX.ZG} + k_4\,\mathrm{FDI} + k_5\,\mathrm{PTXL.CD}\\ &+ k_6\,\mathrm{TOTL.CD} + k_7\,\mathrm{NGDP} + k_8\,\mathrm{NGDP.DI} + k_9\,\mathrm{WDG}\\ &+ k_{10}\,\mathrm{CNLR} + k_{11}\,\mathrm{IHDI} + k_{12}\,\mathrm{LP} + \epsilon \quad (3)\end{aligned}$$

A complete summary of regression statistics for Model 0 may be found in Table 2. A summary of model statistics is reported in Table 3. Regression in terms of equations 2 and 3 yields a weakly significant (p ~ 0.077, Table 2) sensitivity to broad money growth rate, implying an average USD 69.2 million rise in green bond issuance for each percentage point rise in broad money growth rate; however, using BMNY.ZG as an indicator for monetary outcome results in the ECFFI effect of central bank asset purchase (p ~ 0.476 for a 0.008 cents per dollar change, Table 2) being overshadowed by non-QI factors that influence broad money growth rate, which include monetary and quasi-monetary dynamics such as reserve ratios and payments technology.

Model 0	Est. Coef.	Std. Error	t-stat.	P(>|t|)
(Intercept)	-1.313e+09	1.987e+09	-0.661	0.5109
BMNY.ZG	6.918e+07	3.851e+07	1.797	0.0771
CBTAD	8.461e-04	1.181e-03	0.717	0.4762
USDX	-1.770e+09	1.374e+09	-1.288	0.2022
RINR	-1.060e+08	4.110e+07	-2.580	0.0121
INDX.ZG	-2.634e+06	9.736e+06	-0.271	0.7876
FDI	1.778e-02	2.296e-02	0.775	0.4414
PTXL.CD	-5.566e-04	6.207e-03	-0.090	0.9288
TOTL.CD	-9.883e-03	7.710e-03	-1.282	0.2044
NGDP	2.917e-03	2.371e-03	1.230	0.2230
NGDP.DI	-7.788e+05	3.064e+05	-2.542	0.0134
WDG	-3.173e-04	7.640e-04	-0.415	0.6793
CNLR	2.740e+08	6.270e+07	4.370	4.57e-05
IHDI	3.436e+09	2.816e+09	1.220	0.2268
LP	9.010	6.772	1.330	0.1880

TABLE 2: Model 0 Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
0	80	0.5389	0.4396	5.427	1.020e-06

TABLE 3: Model 0 Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

This outcome is consistent with the rationale for using monetary base as an indicator of monetary outcome; we also confirm that government debt is not statistically significant (p ~ 0.679, Table 2), with the standard error more than twice the numerical value of its effect. Given this evidence, we proceed with the study using *Model 1* as follows:

Model 1 - Base Treatment:

$$\mathrm{ECFFI} = \beta_0 + \beta_1\mathrm{CBTAD} + \beta_2\mathrm{MBCD} + \mathrm{footprint} + \epsilon \quad (4)$$

Model 1 - Footprint:

$$\begin{aligned}\mathrm{ECFFI} = {} & \mathrm{treatment} + k_1\,\mathrm{USDX} + k_2\,\mathrm{RINR} + k_3\,\mathrm{INDX.ZG} + k_4\,\mathrm{FDIm} \\ & + k_5\,\mathrm{PTXL.CD} + k_6\,\mathrm{TOTL.CD} + k_7\,\mathrm{NGDP} + k_8\,\mathrm{NGDP.DI} \\ & + k_9\,\mathrm{CNLR} + k_{10}\,\mathrm{IHDI} + k_{11}\,\mathrm{LP} + \epsilon \quad (5)\end{aligned}$$

The revised regression (equations 4 and 5) continues to consider the effects of INDX.ZG (market rate of return) and PTXL.CD (net portfolio investment) despite both terms demonstrating very little statistical significance (p-values 0.441 and 0.929, respectively, Table *4*) in *Model 0*, as BMNY.ZG may mask inputs that these terms otherwise capture. The combined effect of CBTAD and MBCD appears to be statistically significant, but the model suggests that the two factors work in opposite directions: ECFFI reduces by 1.8 cents per dollar rise in monetary base, while central bank assets demonstrate a positive 0.2 cent effect per dollar rise in holdings. The MBCD effect is stronger in both statistical and numeric terms, and the regression suggests that QI in its most fundamental form can be expected to shift green bond issuance by about 1.6 cents against each dollar of intervention; a visual comparison may be made through the charts that follow (Figures *1* and 2), and exact statistics can be found in Table *4*. Model summary statistics are reported in Table *5*.

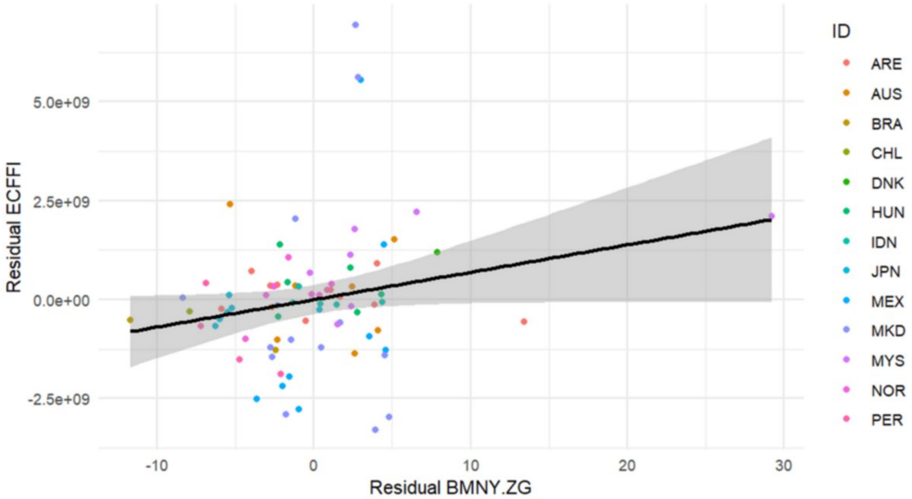

FIGURE 1: Partial Plot of the Model 0 BMNY.ZG Effect

ARE: United Arab Emirates; AUS: Australia; BRA: Brazil; CHL: Chile; DNK: Denmark; HUN: Hungary; IDN: Indonesia; JPN: Japan; MEX: Mexico; MKD: Macedonia; MYS: Malaysia; NOR: Norway; PER: Peru

Country codes are decided as per the International Standard for country codes (UNSD Methodology, 2024)

Original regression performed for this study; data source as specified in Table 1. Plot statistics reported in Table 2.

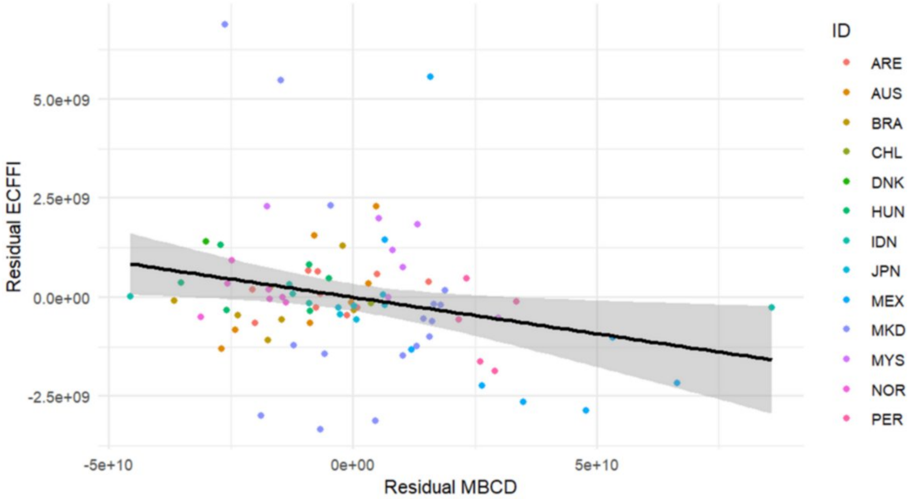

FIGURE 2: Partial Plot of the Base Model 1 MBCD Effect

ARE: United Arab Emirates; AUS: Australia; BRA: Brazil; CHL: Chile; DNK: Denmark; HUN: Hungary; IDN: Indonesia; JPN: Japan; MEX: Mexico; MKD: Macedonia; MYS: Malaysia; NOR: Norway; PER: Peru

Country codes are decided as per the International Standard for country codes (UNSD Methodology, 2024)

Original regression performed for this study; data source as specified in Table 1. Plot statistics reported in Table 4.

Model 1	Est. Coef.	Std. Error	t-stat.	P(>|t|)
(Intercept)	2.526e+08	2.022e+09	0.125	0.9009
MBCD	-1.839e-02	8.334e-03	-2.206	0.0306
CBTAD	2.082e-03	1.214e-03	1.715	0.0908
USDX	-1.903e+09	1.075e+09	-1.770	0.0811
RINR	-1.444e+08	3.843e+07	-3.758	0.0003
INDX.ZG	3.366e+06	8.809e+06	0.382	0.7035
FDIm	-2.160e-02	1.739e-02	-1.242	0.2184
PTXL.CD	3.908e-04	5.724e-03	0.068	0.9458
TOTL.CD	-6.948e-03	6.912e-03	-1.005	0.3181
NGDP	3.462e-03	1.454e-03	2.381	0.0200
NGDP.DI	-3.619e+05	1.573e+05	-2.301	0.0243
WDG	5.448e-04	7.585e-04	0.718	0.4750
CNLR	2.110e+08	5.514e+07	3.826	0.0003
IHDI	2.024e+09	2.761e+09	0.733	0.4660
LP	2.500	7.175	0.348	0.7286

TABLE 4: Model 1 Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
1	86	0.5463	0.4569	6.107	9.721e-08

TABLE 5: Model 1 Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

The model therefore suggests that quantitative easing worth USD 1,000,000 will be accompanied by a USD 16,000 drop in green bond issuance during the same 12-month period; this effect appears despite a strong (and economically consistent) negative 1,444 USD per basis point sensitivity to real interest rates, an issue discussed further in this study. We are able to confirm that net portfolio investment and market return are statistically redundant (p-values 0.946 and 0.704, respectively, Table 4) as components of the footprint, and find that FDI outflow (FDIm) figures are an effective control for open economy capital flows when combined with GDI (TOTL.CD) as a solution to the overlap with FDI.

Model 1 - Modified Footprint (a):

$$\begin{aligned}\mathrm{ECFFI} = \mathrm{treatment} + k_1\,\mathrm{USDX} + k_2\,\mathrm{RINR} + k_3\,\mathrm{FDIm} + k_4\,\mathrm{TOTL.CD} \\ + k_5\,\mathrm{NGDP} + k_6\,\mathrm{NGDP.DI} + k_7\,\mathrm{CNLR} + k_8\,\mathrm{IHDI} + \epsilon \quad (6)\end{aligned}$$

Model 1(a) (equations 4 and 6) incorporates learnings from the outcome of *Model 1* with a modified footprint that more succinctly captures the requisite macroeconomic information. As such, the observed nature of treatment effects remains unchanged, with a positive CBTAD component acting against a stronger negative MBCD effect.

We also find that local population does not capture factors significant to green bond issuance, which implies a direct relationship to GDP as the overall size of an economy. Exact statistics are reported in Table 6; model summary statistics are reported in Table 7.

Model 1(a)	Est. Coef.	Std. Error	t-stat.	P(>|t|)
(Intercept)	3.712e+08	1.514e+09	0.245	0.8070
MBCD	-1.559e-02	4.326e-03	-3.604	0.0006
CBTAD	2.358e-03	1.078e-03	2.187	0.0319
USDX	-2.128e+09	9.452e+08	-2.252	0.0273
RINR	-1.378e+08	3.542e+07	-3.889	0.0002
FDIm	-1.870e-02	1.399e-02	-1.336	0.1856
TOTL.CD	-6.335e-03	5.015e-03	-1.263	0.2105
NGDP	3.742e-03	1.306e-03	2.866	0.0054
NGDP.DI	-3.440e+05	1.493e+05	-2.304	0.0240
CNLR	2.073e+08	4.927e+07	4.207	7.09e-05
IHDI	1.794e+09	2.166e+09	0.828	0.4101

TABLE 6: Model 1(a) Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
1(a)	86	0.5406	0.4793	8.825	2.141e-09

TABLE 7: Model 1(a) Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

This iteration focuses on the effect of economic maturity through IHDI, which demonstrates a very weak relationship; although relative uncertainty may be interpreted as a weak (or non-existent) link between economic maturity and corrections to the QI treatment, it is likely that the Inequality-adjusted Human Development Index is simply a poor proxy for the continuous effect of economic maturity.

One workaround to the possibility of poor substitutability would be to consider direct interaction between the QI treatment and maturity, as between buckets of developed and developing economies, which is the basis for *Model 1(b)*.

Model 1 - Modified Treatment (b):

$$\mathrm{ECFFI} = \text{base treatment} + \beta_3\,(\mathrm{DV}_{0.7} * \mathrm{CBTA}) + \beta_4\,(\mathrm{DV}_{0.7} * \mathrm{MBCD}) + \epsilon \quad (7)$$

Model 1 - Modified Footprint (b)

$$\begin{aligned}\mathrm{ECFFI} = {} & \text{treatment} + k_1\,\mathrm{USDX} + k_2\,\mathrm{RINR} + k_3\,\mathrm{FDIm} + k_4\,\mathrm{TOTL.CD} \\ & + k_5\,\mathrm{NGDP} + k_6\,\mathrm{NGDP.DI} + k_7\,\mathrm{CNLR} + k_8\,\mathrm{DV}_{0.7} + \epsilon \quad (8)\end{aligned}$$

Equations 7 and 8 incorporate the development-treatment interaction through the binary term $\mathrm{DV}_{0.7}$ that takes 0 for economies with IHDI less than 0.7, and 1 otherwise. Independently evaluating objective criteria for identifying an IHDI threshold is far beyond the scope of this study; we arrive at the figure using the 2023-24 UNDP Human Development Report (Human Development Report, 2024), which reports the highest 'High human development' IHDI for 2022 at 0.70, and the lowest 'Ver high human development' IHDI for 2022 at 0.75.

Exact regression statistics are available in Table *8*; notably, ECFFI sensitivity to MBCD and CBTAD for the developing group is about 1.5 times that to each in the base treatment, and approximately equal to *Model 1(a)* coefficients upon adding the interaction effect for the developed group. It is therefore plausible that that markets for green debt in the IHDI < 0.7 group have a larger reaction than their *very high human development* peers. That said, these results demonstrate very weak statistical significance, and their link to economic maturity is ambiguous; mature economies may well demonstrate lower sensitivity and volatility thanks to the presence more efficient markets and generally stable/predictable policy, but this argument is not entirely substantiated by the evidence at hand. Model summary statistics are reported in Table *9*.

Model 1(b)	Est. Coef.	Std. Error	t-stat.	P(>|t|)
(Intercept)	1.828e+09	5.264e+08	3.473	0.0009
MBCD	-2.537e-02	9.877e-03	-2.569	0.0122
MBCD*$DV_{0.7}$	1.412e-02	1.065e-02	1.326	0.1889
CBTAD	4.121e-03	2.340e-03	1.761	0.0824
CBTAD*$DV_{0.7}$	-2.657e-03	2.805e-03	-0.947	0.3466
USDX	-1.771e+09	9.532e+08	-1.858	0.0672
RINR	-1.651e+08	4.169e+07	-3.960	0.0002
FDIm	-2.028e-02	1.467e-02	-1.382	0.1711
TOTL.CD	-6.889e-03	6.180e-03	-1.115	0.2686
NGDP	3.700e-03	1.796e-03	2.060	0.0430
NGDP.DI	-3.753e+05	1.568e+05	-2.393	0.0193
CNLR	2.214e+08	4.570e+07	4.846	6.88e-06
$DV_{0.7}$	-3.853e+06	6.698e+08	-0.006	0.9954

TABLE 8: Model 1(b) Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
1(b)	86	0.5491	0.475	7.408	1.056e-08

TABLE 9: Model 1(b) Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

It appears that the initial case for including a control for development no longer stands, and it would be prudent to err on the side of caution by limiting the scope of empirical study to variables that have an objectively quantitative economic basis.

Model 2 - Base Treatment:

$$\mathrm{ECFFI} = \quad \beta_0 + \beta_1\,\mathrm{CBTAD} + \beta_2\,\mathrm{MBCD} + \mathrm{footprint} + \epsilon \qquad (9)$$

Model 2 - Footprint:

$$\begin{aligned}\mathrm{ECFFI} = {} & \mathrm{treatment} + k_1\,\mathrm{USDX} + k_2\,\mathrm{RINR} + k_3\,\mathrm{FDIm} + k_4\,\mathrm{TOTL.CD} \\ & + k_5\,\mathrm{NGDP} + k_6\,\mathrm{NGDP.DI} + k_7\,\mathrm{CNLR} + \epsilon \qquad (10)\end{aligned}$$

We thus arrive at Model 2 (equations 9 and 10), the basis for deeper investigation into monetary actions that form the QI treatment. There are strong effects of both MBCD (negative 1.48 cents per dollar rise, p ~ 0.0006, Table 10) and CBTAD (positive 0.25 cents per dollar rise, p ~ 0.0246, Table 10) on ECFFI, and with the net *unit QI* (ΔMBCD = ΔCBTAD) effect at negative 1.23 cents per positive dollar of intervention. Visual observations for the QI treatment (Figures 3 and 4) emphasize that these are global aggregates; exact sensitivity varies substantially by economy, and the direction of effect appears to be consistent.

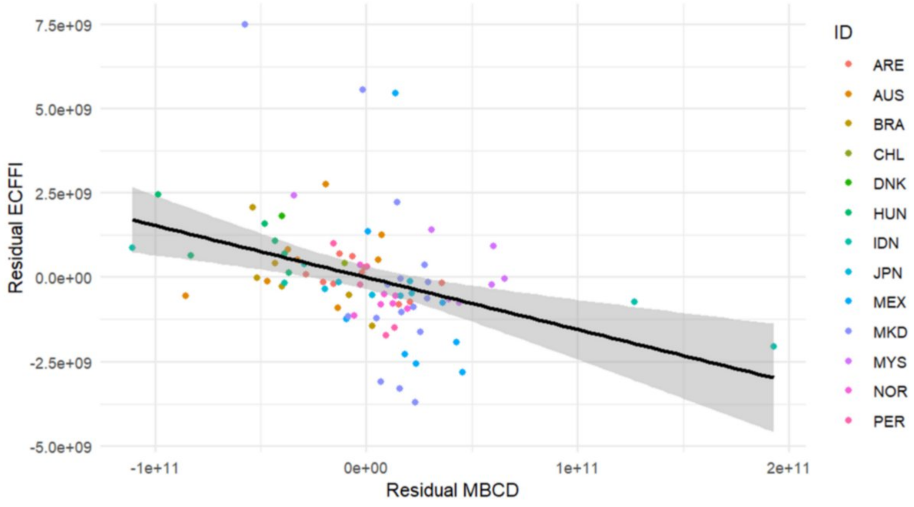

FIGURE 3: Partial Plot of the Base Model 2 MBCD Effect

ARE: United Arab Emirates; AUS: Australia; BRA: Brazil; CHL: Chile; DNK: Denmark; HUN: Hungary; IDN: Indonesia; JPN: Japan; MEX: Mexico; MKD: Macedonia; MYS: Malaysia; NOR: Norway; PER: Peru

Country codes are decided as per the International Standard for country codes (UNSD Methodology, 2024)

Original regression performed for this study; data source as specified in Table 1. Plot statistics reported in Table 10.

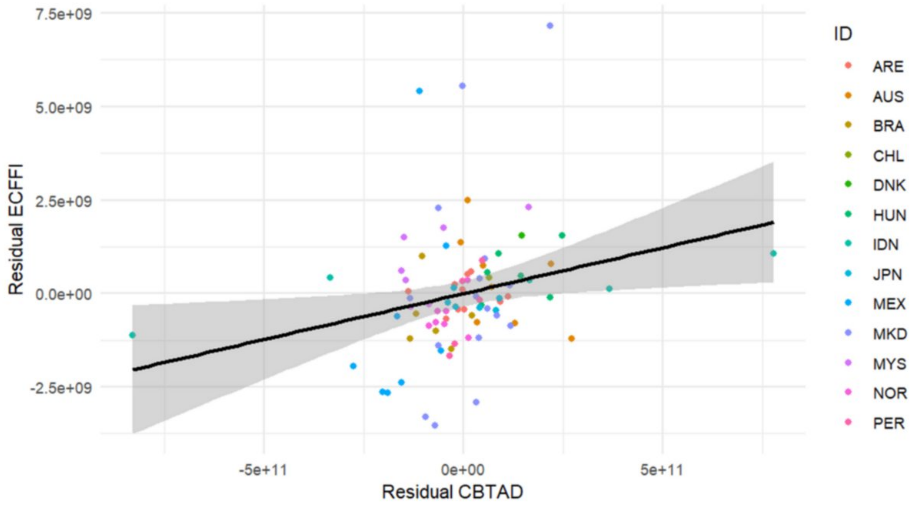

FIGURE 4: Partial Plot of the Base Model 2 CBTAD Effect

ARE: United Arab Emirates; AUS: Australia; BRA: Brazil; CHL: Chile; DNK: Denmark; HUN: Hungary; IDN: Indonesia; JPN: Japan; MEX: Mexico; MKD: Macedonia; MYS: Malaysia; NOR: Norway; PER: Peru

Country codes are decided as per the International Standard for country codes (UNSD Methodology, 2024)

Original regression performed for this study; data source as specified in Table 1. Plot statistics reported in Table 10.

FDI outflows and GDI continue to be very weak controls (p-values 0.1968 and 0.2465. respectively, Table *10*) for their effect on ECFFI; as such, we find it reasonable to continue including the two terms, as these figures explicitly capture overarching investment trends in the economy. Exact regression statistics can be found in Table *10*. Model summary statistics are reported in Table *11*.

Model 2	Est. Coef.	Std. Error	t-stat	P(>|t|)
(Intercept)	1.590e+09	3.545e+08	4.487	2.53e-05
MBCD	-1.548e-02	4.315e-03	-3.588	0.0006
CBTAD	2.453e-03	1.070e-03	2.293	0.0246
USDX	-1.661e+09	7.573e+08	-2.194	0.0313
RINR	-1.425e+08	3.490e+07	-4.082	0.0001
FDIm	-1.816e-02	1.395e-02	-1.302	0.1968
TOTL.CD	-5.796e-03	4.963e-03	-1.168	0.2465
NGDP	3.569e-03	1.286e-03	2.775	0.0070
NGDP.DI	-3.214e+05	1.465e+05	-2.194	0.0313
CNLR	2.272e+08	4.290e+07	5.297	1.11e-06

TABLE 10: Model 2 Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
2	86	0.5364	0.4815	9.770	8.952e-10

TABLE 11: Model 2 Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

We now turn to the traits of the QI treatment. Specifically, we consider the opposing MBCD and CBTAD effects. Intuitively, any change to CBTAD will result in a unit-for-unit change in MBCD, which in turn implies an identical impact; however, we evaluate monetary action and monetary outcome as distinct variables due to peculiarities of statistical records (e.g. exclusive figures for central bank assets involved in QI are not readily available) and the fact that non-QI factors can affect the monetary base. The latter is of particular interest, as it is conceivable that these factors may be captured in some combination of the terms we are already working with.

The first term of interest is RINR, which can be expected to demonstrate a strong economic relationship with the QI treatment and factors that independently affect monetary base; thus, it stands to reason that we can derive a net (ceteris paribus) effect of the QI treatment once RINR is constructed as a partial function of the QI treatment. The term already demonstrates a stronger and more significant effect than that of QI, and one that acts opposite to MBCD, which makes it all the more plausible as an explanatory factor for the unexpected result.

Subsidiary RINR - Regression:

$$\begin{aligned}\mathrm{RINR} &= \beta_0 + \beta_1\,\mathrm{CBTAD} + \beta_2\,\mathrm{MBCD} + \beta_3\,\mathrm{USDX} + \beta_4\,\mathrm{FDIm} \\ &\quad + \beta_5\,\mathrm{TOTL.CD} + \beta_6\,\mathrm{NGDP} + \beta_7\,\mathrm{NGDP.DI} + \epsilon \qquad (11)\end{aligned}$$

Exact regression statistics are presented in Table *12*, and model summary statistics are reported in Table *13*. Coefficients of interest in the regression on RINR yield the partial construction:

$$\mathrm{RINR} = 1.017 \times 10^{-11} \times \mathrm{CBTAD} - 2.906 \times 10^{-11} \times \mathrm{MBCD} (12)$$

Sub. RINR	Est. Coef.	Std. Error	t-stat	P(>|t|)
(Intercept)	2.701	5.945e-01	4.544	7.70e-06
MBCD	-2.906e-11	6.761e-12	-4.298	2.25e-05
CBTAD	1.017e-11	1.804e-12	5.640	3.59e-08
USDX	3.816e+00	1.615e+00	2.364	0.0187
FDIm	-1.571e-10	2.868e-11	-5.479	8.35e-08
TOTL.CD	-7.115e-11	1.180e-11	-6.027	4.36e-09
NGDP	2.132e-11	2.833e-12	7.528	4.69e-13
NGDP.DI	-1.926e-03	5.052e-04	-3.812	0.0002
CNLR	-2.584e-01	1.180e-01	-2.190	0.0292

TABLE 12: RINR Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model label	Observations	R^2	Adjusted R^2	F-statistic	p-value
Sub. RINR	348	0.3835	0.369	26.36	< 2.2e-16

TABLE 13: RINR Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

The ECFFI sensitivity to RINR $[-1.425 \times 10^8$ yields adjustments:

$$\beta^{\mathrm{RINR}}_{\mathrm{CBTAD}} = -0.15 \text{ cents per dollar} \qquad \beta^{\mathrm{RINR}}_{\mathrm{MBCD}} = +0.41 \text{ cents per dollar}$$

For these adjustment figures, the RINR corollary appears to demonstrate insufficient explanatory power to justify the divergence; it especially fails to explain the anomaly in sensitivity to MBCD, for which the adjustment is short by an entire order of magnitude.

Although the RINR approach brings us to a dead-end, an inconsistent strength of intervention leading to the gap in values remains a plausible explanation for the disparity in magnitude; such inconsistency is not expected to explain the opposing effects, but it may indicate that the effects of CBTAD and MBCD cancel each other out for unit QI (i.e. QI theoretically has zero effect on ECFFI) in a manner that is overpowered by the availability of figures. We therefore modify the treatment with the term QEI, introduced as below.

Model 2 - Modified Treatment (a):

$$\mathrm{ECFFI} = \text{base treatment} + \beta_3 \mathrm{QEI} + \epsilon \quad (13)$$

As such, QEI (the specific intensity of quantitative intervention, defined as the change in the locally denominated value of central bank assets per unit change in the locally denominated monetary base) is a poor indicator for the relative intensity of financial intervention, as it can take negative values given real financial inputs (e.g. when monetary base is increasing through exogenous inflows even as the central bank is allowing its assets to mature without replacement), which make intuitive interpretation difficult. Nonetheless, we test its feasibility as a standalone control in order to rule out overlooked effects, as with broad money growth rate. Regression statistics for *Model 2(a)* (equations 10 and 13) are reported in Table *14*. Model summary statistics are reported in Table *15*.

Model 2(a)	Est. Coef.	Std. Error	t-stat.	P(>|t|)
(Intercept)	1.512e+09	3.570e+08	4.237	6.38e-05
MBCD	-1.482e-02	4.317e-03	-3.433	0.0010
CBTAD	2.316e-03	1.069e-03	2.167	0.0334
QEI	-4.085e+06	2.984e+06	-1.369	0.1750
USDX	-1.584e+09	7.551e+08	-2.098	0.0393
RINR	-1.294e+08	3.598e+07	-3.597	0.0006
FDIm	-1.781e-02	1.387e-02	-1.284	0.2032
TOTL.CD	-4.703e-03	4.998e-03	-0.941	0.3497
NGDP	3.275e-03	1.297e-03	2.526	0.0137
NGDP.DI	-2.874e+05	1.477e+05	-1.945	0.0555
CNLR	2.280e+08	4.266e+07	5.345	9.37e-07

TABLE 14: Model 2(a) Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
2(a)	86	0.5477	0.4874	9.082	1.254e-09

TABLE 15: Model 2(a) Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

A generalised interpretation of QEI involves *Ordinary QI* for 0 ⩽ QEI ⩽ 1, where a central bank is engaging in QI as normal; *Extraordinary QI* for QEI > 1, where central bank QI is dampened by non-QI activities; *Exigent Monetary Intervention* for QEI < 0, where central bank QI authority is superseded. It is important to note this is a loose, ad-hoc interpretation of QEI. The regression of Model 2(a) yields a statistically weak (p ~ 0.175, Table *14*) negative USD four million effect for unit QI. Developing on QEI, we put together a more robust QI Metric (QIM) illustrated in Figure *5*, which is tested in a modified treatment for *Model 2(b)*.

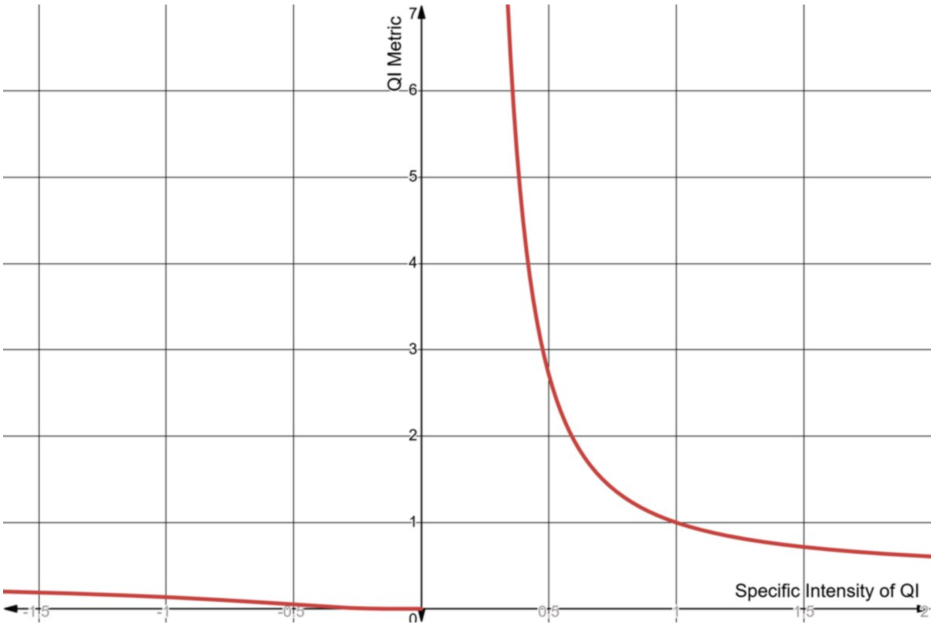

FIGURE 5: Specific Intensity of QI (QEI) - QIM Relation

Model 2 - Modified Treatment (b):

$$\text{ECFFI} = \text{base treatment} + \beta_3\text{QIM} + \epsilon \quad (14)$$

QIM is defined as $e^{\frac{1}{QEI}-1}$, preserving the distinction between QI and stronger monetary intervention, while maintaining QIM > 0. Ordinary QI occurs between infinity and 1, with unit QI at QIM = 1, allowing for greater sensitivity to normal QI in an economy. Regression as above suggests that the statistical effect of QIM (p ~ 0.174, Table 16) is as weak as that of QEI, and increasing at negative USD 500 million for unit QI; exact regression statistics can be found in Table 16. Model summary statistics are reported in Table 17.

Model 2(b)	Est. Coef.	Std. Error	t-stat	P(>|t|)
(Intercept)	1.862e+09	4.044e+08	4.606	1.65e-05
MBCD	-1.513e-02	4.297e-03	-3.521	0.0007
CBTAD	2.265e-03	1.073e-03	2.111	0.0381
QIM	-5.312e+08	3.873e+08	-1.372	0.1742
USDX	-1.627e+09	7.534e+08	-2.160	0.0340
RINR	-1.425e+08	3.470e+07	-4.108	0.0001
FDIm	-1.727e-02	1.389e-02	-1.243	0.2176
TOTL.CD	-5.674e-03	4.935e-03	-1.150	0.2539
NGDP	3.568e-03	1.279e-03	2.790	0.0067
NGDP.DI	-3.265e+05	1.457e+05	-2.241	0.0280
CNLR	2.245e+08	4.270e+07	5.257	1.33e-06

TABLE 16: Model 2(b) Regression Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

Model Label	Observations	R^2	Adjusted R^2	F-statistic	p-value
2(b)	86	0.5477	0.4874	9.083	1.250e-09

TABLE 17: Model 2(b) Summary Statistics

e+i : i^{th} exponent of 10

Original regression performed for this study; data source as specified in Table 1.

It thus appears that the MBCD-CBTAD anomaly is rooted in mechanics exogenous to the QI treatment; we conduct a brief evaluation of this anomaly in the following section, and return to the central focus of this study in the form of broad-based discussion of the implications of *Model 2* for managing economic cycles.

Discussion

The analysis in this paper has been done in two parts, keeping in view the question posed in the introduction: How can management of economic cycle fluctuations be leveraged to stimulate higher green bond investment?

As the CBTAD increases, the issuance of green bonds also rises. This means that as liquidity is injected into the economy, it promotes the purchase of sustainable financial instruments. Numerically, according to the model’s findings, there is an average increase in CBTAD by 0.25 cents per dollar rise in ECFFI. In contrast, MBCD has a negative effect, decreasing by 1.48 cents per dollar rise in ECFFI, potentially indicating a dilution of incentives for sustainability investments due to shifts in relative yields or macroeconomic conditions. Thus, the net effect of QI on green bond investment is conditionally positive, depending on the relative magnitude of the central bank balance sheet and total monetary base expansion. It appears that factors exogenous to the specified model (Model 2) play a role in the dynamics of this money supply, particularly the central bank assets anomaly. A thorough empirical examination of this anomaly would warrant an additional independent study. Although its precise evaluation is beyond the intended scope of the current analysis, we briefly discuss possible sources of the anomaly to better substantiate the policy implications of the QI effect considered here.

Notably, the treatment effect anomaly is not entirely inconsistent with studies investigating green bond holdings in the context of Green QI (i.e. intervention with emphasis on green debt). QE on a whole sees the central bank largely purchasing green bonds from existing holders, particularly banks and private individuals, rather than directly funding new green issuances. This results in a shift in secondary ownership, where the proportional private holdings of green bonds drop sharply, while those of the central bank rise quickly and remain elevated; however, private actors do not appear to replenish their green bond holdings sufficiently (Monasterolo and Raberto, 2017). This is more pronounced in case of Green QE, suggesting that Green QI generally acts more as a portfolio reallocation mechanism than as a stimulus for additional green financing, which provides a certain degree of mechanistic grounding for the flow-through that results in the anomaly.

The positive sensitivity to central bank asset holdings may be attributed to the selection of securities that are part of the QI bucket, an explanation that may be validated by means of self-reported figures from monetary authorities; for instance, CBTAD sensitivity is fully explained if ~0.25% of the average value of the global QI bucket belongs to green bonds. In general, QI may be viewed as a policy mechanism to influence economic cycles, suggesting that its effect on green bond issuance tracks said cycles, interacting with the existing impact. Monetary authorities employ QE as a means of facilitating investment and associated borrowing, during economic slowdowns and slumps; likewise, QT is meant to rein in an over-heated economy, occurring mainly near the peak of high-growth periods. Consequently, lower levels of investment when QE is implemented (and high levels at the start of QT) likely reinforce the anomaly. The underlying mechanism for the anomaly demands more deliberate consideration, and three channels through which negative sensitivity to MBCD may be achieved are presented below.

Policy intervention for recession management and prevention may target consumption, which (supported by adjacent policy measures) may divert funds from capital markets; this diversion may only occur for ‘expensive’ securities (e.g. green bonds), or across security classes. A consumption channel may be tested for by comparing general capital market trends against changes to consumption patterns during QE. Credit supply is procyclical and may also play a role in explaining the anomaly. The interest rate effect of QI (and specifically ΔMBCD) directly affects bond yields; investors may be less willing to forego an additional ‘greenium’ when yields fall and be more comfortable doing so when yields are generally high. The existence of this credit supply channel may be confirmed by decomposing the general debt market and specific green bond effects of QI. Credit demand may also be a factor, as ECFFI represents green bond issuance. The yield vector of QI affects a firm's cost of capital, and the 'greenium' may be a deciding factor in the decision to bear the regulatory costs of a green bond classification; lower yield may reduce a firm's willingness take additional steps, as alternative sources of finance will be viable. The test for the credit supply channel may apply here, but it will not be as conclusive, as a credit demand argument relies heavily on the technical classification of a security as a green bond. It is unlikely that these phenomena act in isolation; a more general and precise model of the QI effect may be expected to incorporate interactions between the proposed corollaries to the anomaly (if confirmed), in addition to their direct impact.

Furthermore, a one-shot monetary stimulus (such as temporary QE) could lower interest to assist the offset of recessionary pressures. While the initial surge in liquidity may encourage the issue of green bonds, the absence of sustained reinvestment or complementary measures may result in a transitory boost. The inherently temporal nature of such a policy presents additional difficulties since it could raise inflation expectations, eventually promoting QT and risking sudden market corrections. Notably our results show that the average rise in green bond issuance is approximately 0.97 cents for every $1 eliminated by QT. While this suggests a compensatory effect during liquidity withdrawals, frequent short-term QE interventions or early reversals might damage central bank credibility by obscuring inflation objectives and restricting policy freedom.

Having analyzed the model's findings and their implications for managing economic cycles, we now dive into exploring other strategies to promote green bond investment while simultaneously implementing effective macroeconomic stabilization policies. As seen in the findings of our model, the central bank's reliance on broad monetary expansion has a negative impact on green bond investment; hence, it should focus on directly purchasing green bonds as it ensures capital flow into sustainable projects. If QE is still preferred as a method, it should be transformed into green bond-focused QI which can be done by incorporating green bonds into asset purchase programs to maintain its attractiveness. They should also offer liquidity facilities that focus on institutions investing in sustainable finance projects. Lastly, they should implement yield protection mechanisms like giving guarantees or subsidies to mitigate the 'greenium' effect caused.

Examining the existence of alternative monetary policy tools like the repo rate and capital reserve ratio (CRR) that can achieve significant sustainable economic objectives. These levers can be fine-tuned to favor green investment momentum without unduly distorting overall macroeconomic conditions. For example, offering better repo rates for green collateral or setting differential CRRs. RINR is also a tool of monetary policy, whose effect on green bond issuance can be examined using the beta values of the model. More precisely, we examine the correlation between RINR and green bonds. The beta model findings reveal that a low RINR has a pronounced stimulative effect on the issuance of green bonds. In Model 2, RINR exhibits a strong negative coefficient (per 1 percentage point: -142.5 million dollars) with high statistical significance ($p < 0.001$), which implies that lower RINR substantially boosts green bond activity.

This study acknowledges a significant limitation: the debate over whether green finance should be a monetary priority at all. (Joyce, et al., 2012) talks about the sluggish recovery in Western economies where the recessionary forces might be extremely strong, such that QE may have been limited, conducted at an insufficient scale, or needed to be supported by other methods. Hence, it seems unnecessary to complicate monetary policy further by putting in sustainability goals. Instead, monetary policy could focus solely on managing economic cycles, while separate targeted policies can be formulated with the sole intention of addressing sustainability goals. In addition to monetary policy, fiscal policies can also be used, which play a crucial role in promoting green bond investment. Looking at the beta values of FDI outflows, we see that FDI outflows show a much weaker relationship with green bond issuance, a p-value of around 0.1968. The model shows that changes in the interest rates, for example, a lower RINR, enhance the attractiveness of long-term investments like green bonds due to lower cost of capital.

In summary, the beta model emphasizes that policies that aim to lower real interest rates in conjunction with fiscal support and green-focused QE during a recession or declining interest rates are more likely to have a greater impact on green bond investment than those that only seek to affect trends in foreign direct investment.

The government can use targeted tax incentives, introducing subsidies and managing FDI flows, which are tools of fiscal policy that promote green bond issuance.

One of the model's noteworthy findings is that CNLR (Net Lending/Borrowing as % of GDP) has a strong positive effect on ECFFI, which highlights the importance of the government's fiscal policy in the issuance of green bonds, leading to an overall increase in green bond growth. P-values < 0.0005 in multiple instances, CNLR continuously showed a statistically significant influence on green bond investment. A 1 percentage point increase as a proportion of GDP in net lending leads to an increase in green bond investment by approximately $227 million.

To promote green bond investment while simultaneously supporting economic recovery, policymakers can consider a multifaceted strategy that integrates fiscal, regulatory, and investment measures. Providing targeted tax incentives and subsidies is crucial. For example, governments can introduce direct subsidies for green/renewable projects, which result in a decrease in the cost of capital for such sustainable investments. Simultaneously, creating an atmosphere favorable for FDI through streamlined regulations and transparent policies can enhance investor confidence and increase the amount of capital available for environmentally friendly projects. Fiscal policy, particularly deficit-financed spending, could yield positive outcomes in larger economies where sensitivity to proportional fiscal changes is outweighed by the expansionary effect. In contrast, in smaller economies, a cautious and well-calibrated financing approach is required, as fiscal deficits may have a more noticeable effect on macroeconomic variables, potentially aggravating vulnerabilities like inflation.

On the regulatory front, policies promoting an increase in sustainable asset holding by financial institutions are critical. Lowering capital requirements for investment in green bonds enhances long-term attractiveness of green bonds by reducing the cost of capital, thereby leading to the reallocation of portfolios towards sustainable assets. This policy adjustment leads to a parallel credit expansion, thereby supporting recession recovery, while also maintaining the attractiveness of green bonds.

Finally, since the study shows that traditional QI may be sub-optimal for spurring green bond investment in economic downturns, we can conclude that in different cycles of the economy, different plans of action should be used by the government due to the variations in effectiveness on influencing green bond investments.

In a recessionary economy, fiscal policy or central banks engaging in direct green bond investment might help to invigorate demand better. During periods of elevated inflation, quantitative tightening could provide a more prudent route than fiscal incentives by helping stabilize price levels without unnecessary constrictions to growth. When the economy is in a relatively stable position, sustaining low interest rates and favoring FDI inflows can accelerate green bond growth.

Conclusions

This study provides empirical evidence of the relationship between QI and green bond issuance. The results show that expansion of central bank assets, which correlates with a rise in green bond issuance, is the main driver of the conditionally positive net effect of QI on green bond investments. On the other hand, a negative correlation exists between green bond investment and monetary base expansion. This suggests that while asset purchases by the central bank may indirectly promote green finance, more extensive monetary growth may take funds away from sustainable investments. Despite the implications, this study has limitations. It does not account for macroeconomic factors like an investor's choice of risk, credit cycles, regulatory laws, etc. Since the study focuses on macro-level impact, it fails to account for the micro-level changes that have an impact on investment decisions. This study also uses a model examining the linear relations and hence fails to predict future long-term impact as well as the non-linear aspect of the relationship between QI and green bonds. This model also does not consider time-dependent relationships. While the study uses CNLR in enhancing green bond issuance, it does not differentiate between fiscal instruments like tax incentives, subsidies, or green bond issuance by the government directly. In our study, FDI was only employed as a control variable, and its specific impact on green bond investment was not investigated, even though our study considers GDI in aggregate rather than decomposing it into individual components. It is conceivable that FDI levels could have a significant impact on green bond investment particularly in contexts where sustainability goals are not explicit monetary objectives. Research on green bonds and their relationship with economic cycle management has a lot of scope for future research. Even though our study focuses on global aggregates, it can be used as a comparative framework to depict the contrast of the model's effects on developed and developing markets. Studying the different monetary policy structures regionally and their impact on sustainable finance helps carry the research to a deeper level. For example, higher consumption may be supported by lower investment in green bonds or bonds in general. This can be proven by a study of QI over bond consumption statistics, and this may help identify a source for the treatment effects anomaly. Studying investor behavior in response to changes in QI is also an area that can be researched on a more micro level. Investigation in studying whether the prolonged QE leads to asset bubbles in sustainable finance markets provides resourceful and important insights to future policymakers.

Future research implications include using advanced modeling methods like time series analysis, which factors inter-temporal dynamics into the framework and captures long-term effect of QI on green bonds. Another promising area of research is evaluating green QI mechanisms, where these mechanisms include sustainability in their monetary policy framework, against the conventional QI to test its effectiveness in stimulating green bond growth in economic downturns. It will be important to consider the effect of QI on sectoral capital flows in terms of the costs, benefit, and political implications that would accompany its use as a tool to influence green investment; this includes the relative attractiveness of green bonds compared to other sustainable financial investments like loans incorporating ESG and carbon credit markets, and a broader evaluation of the opportunity costs associated with pursuing green-investmentoriented monetary policy rather than more targeted regulatory or fiscal measures, including ESG disclosure requirements, green subsidies, or tax incentives.

Appendices

Appendix I: Input statistics

Upon evaluating the availability and inter-operability of data sources, we settle on the following statistics as inputs for the initial econometric analysis. *Current* refers to the data period (e.g. for 1999 USD/GBP exchange rate, current USD/GBP spot rate is circa 1999 at the time of recording).

ECFFI in *current US$* representative of annual green bond investment by country; CBTAD in *current US$* representative of central bank assets by country in a one-year period; MBCD in *current US$* converted from local currency MBCX at the current exchange rate on record as USDX in $\frac{US\$}{XDC}$, as a measure of monetary base by country; QIM in arbitrary units for a scalar indicator of QEI $\frac{\Delta CBTAD}{\Delta MBCX}$ indexed as $e^{\frac{1}{QEI}}-1$; BMNY.ZG % as an indicator of annual broad money growth rate by country; RINR % as an indicator of real interest rate by country in a one-year period; INDX.ZG % as a weak indicator economic growth by country; FDI in *current US$* representative of net FDI flows by country; FDIm in *current US$* representative of FDI outflows by country; PTXL.CD in *current US$* representative of net portfolio investment flows by country; TOTL.CD in *US$* representative of GDI by country; NGDP in *current US$* representative of GDP by country; WDG in *current US$* derived from the product of NGDP and sovereign debt as a percentage of GDP, as a weak indicator of fiscal transfers by country; CNLR % representing net lending/borrowing as a percentage of GDP, as an indicator of fiscal transfers by country; IHDI in arbitrary units as a proxy for economic maturity; LP representing local population as a control for the size of NGDP; NGDP.DI representing the GDP deflator as a control for price level and associated market shocks.

Appendix II: Operations on data

This section summarizes operations that are potential sources of error in the empirical analysis. Structural modifications organized by operation and data source are listed first, followed by numeric modifications on data points.

Structural Operations - Pivot (years field to economy - year entries): ECFFI, MBCX, USDX, FDIm, IHDI, BMNY.ZG, RINR, INDX.ZG, PTXL.CD, TOTL.CD; Secondary Key Cross-ref. (ISO alpha-3 code): FDIm, CBTAD, CBTAX;

Numerical Operations - Magnitude Correction: ECFFI [+9], MBCX [+6], FDIm [+6], CBTAD [+9], CBTAX [+9]; Composition: FDI [FDIx - FDIm], delta_MBCX [MBCX - lag(MBCX)], delta_CBTAX [CBTAX - lag(CBTAX)];

Appendix III: Comments on the choice of model

The relative ease of QI transmission and cyclicality of investment flows make a convincing case for a time-series or otherwise auto-regressive analysis of treatments, as is conventional in evaluating the economic impact of monetary policy measures. Such models would also improve the predictive precision of analysis, simulating changes in green bond investment as a more direct outcome (rather than a general effect) of inputs. However, the nascent green bonds space has yet to achieve the standardization of reporting practices as those for more traditional markets and metrics, which limits the frequency for which internationally consistent data may be sourced; an annual (or even semi-annual) frequency of inputs is insufficient to empirically substantiate hypotheses regarding the direct impact of monetary policy on investment, and interrupted time-series exacerbate this issue.

A simpler treatment-control approach to analysis provides the flexibility required to deal with gaps in investment data, as the specification we employ compares figures by footprint rather than time identifiers, which instead anchor each QI-footprint pair. Thus, we choose to orient the study towards investigating the nature of QI effects rather than a functional relationship that will be prone to bias and overfitting, given the limitations of available empirical data. As more data enters the public domain, there is scope for introducing greater nuance in model specification and the composition of a footprint; the present linear specification suffers from heteroskedasticity that restricts its utility as a predictive model. A step up in complexity that we find worth considering is the specification of sensitivity to QI treatment as a function of footprint controls, which amounts to assigning sensitivity for every economic state that can be described by the footprint, yielding more practical insights applicable to specific environments.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Manha Sorathiya, Shaunak Kulkarni, Zaara Sadh, Gitanjali Mohanty

Acquisition, analysis, or interpretation of data: Manha Sorathiya, Shaunak Kulkarni, Zaara Sadh

Drafting of the manuscript: Manha Sorathiya, Shaunak Kulkarni, Zaara Sadh

Critical review of the manuscript for important intellectual content: Manha Sorathiya, Zaara Sadh, Gitanjali Mohanty

Supervision: Gitanjali Mohanty

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

Manha Sorathiya and Zaara Sadh contributed equally to the work and should be considered co-first authors. Dataset files and R scripts used are available on request to Manha Sorathiya (manhasorathiya3@gmail.com). Standard Disclosure: The datasets employed in this study have been collected from assorted websites, notably hosted by the World Bank, IMF, and various UN bodies; an exhaustive list is included in the references section.

References

1. Abiry R, Ferdinandusse M, Ludwig A, Nerlich C: Climate Change Mitigation - How Effective Is Green Quantitative Easing?. European Central Bank, Frankfurt, Germany; 2022. 10.2866/22488
2. All composite indices and components time series. (2024). Accessed: December 2024: https://hdr.undp.org/data-center/documentation-and-downloads.
3. Benkhodja MT, Xiaofei MA, Razafindrabe T: Build back better: The role of green monetary and fiscal policies. 2021, 10.2139/ssrn.3977541
4. Broad Money Growth. (2024). Accessed: December 2024: https://data.worldbank.org/indicator/FM.LBL.BMNY.ZG.
5. Catalano M, Forni L: Fiscal Policies for a Sustainable Recovery and a Green Transformation. Policy Research Working Paper No. 9799. 2021.
6. Central Bank Total Assets Data. (2024). Accessed: December 2024: https://data.bis.org/topics/CBTA/data.
7. Climate Change Indicators Dashboard: Green Bonds. International Monetary Fund. 2023.
8. Diluiso F, Annicchiarico B, Kalkuhl M, Minx JC: Climate actions and macro-financial stability: The role of central banks. Journal of Environmental Economics and Management. 2021, 110:102548. 10.1016/j.jeem.2021.102548
9. Ferrari A, Landi VN: Toward a green economy: the role of the central bank's asset purchases. International Journal of Central Banking. 2023, 19:287-340.
10. Foreign Direct Investment. (2024). Accessed: December 2024: https://unctadstat.unctad.org/datacentre/reportInfo/US.FdiFlowsStock.
11. Gross Capital Formation. (2024). Accessed: December 2024: https://data.worldbank.org/indicator/NE.GDI.TOTL.CD.
12. Human Development Report. (2024). https://hdr.undp.org/content/human-development-report-2023-24.
13. International Financial Statistics. (2023). Accessed: December 2024: https://prosperitydata360.worldbank.org/en/dataset/IMF+IFS.
14. Joyce M, Miles D, Scott A, Vayanos D: Quantitative easing and unconventional monetary policy—An introduction. The Economic Journal. 2012, 122:F271-F288. 10.1111/j.1468-0297.2012.02551.x
15. Mas JF: Central banks and climate justice: the case for green quantitative easing and its justification. PhD thesis, University of Reading. 2023.
16. Monasterolo I, Raberto M: Is there a role for central banks in the low-carbon transition? A stock-flow consistent modelling approach. 2017, 10.2139/ssrn.3075247
17. Monetary Policy for the Green Transition. (2024). https://www.bis.org/events/green_swan/paper_session3.pdf.
18. Otek Ntsama UY, Yan C, Nasiri A, Mboungam AHM: Green bonds issuance: insights in low- and middle-income countries. International Journal of Corporate Social Responsibility. 2021, 6:2 . 10.1186/s40991-020-00056-0
19. Portfolio Investment. (2024). Accessed: December 2024: https://data.worldbank.org/indicator/BN.KLT.PTXL.CD.

20. Quantitative Easing for Economic Recovery Must Consider Climate Change. (2020). https://www.wri.org/insights/quantitative-easing-economic-recovery-must-consider-climate-change.
21. Real Interest Rate. (2024). https://data.worldbank.org/indicator/FR.INR.RINR.
22. Rostow WW: The stages of economic growth. The Economic History Review. 1959, 12:1-16. 10.2307/2591077
23. S and P Global Equity Indices. (2024). Accessed: December 2024: https://data.worldbank.org/indicator/CM.MKT.INDX.ZG.
24. The Climate Impact of Quantitative Easing. (2017). https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2017/05/ClimateImpactQuantEasing_Matikainen-et-al.pdf.
25. UNSD Methodology. (2024). https://unstats.un.org/unsd/methodology/m49/overview/.
26. World Economic Outlook Database. (2024). Accessed: December 2024: https://www.imf.org/en/Publications/WEO/weo-database/2024/April.
27. Zhang Y, Xu T, Wu S: The promoting effect of green bonds on reducing carbon emission intensity through energy structure transition. Sustainability. 2024, 16:9318. 10.3390/su16219318
28. Zhou D, Kythreotis A: Why issue green bonds? Examining their dual impact on environmental protection and economic benefits. Humanities and Social Sciences Communications. 2024, 11:1761. 10.1057/s41599-024-04318-1