Lisbon School of Economics & Management
Universidade de Lisboa

MASTER

INTERNATIONAL ECONOMICS AND EUROPEAN STUDIES

MASTER´S FINAL WORK

DISSERTATION

DOES THE ECB'S DECARBONIZATION POLICY ON CORPORATE BOND HOLDINGS ALLOW A LOWER COST OF GREEN FINANCING?

RAHUL SURENDRA JIVAN

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SUPERVISION:
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"The green transition poses a uniquely difficult policy challenge, because the stakes of failure are so high and yet the path to success is so complex.

But the answer to this challenge is not to dilute our ambition. It is not to detract our focus from the goal of net zero. And it is not to delay the time for action"

Christine Lagarde, 2023

Glossary

APP – Asset Purchase Programmes

BLUE – Best Linear Unbiased Estimator

C&E – Climate-related and Environmental

CSPP – Corporate Sector Purchase Programme

DiD – Difference-in-Differences

DSGE – Dynamic General Stochastic Equilibrium

ECB – European Central Bank

EIB – European Investment Bank

EU – European Union

FE – Fixed Effects

GHG – Greenhouse Gas

MPSR – Monetary Policy Strategy Review

PEPP – Pandemic Emergency Purchase Programme

QE – Quantitative Easing

RE – Random Effects

SCOPE1 – Scope 1 Emissions

SCOPE2 – Scope 2 Emissions

SCOPE3 – Scope 3 Emissions

YTM – Yield-to-Maturity

ABSTRACT, KEYWORDS AND JEL CODES

This dissertation aims to examine whether the ECB announcement of 19 September 2022, which outlines the details on the central bank's plan to gradually decarbonise its corporate bond holdings, resulted in a decrease in the cost of financing for eligible green bonds. To conduct this analysis, we followed the framework provided by Eliet-Doillet & Maino (2022), and used panel data from 3 January 2022 until 2 April 2024, based on the bonds of the ECB's Corporate Sector Purchase Programme portfolio. After adjusting the model with the inclusion of macroeconomic variables such as inflation and interest rate, to account for the inherent arising volatility during the studied period, we employed a Difference-in-Differences analysis. Our findings indicate that this announcement did not have a statistically significant impact on eligible green bonds. Instead, as expected, inflation and interest rates had highly statistically significant impacts on the cost of financing for green and conventional bonds.

KEYWORDS: Climate Change; Central Banks; Unconventional Monetary Policy; Green Bonds; Cost of Financing

JEL CODES: E52, E58, G12, Q54, Q58

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DOES THE ECB'S DECARBONIZATION POLICY ON CORPORATE BOND HOLDINGS ALLOW A LOWER COST OF GREEN FINANCING?

By Rahul Jivan

1. Introduction

Climate-related and Environmental (C&E) issues represent one of the primary concerns of the general population due to their numerous negative consequences (Dalen & Henkens, 2021). Thus, mankind faces one of the most difficult challenges in the fight against climate change, with an increasingly global average temperature, as well as a rise of natural hazards and extreme natural events. Whether through physical or transition risks, climate change presents a threat to the global economy (European Central Bank, 2021), with severe implications for the stability of the global financial system, due to its impacts on economic outcomes, resources, and wider range of activities involving the three major sectors of an economy (Batten, 2018).

Although politicians are the primary actors in the fight against global warming, there is a growing consensus that central banks must increase their efforts, as it is likely that climate change will affect price stability, overall financial stability, and banking supervision, all of which are areas of competence for central banks (Schnabel, 2021). In this context, the European Union (EU) has emerged as the international leader in climate change policies through its main institutions – the European Commission, European Council, Council of the EU, and the European Parliament (Wurzel & Connelly, 2011). More recently, the European Central Bank (ECB) completed its first monetary policy strategy review in nearly two decades, further confirming the ECB's strong commitment to incorporate climate change considerations into the monetary policy framework (Schnabel, 2021).

The abovementioned review included a new form of 'green' quantitative easing (QE), which is defined as a tilting of the portfolio held by a central bank towards the green sector (Abiry *et al.*, 2022), representing a departure from the 'market-neutral' principle which has been a longstanding guideline for the ECB's asset purchase programs, and simultaneously, transitioning to a 'market-efficiency' principle, addressing externalities such as climate change, without prejudice of price stability (Schnabel, 2021). This approach would aim to lower the cost of green investments compared to their brown counterparts. In turn, investors would pick green investments that would reduce the consumption of non-renewable energies and the overall level of carbon emissions (Aloui *et al.*, 2023). Consequently, the lower cost of green financing can enable firms to opt for these investments (Bremus, Schütze, & Zaklan, 2021).

Based on the announcement published by the ECB on the 19th of September 2022, which details how the central bank aims to gradually decarbonise its corporate bond holdings, and following a similar methodology applied by Eliet-Doillet & Maino (2022), this dissertation aims to investigate whether this announcement led to a decrease in the cost of bond financing for green projects/firms vis-à-vis conventional/brown bonds, with a clear focus on the ECB's Corporate Sector Purchase Programme (CSPP) portfolio, allowing an examination on the effectiveness of the ECB's unconventional monetary policy in supporting the scaling up of green finance after this announcement.

This study contributes to the literature at least in two ways. Firstly, it will examine the announcement of the ECB which operationalized the tilting framework to be applied to the central bank's corporate bond holdings, which is a significant milestone of the ECB's climate action plan (European Central Bank, 2022). Secondly, the period of the analysis captures the most recent period of higher volatility of interest rates and inflation, with successive rate hikes by the central bank, at the fastest pace ever recorded by the ECB (Lagarde, 2024), as well as a discontinuiment of CSPP reinvestments. One must emphasize that this represents a significant change in the macro environment when compared to other similar studies whose analyses refer to a period of lower volatility.

To anticipate the findings, we find that, based on our sample and period of study, there seems to be no statistically significant evidence on our hypothesis of lower cost of financing for green bonds vis-à-vis its counterparts. Instead, we find that the original framework utilized contains omission of variables for higher periods of volatility. Therefore, we controlled for inflation and interest rate to build an enhanced framework, leading to the conclusion that these macroeconomic variables had highly positive statistically significant effects in the Yield-to-Maturities. On the other hand, even after controlling these variables, eligible green bonds did not present a statistically significant reduction in Yield-to-Maturities when compared to eligible conventional bonds.

The dissertation is organized in the following manner: Section 2 offers an overview of the relevant literature. Section 3 describes the data. Section 4 presents the utilized methodology, the analysis of empirical results, as well as its limitations. Section 5 concludes.

2. LITERATURE REVIEW

The primary mandate of central banks is generally to ensure price stability, and in the case of the ECB, it also includes the support to the general economic policies of the EU, without prejudicing its primary objective. In this regard, the ECB's Monetary Policy Strategy Review (MPSR) in 2021 was quite significant, including new secondary goals, such as climate change. This represents a significant change, as previously there was a firm consensus that climate risk should not play any role in the central bank's monetary policy operations (Weder di Mauro, et al., 2021).

So, what exactly are green bonds? Green bonds can be defined as "fixed income securities which finance investments with environmental or climate-related benefits" (Ehlers & Packer, 2017, p. 89). Though initially issued in 2007, in its early stages the green bond market was largely driven by supranational issuers such as the European Investment Bank (EIB) (Cortellini & Panetta, 2021), as corporate green bonds were relatively insignificant prior to 2013, only becoming popular in recent years (Flammer, 2021). Even so, some authors argue that as it is a relatively new concept, there is no commonly agreed definition for green bonds (Fatica, Panzica, & Rancan, 2021).

Considering this relatively underdeveloped research field, one must highlight that there has been an emerging literature that has examined the pricing differentials between green and conventional bonds or the impact that the central banks' policies can have on climate change. Within the nature of our research, our dissertation is closely related to the cost of financing of companies, namely the differential of yields between conventional and green labels, which present a panoply of results, depending on the sample and period studied.

From one perspective, Hachenberg & Schiereck (2018) use i-spreads to differentiate between conventional and green bonds, as this approach has the advantage to separate the interest and credit part of the yield. In their findings, they find limited evidence on price differentials between both, for the period of October 2015 until March 2016. Authors such as Fatica et al. (2021) found that companies with high environmental performance benefit from a lower cost of debt, and in addition to that, green bonds with external review compare positively vis-à-vis 'self-labelled' green bonds, although their main conclusion was that there is no evidence of pricing benefits for green bonds against its conventional counterparts. Kumar (2022) provided a full apraisal of the topic from a variety of perspectives drawn from the existing literature, leading to the conclusion of no significant differences on yields between conventional and green bonds.

On the other hand, from a sample starting in July 2013 and ending in December 2017, Zerbib (2019) evidences a low but significant yield differential between green and conventional bonds, through the comparison of green bonds and an equivalent syntethic non-green bonds via a matching method. Using the same methodology but for a different sample, Gianfrate & Peri (2019) show that green bonds can represent an effective way for achieving a lower cost of capital, whereas Löffler et al. (2021) clearly conclude the existence of a "greenium", achieving estimation results of statistically significant 15-20 bps lower yields in green bonds compared to conventional.

We make the connection to the other strand of literature we propose to study, namely the one that considers the role of the central banks. Several authors are pushing for central bankers to implement policies that have a direct impact on climate change, as the overall literature is positive towards these actions (European Central Bank, 2021). For instance, Hilmi *et al.* (2021) came forward with a general panel model to test the hypothesis of QE impact on environmental policy objectives, with the goal to evaluate whether modifications on the ECB's QE policy variables would affect the environmental performance for countries in the Eurozone, having concluded that there seems to be a direct synergy between monetary and environmental policies.

Bremus, Schütze, & Zaklan (2021) were pioneers in analyzing the implications of central bank Asset Purchase Programmes (APPs) on yields in the green bonds market, through a difference-in-differences approach, while exploiting exonogeous variables such as the ECB's announcements of the CSPP in 2016 and Pandemic Emergency Purchase Programme (PEPP) in 2020, having determined that the ECB's APPs are efficient policies for a transition towards a low-carbon economy, as the ECB corporate bond purchases were effective at improving financing conditions for issuers of eligible green assets. Similarly, Eliet-Doillet & Maino (2022) studied whether the Monetary Policy Strategy Review (MPSR) led to a decreased cost of financing for green bonds, while concluding that ECB-eligible green bonds reacted with a statistically significant reduction in average Yield-to-Maturities when compared to ECB-eligible conventional bonds.

While not directly related to our focus, the contributions of Dafermos et al. (2018) are crucial for the literature. In their study, they used a stock-flow-fund ecological macroeconomic model, to study the interaction between climate change and financial stability, which led to the evidence that climate change can lead to a portfolio reallocation that can cause a gradual decline in the price of corporate bonds. Within their model, they assess whether a green corporate QE programme can reduce the risks imposed on the financial system by climate change, and the results show that it can reduce climate-induced financial instability and combat global warming.

Similarly to Dafermos et al. (2018), Ferrari & Valerio (2020), provide a first primordial tentative to model green QE programme in a standard macroeconomic framework like dynamic stochastic general equilibrium (DSGE) models. Their results emphasize that green QE is able to reduce GHG emissions, although with limited effects in reducing the stock of pollution, ultimately leading to a postive but small gain derived from such programme.

3. DATA

Our sample is composed of all the unique corporate bond holdings held by the ECB from 3 January 2022 until 2 April 2024, in its CSPP portfolio. This choice is driven by the fact that the sample focus solely on instruments eligible for CSPP, i.e., (i) have a minimum rating of BBB- or equivalent; (ii) are denominated in euros; (iii) are issued by a non-bank corporation; (iv) are issued by a corporation established in the euro area defined by the country where the issuer is incorporated; and (v) have a minimum maturity of six months and a maximum remaining maturity of 30 years (Bremus, Schütze, & Zaklan, 2021). Additionally, this timeframe allows to capture periods of different monetary policy stances, both in conventional and non-conventional, considering the volatility of interest rates and the tilting applied to the CSPP portfolio, respectively.

From 3 January 2022 until 2 April 2024, a total of 682 unique securities were held in the ECB's CSPP portfolio. Data for each one of the corporate holdings held on the CSPP, namely its identifier (ISIN) was collected through the historical list in National Bank of Belgium's repository (csv file). Using the bonds' ISIN, daily Mid Yield-To-Maturity for the abovementioned period was taken from the Bloomberg fixed income database, and considering the unavailability of this metric for some bonds, it was decided to remove them from the sample, leaving a total of 562 unique bonds. Amid these bonds, green bonds were verified through Bloomberg's "Green Bond" indicator. From the 562 observations, a panel dataset was applied, with the cross-section identifier being the ID, which is composed by the unique ISINs per bond, and the time series utilized is daily dates (excluding weekends) from 3 January 2022 until 2 April 2024, leaving a total of 329,894 observations. We underline that Yield-to-Maturity is not available for all dates as some bonds were issued later on the period of study, and hence, regressions will have their number of observations equal to 304,636.

3.1. Variables and Correlation Matrix

We can separate the variables of our database in two ways, one set of variables to be utilized only for the purpose of descriptive statistics, while the other set will be utilized for the econometric approach. Starting with the former, the variables Scope 1 Emissions, Scope 2 Emissions and Scope 3 Emissions (SCOPE1, SCOPE2 and SCOPE3, respectively) were collected from Bloomberg's fixed income database, where SCOPE1 represents the direct greenhouse gas (GHG) emissions from sources that are owned or controlled by the company, SCOPE2 refers to indirect GHG emissions from purchased heat and electricity and SCOPE3 relates to emissions from the supply chain and other sources not controlled by the company (Cohen, Kadach, & Ormazabal, 2023). To differentiate economic functions or business characteristics, the variable Industry_Sector was collected from Bloomberg's Industry Classification System. For the variables utilized in the model, YTM refers to the daily mid yield-to-maturity of each bond, whereas Inflation and Euribor_3m were collected from the ECB Data Portal to assess the inflation in the Eurozone and to act as a proxy for the interest rate level for the latter, and Post_Green represents an interaction term to refer to the YTM of a green bond after 19th September 2022. The remaining variables for the purpose of descriptive statistics are duly detailed in Table A. II.

While analysing the correlation matrix (Table A. I), it is possible to identify that some variables present a high level of correlation, such as SCOPE1 with SCOPE2, and SCOPE2 with SCOPE3, which is expected considering the nature of their definition and relation. There is also a significant inverse correlation between the variables Inflation and Euribor_3m, i.e., an increase in the proxy for interest rate is correlated with a decrease in inflation and vice-versa, which is also in line with economic literature. One must highlight that there is a medium level of correlation between Euribor_3m and YTM, although also expected considering that higher levels of interest rate increase the cost of financing of a security. A few variables present a higher level of correlation considering the construction of its variables, such as Post_Green and GreenBond.

3.2. Descriptive Statistics

Table I shows the descriptive statistics of our sample, while Table II allows for a differentiation between green and conventional bonds. Table III presents the number of conventional and green bonds decomposed at the industry level. The sample is tilted towards conventional bonds, as only approximately 14% of the sample is composed of green bonds. Conventional bonds clearly present higher levels of Scope 1, 2 and 3 Emissions, whereas green bonds show on average a higher cost of financing vis-à-vis its conventional counterparts. The high level of standard deviation of the YTM in conventional bonds emphasizes the need to winsorize the outlier values of the series, and for what concerns the industry sector of the CSPP's holdings, conventional bonds are leaning towards Consumer and Non-Cyclical, while green bonds are mostly split between the Utility and Financial sectors.

TABLE I

DESCRIPTIVE STATISTICS OF THE SAMPLE

Variable	Mean	Std. dev.	Min	Max
Scope 1 Emissions	5757,38	19270,91	0,01	140910,30
Scope 2 Emissions	830,95	1689,78	0,00	7821,54
Scope 3 Emissions	52137,96	122112,70	0,70	550498,90
Emissions per Capita – Country	8,21	3,67	3,69	14,44
CDP Climate Change Score	5,38	2,79	0,00	8,00
Coupon	1,68	1,21	0,00	7,75
Amount Issued (in Million USD)	677	290	100	3000
Yield-to-Maturity	3,40	3,34	-30.60	78.99

Source: Own Elaboration in STATA.

TABLE II

DESCRIPTIVE STATISTICS DIFFERENTIATED PER CONVENTIONAL AND GREEN BONDS

Green Bonds (# distinct = 78)				
Variable	Mean	Std. dev.	Min	Max
Scope 1 Emissions	445,08	1147,22	0,93	4275,80
Scope 2 Emissions	710,56	767,24	0,01	2358,04
Scope 3 Emissions	4811,12	19043,40	2,45	161447,40
Emissions per Capita – Country	8,00	2,75	3,69	14,44
CDP Climate Change Score	3,08	3,47	0,00	8,00
Coupon	1,70	1,24	0,13	4,88
Amount Issued	621	200	300	1250
Yield-to-Maturity	3,80	1,70	-1,92	12,04

Conventional Bonds (# distinct = 484)				
Variable	Mean	Std. dev.	Min	Max
Scope 1 Emissions	6613,49	20633,08	0,01	140910,30
Scope 2 Emissions	850,35	1793,86	0,00	7821,54
Scope 3 Emissions	59765,01	129757,60	0,70	550498,90
Emissions per Capita – Country	8,24	3,79	3,69	14,44
CDP Climate Change Score	5,75	2,47	0,00	8,00
Coupon	1,68	1,21	0,00	7,75
Amount Issued	686	301	100	3000
Yield-to-Maturity	3,34	3,52	-30,60	78,99

Source: Own Elaboration in STATA.

TABLE III

NUMBER OF CONVENTIONAL AND GREEN BONDS PER INDUSTRY SECTOR

Industry Sector	# Conventional Bonds	# Green Bonds
Basic Materials	20	
Communications	32	3
Consumer, Cyclical	39	2
Consumer, Non-Cyclical	187	7
Energy	29	
Financial	60	21
Industrial	70	5
Technology	7	1
Utilities	41	39

Source: Own Elaboration in STATA.

4. METHODOLOGY

Our study largely follows the hypothesis conveyed by Eliet-Doillet & Maino (2022), namely in what considers the development of a model to test the impact of bond price reactions, which involves conducting an econometric approach through a Difference-in-Differences (DiD) analysis, as per the following regression specification:

(1) $YTM_{it} = \beta_0 + \beta_1(greenbond * post)_{it} + \Gamma_w + \mu_i + \epsilon_{it}$

Based on a panel dataset, eligible green bonds in the CSPP portfolio represent our treatment group, while our control group consists of eligible conventional bonds also present in our sample. As such, YTM represents the mid Yield-to-Maturity of bond i on day t, greenbond is a binary variable equal to 1 if it refers to an eligible green bond. Since our focus is the announcement of the ECB which operationalized the tilting framework to be applied to the central bank's corporate bond holdings on 19 September 2022, the *post* variable is binary, equal to 1 if the observation is after that date. Similarly to Eliet-Doillet & Maino (2022) and Bremus, Schütze, & Zaklan (2021), we included week-fixed effects, designated by Γ, while at the same time we have winsorized YTM at the first and ninety-ninth percentiles, considering the high standard deviation observed in conventional bonds as per Table I. Our expectation is that the differential between ECB-eligible green bonds and ECB-eligible conventional bonds will be reduced.

TABLE IV

RESULTS OF REGRESSION (1) – FIXED-EFFECTS MODEL

Dependent Variable: ytm					
Group Variable: id					
Independent Variables	Coefficient	St. Dev	P >|t|	[95% Conf. Interval]	
post_green	1.5122	0.0127	0.000	1.4873	1.5370
Observations	304,636				
Number of Groups	562				
R-squared (within)	0.1368				
Prob > F	0.0000				
Week FE	Yes				

Source: Own Elaboration in STATA.

Hypothesis: The ECB announcement decreases Yield-to-Maturities for ECB-eligible green bonds relative to ECB-eligible conventional bonds.

The results clearly go against the expected results: if we interpret the estimated equation causally, it implies that the ECB announcement increased the Yield-to-Maturities for ECB-eligible green bonds vis-à-vis the conventional counterparts, which is certainly not what we expect. Although the coefficient is highly statistically significant, the equation likely suffers from omitted variables, which is logical considering the period of our sample. The approached methodology by Eliet-Doillet & Maino (2022) was conveyed for a period where the ECB's interest rate was virtually zero and with relatively low inflation compared to our period of study. Consequently, and considering the macroeconomic context at hand, we propose to include the variables "Euribor_3m" and "Inflation", to act as a proxy for the interest rate level and inflation in the Eurozone, respectively. In addition to that, we also propose to include the variables "week" and "week2", to test for a linear time trend and quadratic time trend, respectively. As it refers to a different approach than the ones carried out in the existing literature, we will deeply examine each econometric assumption and compare the specification of the model (fixed vs random effects) to assess whether there is a systematic difference. The regression is as follows:

(2) $YTM_{it} = \beta_0 + \beta_1(greenbond * post)_{it} + \beta_2(euribor_{3m}) + \beta_3(inflation) + \beta_4(week) + \beta_5(week2) + \mu_i + \epsilon_{it}$

TABLE V

RESULTS OF REGRESSION (2) – FIXED EFFECTS MODEL

Dependent Variable: ytm

Group Variable: id					
Independent Variables	Coefficient	St. Error	P >|t|	[95% Conf. Interval]	
post_green	(0.1165)	0.0095	0.000	(0.1352)	(0.0978)
week	0.0364	0.0004	0.000	0.0359	0.0371
week2	(0.0005)	0.0000	0.000	(0.0006)	(0.0005)
euribor_3m	0.6538	0.0012	0.000	0.6514	0.6562
inflation	0.1856	0.0008	0.000	0.1841	0.18713
Observations	304,636				
Number of Groups	562				
R-squared (within)	0.5729				
Prob > F	0.0000				

Source: Own Elaboration in STATA. Negative values in parentheses.

TABLE VI

RESULTS OF REGRESSION (2) – RANDOM EFFECTS MODEL

Dependent Variable: ytm					
Group Variable: id					
Independent Variables	Coefficient	St. Error	P >|z|	[95% Conf. Interval]	
post_green	(0.1152)	0.0095	0.000	(0.1338)	(0.0966)
week	0.0364	0.0004	0.000	0.0356	0.0371
week2	(0.0005)	0.0000	0.000	(0.0006)	(0.0005)
euribor_3m	0.6537	0.0012	0.000	0.6513	0.6561
inflation	0.1856	0.0008	0.000	0.1841	0.1871
Observations	304,636				
Number of Groups	562				
R-squared (within)	0.5729				
Prob > chi²	0.0000				

Source: Own Elaboration in STATA. Negative values in parentheses.

The differences in the coefficients between both models are relatively small for all variables, which indicates that the practical differences in the estimates may be limited. Nevertheless, we computed the Hausman test, where a rejection of the test provides statistical evidence for a fixed effects specification. (Amini, Delgado, Henderson, & Parmeter, 2012). The result of the test indicates a systematic difference between both models, while strongly favoring the fixed effects model.

TABLE VII

REGRESSION (2) - HAUSMAN TEST (SIGMAMORE)

	Coefficients			
Independent Variables	Fixed-Effects	Random-Effects	Difference (RE - FE)	Std. Error
post_green	(0.1165)	(0.1152)	(0.0014)	0.0004
week	0.0364	0.0364	(0.0000)	0.0000
week2	(0.0005)	(0.0005)	0.0000	0.0000
euribor_3m	0.6538	0.6537	0.0001	0.0000
inflation	0.1856	0.1856	0.0000	0.0000
chi²	13.02			
Prob > chi²	0.0112			

Source: Own Elaboration in STATA. Negative values in parentheses.

Considering that we have established the preference for the fixed effects model, we analyzed whether the defined methodology complies with the assumptions FE.1 to

FE.7 (see Figure A.1) established by Wooldridge (2013). The validity of the assumptions are duly detailed in the appendix.

4.1. Analysis of the Results

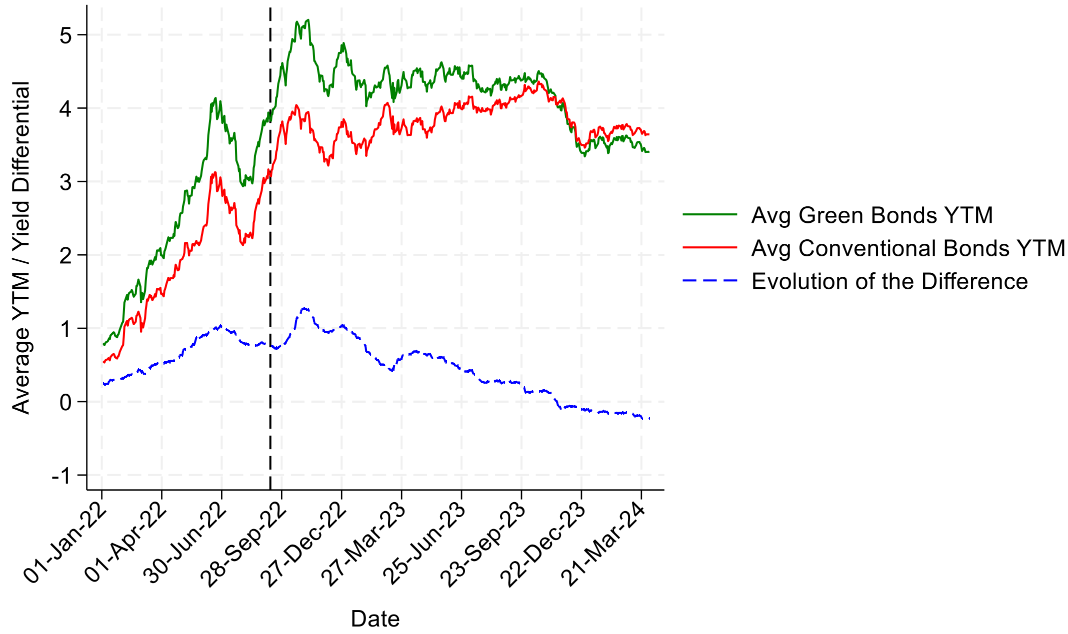

FIGURE 1 – AVERAGE YIELD-TO-MATURITY – GREEN VS CONVENTIONAL BONDS
Source: Own Elaboration in STATA.

In Figure 1, we can observe the evolution of the average Yield-to-Maturity for both green and conventional bonds, as well as the evolution of the difference. After the ECB announcement of 19 September 2022 (vertical line), and observing the behavior of the difference, there was a sudden peak in the average difference between the Yield-to-Maturity for green bonds versus its counterparts. Nevertheless, this evolution inverts from a positive to negative difference, i.e, eligible green bonds seem to present, on average, a reduction in Yield-to-Maturities when compared to eligible conventional bonds, in the remainder of the period.

Our Hypothesis was formally tested in Table VIII, and we find that, following the ECB announcement of 19 September 2022, the effect is not statistically significant at any conventional levels. In addition to that, the 95% confidence interval includes the value 0, further indicating a lack of statistical significance. These findings suggest that the announcement did not lead to a decrease in the cost of financing for green bonds vis-à-vis conventional bonds. This goes clearly against the results of authors such as Bremus et al. (2021) and Eliet-Doillet & Maino (2022), which were pioneers of the initial model we used.

TABLE VIII

FINAL MODEL – FIXED EFFECTS

Dependent Variable: ytm					
Group Variable: id					
Independent Variables	Coefficient	Robust St. Error	P >|t|	[95% Conf. Interval]	
post_green	(0.1164)	0.1098	0.289	(0.3322)	0.0992
week	0.0364	0.0016	0.000	0.0333	0.0394
week2	(0.0005)	0.0000	0.000	(0.0006)	(0.0005)
euribor_3m	0.6538	0.0144	0.000	0.6254	0.6821
inflation	0.1856	0.0071	0.000	0.1716	0.1996
Observations	304,636				
Number of Groups	562				
R-squared (within)	0.5729				
Prob > F	0.0000				

Source: Own Elaboration in STATA. Negative values in parentheses.

On the other hand, our proxy for interest rate and inflation has positive statistically significant effects, with "Euribor_3m" representing the strongest effect on YTM (approximately 65 bps), which is an expected relationship considering the environment of high interest rates. Next comes up the variable "Inflation", with an effect of circa 19 bps on YTM. The time-identifying variables "week" and "week2" are also statistically significant, demonstrating that there are temporal patterns in our sample. However, as abovementioned, since the time-identifying variables demonstrate a severe level of correlation, we will refrain from analyzing its linearity or quadratic trends on the dependent variable. These results indicate that the volatility of interest rates and inflation had much more impact in the variation of Yield-to-Maturity for both green and conventional bonds when compared to the ECB announcement of 19 September 2022.

4.2. Limitations of the Model

In an effort to avoid misinterpretations of the results, we start this sub-chapter by clearly stating that there are some intrinsic limitations on our study. While our study provides valuable insights into the differentials on Yield-to-Maturity of green bonds compared to conventional bonds, several limitations must be acknowledged. Firstly, it is important to note that the estimators used in our model are not BLUE. This deviation may result in inefficiencies in the estimation process, potentially affecting the precision of our coefficients. Although robust standard errors were employed to mitigate heteroskedasticity and autocorrelation, caution should be exercised when interpreting the results.

Secondly, the composition of our sample might present another limitation. The dataset is clearly tilted towards bonds held by the ECB in its CSPP portfolio, due to the nature of our sample. This may lead to selection bias, limiting the generalizability of our findings to the general bond market and thus, a differentiation between the (subset) of eligible bonds and non-eligible bonds is not possible. In addition to that, the total number of green bonds in our sample is equal to 78, which may limit the statistical power of our analysis and affect the robustness of our conclusions regarding Yield-to-Maturities of green bonds.

Thirdly, while we consider our ECB announcement to be a reasonably exogenous shock, it might not be considered as strong as an assumption like the Monetary Policy Strategy Review announcement, which delineated climate change as one of the secondary goals of the Central Bank, having a central role on the review, which was widely unexpected (Weder di Mauro, et al., 2021).

The period covered by our sample is also characterized by significantly high volatility in interest rates and inflation. These conditions significantly influence bond yields as observed in the previous chapter and provided in standard economic literature, which in turn led to the insignificance of our key variable of study. Even though we controlled for these factors within our model, their inherent volatility led to polarizing results, which are not in line with the ones observed in this field of study. Lastly, our variables for interest rate and inflation reflect a relatively high correlation, even though we have tested for multicollinearity.

5. CONCLUSION

In this investigation, we provided insights on how central banks can use their unconventional monetary policy to advance the fight against climate change. Centred on the ECB announcement of 19 September 2022, which detailed on the central bank's plan to gradually decarbonise its corporate bond holdings, we used the framework built by Eliet-Doillet & Maino (2022), to assess if the announcement commanded a decrease in the cost of financing for green bonds when compared to its counterparts. Unlike Eliet-Doillet & Maino (2022), our sample consists solely of bonds held by the ECB in its CSPP.

Our initial findings revealed that the announcement caused a positive yield differential between green and conventional bonds, a result that was deemed as quite unconventional. Such outcomes led us to believe that the model suffered from ommited variables. As our period of study, starting in 3 January 2022 until 2 April 2024, included the period of higher volatility of interest rates and inflation, we decided to build an enhanced model, with the inclusion of these macroeconomic variables. The conclusion was crystal clear, as the initial model suffered from omitted variables.

After certifying the assumptions of the revised model, we found that: (i) eligible green bonds did not present a statistically significant reduction in Yield-to-Maturities when compared to eligible conventional bonds; (ii) in contrast, interest rate and inflation had highly statistically significant positive effects in the Yield-to-Maturities. Additionally, we find that there are temporal patterns on our data, based on the combination of linear and quadratic time-identifying variables utilized in our regression. The obtained results show no clear link between the unconventional monetary policy of the ECB and its impact on the green bond market. This might be related to the fact that the primary objective of the ECB is price stability, and in periods of higher inflation, secondary objectives might be set aside.

We must clearly stress that our work comes with significant limitations, starting with the sample which is tilted towards eligible bonds for the CSPP portfolio, which limits the generalization of our results to the green bond market. Additionally, it is debatable if the ECB announcement of 19 September 2022 acts as a reasonable enough exogenous shock, especially when compared to the Monetary Strategy Policy Review. Although we have taken the necessary steps to cover for the analytical limitations, our final model contains non-BLUE estimators, and our period of study comes with a high level of volatility of interest and inflation rates, ultimately leading to the insignificance of our key variable of study.

While our study provides valuable insights into the yield differentials of green bonds vis-à-vis conventional bonds following the central bank's action, to fully understand the differences between both and in order to generalize its results to the bond market, further research on this topic should include a sample with a longer period, as well as the consideration of eligible and non-eligible bonds, with an additional control group composed of bonds outside of the scope of market of the ECB.

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TABLE A. I

CORRELATION MATRIX

Variable	SCOPE1	SCOPE2	SCOPE3	GreenBond	EmissionsPerCapita_Country	CDP_Climate_Score	CPN	AmountIssued	YTM	Maturity	Post_Green	Euribor_3m	Inflation
SCOPE1	1												
SCOPE2	0,76*	1											
SCOPE3	0,29*	0,55*	1										
GreenBond	-0,11*	-0,03*	-0,16*	1									
EmissionsPerCapita_Country	-0,02*	0,07*	-0,01*	-0,02*	1								
CDP_Climate_Score	0,15*	0,01*	0,13*	-0,33*	-0,15*	1							
CPN	-0,05*	-0,06*	-0,05*	0,00*	-0,05*	-0,04*	1						
AmountIssued	0,13*	0,29*	0,25*	-0,08*	0,09*	0,12*	0,04*	1					
YTM	-0,07*	-0,12*	-0,12*	0,10*	-0,03*	-0,06*	0,10*	-0,05*	1				
Maturity	-0,10*	-0,05*	-0,01*	0,16*	0,05*	-0,01*	0,15*	0,13*	0,16*	1			
Post_Green	-0,09*	-0,02*	-0,13*	0,81*	-0,02*	-0,27*	0,00	-0,06*	0,16*	0,13*	1		
Euribor_3m	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,46*	0,00	0,20*	1	
Inflation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,12*	0,00	-0,08*	-0,63*	1

* Statistically Significant at 5%

Source: Own Elaboration in STATA

TABLE A. II

VARIABLES DEFINITION

Variable Name	Description
SCOPE1	Scope 1 greenhouse gas (GHG) in thousands of metric tonnes, if available, otherwise direct carbon dioxide (CO2) emissions, otherwise estimated Scope 1 emissions based on Bloomberg's proprietary model or an industry intensity model
SCOPE2	Scope 2 greenhouse gas (GHG) in thousands of metric tonnes, if available, otherwise indirect carbon dioxide (CO2) emissions, otherwise estimated Scope 2 emissions based on Bloomberg's proprietary model or an industry intensity model
SCOPE3	Scope 3 greenhouse gas (GHG) in thousands of metric tonnes, if available, otherwise estimated Scope 3 emissions based on Bloomberg's proprietary model or an industry intensity implied model
GreenBond	Indicates if the net proceeds of the fixed income instrument will be applied toward green projects or activities that promote climate change mitigation or adaptation, or other environmental sustainability purposes
Industry_Sector	Legacy BICS (Bloomberg Industry Classification System) level I classification of the security based on its business or economic function and characteristics
EmissionsPerCapita_Country	Emissions of carbon dioxide (CO2) per capita for the relevant country. Relates to the security's country of risk, not the security itself
CDP_Climate_Score	CDP's Climate Change Score reflects the level of company commitment to climate change mitigation, adaptation, and transparency. CDP scores companies that respond on-time to the questionnaire sent on behalf of an investor request
CPN	Interest rate of the security at the identified date
AmountIssued	Cumulative amount issued from the original security pricing date through to the current date for debt securities. The amount will include taps/increases or reopening
YTM	Daily mid Yield-to-Maturity of each holding at the identified date
ID	Identifier of the ISIN of each holding
Maturity	The legal final maturity of the bond as stated in the official documentation
Post	Equal to 1 if after 19 September 2022
Week	Week identifier of the period of study. Incorporated to test for a linear time trend
Week2	Week identifier squared, in order to test for a quadratic time trend
Post_Green	Equal to 1 if after 19 September 2022 and if it is a green bond
Euribor_3m	3 Months Euribor Rate (historical data) to act as a proxy of the interest rate levels

Inflation	Inflation in the Eurozone

Source: Bloomberg. Variable ID was collected from the Bank of Belgium, Euribor_3m from the Bank of Finland and Inflation was collected from the ECB Data Portal.

Assumption FE.1
For each i, the model is

$$y_{it} = \beta_1 x_{it1} + \ldots + \beta_k x_{itk} + a_i + u_{it}, t = 1, \ldots, T,$$

where the β_j are the parameters to estimate and a_i is the unobserved effect.

Assumption FE.2
We have a random sample from the cross section.

Assumption FE.3
Each explanatory variable changes over time (for at least some i), and no perfect linear relationships exist among the explanatory variables.

Assumption FE.4
For each t, the expected value of the idiosyncratic error given the explanatory variables in *all* time periods and the unobserved effect is zero: $E(u_{it}|\mathbf{X}_i, a_i) = 0$.

Under these first four assumptions—which are identical to the assumptions for the first-differencing estimator—the fixed effects estimator is unbiased. Again, the key is the strict exogeneity assumption, FE.4. Under these same assumptions, the FE estimator is consistent with a fixed T as $N \rightarrow \infty$.

Assumption FE.5
$\mathrm{Var}(u_{it}|\mathbf{X}_i, a_i) = \mathrm{Var}(u_{it}) = \sigma_u^2$, for all $t = 1, \ldots, T$.

Assumption FE.6

For all $t \neq s$, the idiosyncratic errors are uncorrelated (conditional on all explanatory variables and a_i): $\mathrm{Cov}(u_{it}, u_{is}|\mathbf{X}_i, a_i) = 0$.

Under Assumptions FE.1 through FE.6, the fixed effects estimator of the β_j is the best linear unbiased estimator. Since the FD estimator is linear and unbiased, it is necessarily worse than the FE estimator. The assumption that makes FE better than FD is FE.6, which implies that the idiosyncratic errors are serially uncorrelated.

Assumption FE.7
Conditional on $\mathbf{X}_i$ and a_i, the u_{it} are independent and identically distributed as $\mathrm{Normal}(0, \sigma_u^2)$.

FIGURE A.1 – Fixed Effects Model Assumptions

Source: Wooldridge (2013), p. 509.

Assumptions FE.1 and FE.2 are complied with, based on the regression specification and the chosen sample. For FE.3, we check whether each explanatory variable changes over time and if no perfect linear relationships exist.

TABLE A. III

VARIANCE INFLATION FACTOR

Variable	VIF	1/VIF
week2	54.26	0.0184
week	31.06	0.0322
inflation	5.43	0.1843
euribor_3m	2.59	0.3865
post_green	1.16	0.8651
Mean VIF	18.90	

Source: Own Elaboration in STATA.

TABLE A. IV

TIME VARIATION OF VARIABLES IN REGRESSION (2)

Variable		Mean	Std. Dev	Min	Max	Observations
ytm	Overall	3.3507	1.7461	(1.779)	10.084	N = 304636
	Between		1.2621	(1.664)	9.692	n = 562
	Within		1.2057	(5.308)	10.598	T-bar = 542.057
post_green	Overall	0.0948	0.2930	0	1	N = 329894
	Between		0.2364	0	0.6831	n = 562
	Within		0.1733	(0.5883)	0.4116	T-bar = 587
week	Overall	24.298	15.456	1	52	N = 329894
	Between		0	24.298	24.298	n = 562
	Within		15.456	1	52	T-bar = 587
week2	Overall	829.279	819.562	1	2704	N = 329894
	Between		0	829.279	829.279	n = 562
	Within		819.562	1	2704	T-bar = 587
euribor_3m	Overall	2.1231	1.7460	(0.576)	4.002	N = 329894
	Between		0	2.1231	2.1231	n = 562
	Within		1.7460	(0.576)	4.002	T-bar = 587
inflation	Overall	6.4248	2.5754	2.4	10.6	N = 329894
	Between		0	6.4249	6.4249	n = 562
	Within		2.5754	2.4	10.6	T-bar = 587

Source: Own Elaboration in STATA. Negative values in parentheses.

All explanatory variables show within variation (see Table A. IV), satisfying the first requirement, while the results of the Variance Inflation Factor (VIF) analysis display that the key variable of study and euribor_3m are below the default cutoff value of 5. On the other hand, inflation presents a moderate level of correlation. The variable week and week2 present a severe correlation, which is expected considering that week2 is built based on the variable week. This does not represent a limitation in itself, as the only constraint will be interpreting the individual coefficients for the time-identifying variables, which is not the goal of our study. With these results, no problematic multicollinearity is observed for our key variable, and hence, FE.3 is satisfied. In order to assure that the estimators are unbiased, it is crucial to test the strict exogeneity assumption FE.4. However, our approach will be to only test strict exogeneity to our key variable post_green. In this sense, lead_post_green was generated to test whether future values of post_green are correlated with the current residuals.

TABLE A. V

EXOGENEITY ASSUMPTION TEST (FIXED-EFFECTS REGRESSION FOR RESIDUALS)

Dependent Variable: resid					
Group Variable: id					
Independent Variables	Coefficient	St. Dev	P >|t|	[95% Conf. Interval]	
lead_post_green	0.0045	0.0100	0.656	(0.0152)	0.02416
Observations	243,317				
Number of Groups	562				
R-squared (within)	0.0000				
Prob > F	0.6558				

Source: Own Elaboration in STATA. Negative values in parentheses.

We can analyze that the p-value of the F-test is much larger than the conventional significance levels (0.6558), with an R-squared of virtually 0, indicating that the lead_post_green, explains effectively none of the variation in the residuals. In addition to that, the coefficient is nearly 0 as well, which is a good sign, as the test signals that the expected value of the idiosyncratic error given the key explanatory variable in all time periods and the unobserved effect is zero. We have tested that our key variable of study complies with the first four assumptions, allowing to identify it as unbiased.

To guarantee that the estimator for our key variable is the Best Linear Unbiased Estimator (BLUE), we need to guarantee homoscedasticity, i.e., constant variance of the idiosyncratic errors, for all explanatory variables in the defined timeframe. With the purpose of assessing the presence (or not) of heteroscedasticity, we regressed the explanatory variables with squared residuals as the dependent variable.

TABLE A. VI

HOMOSKEDASTICITY ASSUMPTION TEST

Dependent Variable: $resid^2$

Independent Variables	Coefficient	St. Error	P >|z|	[95% Conf. Interval]	
post_green	(0.1264)	0.0145	0.000	(0.1545)	(0.0980)
week	(0.0099)	0.0011	0.000	(0.0122)	(0.0077)
week2	0.0002	0.0000	0.000	0.0002	0.0003
euribor_3m	(0.13938)	0.0035	0.000	(0.1462)	(0.1326)
inflation	(0.0960)	0.0023	0.000	(0.1004)	(0.0916)
Observations			304,636		
R-squared (within)			0.0084		
Prob > F			0.0000		

Source	SS	dF	MS
Model	13958.22	5	2791.64387
Residual	1656349.09	304,630	5.43724877
Total	1670307.31	304,635	5.478297902

Source: Own Elaboration in STATA. Negative values in parentheses.

The model is highly statistically significant, suggesting that the squared residuals are related to at least some of the explanatory variables, and furthermore, all explanatory variables have statistically significant coefficients, meaning that the variance of the errors is not constant. There is strong evidence of heteroscedasticity in our model, which clearly violates assumption FE.5.

TABLE A. VII

AUTOCORRELATION ASSUMPTION TEST

Wooldridge Test for Autocorrelation in Panel Data	
H0: no first-order autocorrelation	
F(1, 561)	150.928
Prob > F	0.0000

Source: Own Elaboration in STATA.

For FE.6, we test if there is first-order autocorrelation in our panel data, and according to Table A. VII, we can observe strong evidence of first-order autocorrelation in our model, noticeably violating assumption FE.6. For FE.7, we computed the skewness and kurtosis tests for normality, which indicate that the distribution of residuals of our sample is significantly skewed and deviated from a normal distribution. As for large sample sizes the statistic becomes overly sensitive, we also tested through a visual inspection.

TABLE A. VIII

SKEWNESS AND KURTOSIS TESTS FOR NORMALITY

	Obs	Pr(Skewness)	Pr(Kurtosis)
Residuals	304,636	0.0000	0.0000

Source: Own Elaboration in STATA.

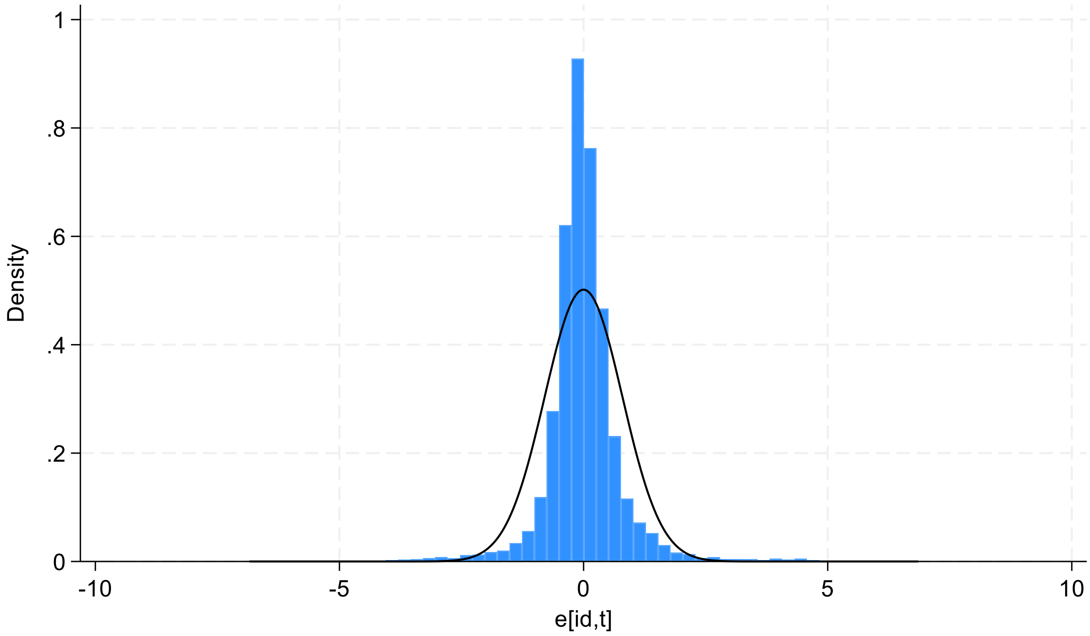

FIGURE A.2 – Histogram – Normality Assumption
Source: Own Elaboration in STATA.

Through a visual inspection of Figure A.2, we can observe that the normality assumption is violated, however the large sample size mitigates some potential issues. To summarize, while our estimators are unbiased, they are not BLUE, which can lead to higher variance than necessary, ultimately causing less power in hypothesis tests and affecting the statistical significance of the results. To overcome these issues, we will use robust standard errors to account for heteroscedasticity and autocorrelation, which shall allow the improvement of the reliability and precision of our results, even if our estimators are not BLUE.