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Unconventional green

Andrea Zaghini*

Abstract

We analyze the effects of the PEPP (Pandemic Emergency Purchase Programme), the temporary quantitative easing implemented by the ECB immediately after the burst of the Covid-19 pandemic. We show that the differences in aim, size and flexibility with respect to the traditional Corporate Sector Purchase Programme (CSPP) were able to significantly involve, in addition to the directly targeted bonds, also the green bond segment. Via a standard difference-in-differences model we estimate that the yield on green bonds declined by more than 20 basis points after the PEPP. In order to take into account also the differences attributable to the eligibility to the programme, we employ a triple difference estimator. Bonds that at the same time were green and eligible benefitted of an additional premium of 39 basis points.

JEL classification: G15,G32, E52, C21.
Keywords: Green bonds, ECB, Corporate quantitative easing, triple difference estimator.

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1 Introduction

On 18 March, 2020, in the wake of the diffusion of the Covid-19 pandemic, the ECB launched the Pandemic Emergency Purchase Programme (PEPP). The programme was a new private and public sector quantitative easing (QE) of temporary nature and was announced as different from the existing CSPP (Corporate Sector Purchase Programme). The aim of the PEPP was to face the financial markets disruptions and any involuntary tightening of the monetary policy conditions due to the Covid-19 induced crisis. Indeed, while the Covid-19 virus had been spreading since late 2019, market reactions started only after the first significant set of interventions taken in Italy on 23 February, 2020. In the following 30 days, stock markets collapsed and volatility surged. The same noticeable development also affected the bond market, in which the yield of both investment grade (IG) and high yield (HY) bonds skyrocketed in the euro area above the peaks reached during the sovereign debt crisis in 2012.

The PEPP shares many features with the CSPP, concerning in particular the eligibility of the bonds. When in September 2019 the ECB announced a new wave of asset purchases at a monthly pace of euro 20 billion, the goal was to reinforce the expansive monetary policy and alleviate the euro-area companies' financing conditions. Following the experience of the first ever corporate quantitative easing (2016-2018), the ECB expected the programme to have an impact on targeted bonds through both prices (Todorov 2020) and quantities (De Santis and Zaghini 2021), and to trigger a portfolio rebalancing through which also bonds of lower quality might benefit from a reduced issuance cost (Zaghini 2019). In addition, given a sufficient time span, other channels could kick in that would involve companies with no access to the bond market by relaxing banks' lending constraints (Grosse-Rueschkamp et al. 2019; Arce et al. 2021).

The eligibility of the bonds to the CSPP was linked to three main characteristics: at least one investment grade rating from the top rating agencies,

the denomination in euro, the incorporation of the issuing institution in a euro-area country. While non-financial corporations (NFCs), insurance corporations and other non-bank financial institutions were allowed to the programme, banks were excluded. These characteristics of the CSPP remained valid for the PEPP as well.

However, the PEPP also significantly differs from the CSPP as concerns the programme implementation across asset classes. Purchases were conducted in a flexible manner on the basis of market conditions and with a view to avoid a tightening of financing conditions inconsistent with countering the downward impact of the pandemic on the projected path of inflation. Furthermore, the size of the PEPP, at an initial rate of euro 120 billion per month, was much larger than that of the CSPP.

While the literature is abundant regarding the CSPP, it is surprisingly scant concerning the effect of PEPP. We aim at filling this gap by investigating whether the increased size and flexibility of the programme influenced corporate bonds differently across the market, even within the class of eligible bonds.

We focus on green bonds and we do so for two main reasons. The first concerns the fact that the main mechanism through which central bank's purchases are able to affect the economy is the portfolio rebalancing channel, that hinges on imperfect asset substitutability and preferred-habitat investors. This channel is able to move investors away from the targeted bonds and towards the non-targeted ones, thus influencing the asset pricing in different market segments. However, when there is strong segmentation, the direct effect of the QE experienced by the assets effectively targeted will be larger than the indirect effect experienced by non-targeted assets (Bernanke 2012, D'Amico and King, 2013, Vayanos and Vila 2021). Green bonds are among the less substitutable assets, since they represent a still limited share of the market and have a built-in feature that make them different from all other bonds: their proceeds are univocally committed to the financing of

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low-carbon, climate-friendly projects. Thus we expect a stronger effect on this segment.

The second reason is that green bonds were the most likely target of the increased flexibility of the PEPP.[1] Indeed, the President of the ECB, Christine Lagarde, has always been recognized as a champion in the fight against climate change. Already when she was Managing Director at the IMF she pushed for a larger involvement of financial markets in the funding of mitigation and adaptation costs. As President of the ECB, she started a campaign backing the need for central banks to devote greater attention to understanding the impact of climate change at large, not only for its implications for inflation dynamics (Lagarde 2020). In addition, she supported the direct involvement of central banks in addressing the challenges of climate change and including climate change considerations in monetary policy operations, in particular in the areas of collateral framework and corporate sector asset purchases (Lagarde 2021).[2]

In order to investigate whether green bonds performed better than other bonds after the PEPP, we have to take into account two layers of difference, the one between green and non-green bonds, and that between eligible and non-eligible bonds. Indeed, there are green bonds that are eligible to the PEPP and green bonds that are not. Taking into account this circumstance is of utmost importance in setting the econometric approach, since otherwise the identification strategy would not be complete and the estimated effects on

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[1]The purchases under the CSPP were committed to maintain the market neutrality, i.e. they should be proportional to the market portfolio. This approach has been criticized and shown to be tilted towards "brown" firms, that represent the vast majority of euro-area issuers (Dafermoset al. 2020; Papoutsi et al. 2021; Schoenmaker 2021).

[2]At the same time, an increased role of green issuance was expected in the European market due to the idea that a "green recovery" through sustainable energy investments could have helped governments out of the Covid-19 crisis and towards a low carbon environment (Bleischwitz 2020, IEA 2020, IMF 2020, NGFS 2020). As a matter of fact, few months later, the EU announced the NextGenerationEU, a recovery instrument endowed with 750 billion euro, that provides financial support for investments and reforms, with a minimum of 37% of the total amount granted to each member state dedicated to climate change measures.

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green bonds could not be attributed to the ECB monetary policy. Consider for instance a traditional difference-in-differences (DID) regression centred on the PEPP announcement that isolate the effect on eligible green bonds with respect to eligible non-green bonds. Also assume that the effect in the period post announcement is estimated at 30 basis points. Can we say that the PEPP effect on (eligible) green bonds is 30 basis points? Not yet, because we do not know what happened to green bonds in the segment of non-eligible bonds. Indeed, suppose that over the same time span green bonds outperformed non-green bonds also among non-eligible bonds by again 30 basis points. This would put the estimated effect of the PEPP in a completely different light, suggesting that it was most likely nil.

We proceed as follows. First, we run two separate DID regressions for the group of eligible bonds only and the group of green bonds only, respectively. We then perform a difference-in difference-in differences regression (or triple difference estimator - DDD) to check whether within the group of bonds eligible to the PEPP, those that were also green benefitted of a different market pricing. The DDD approach has the advantage that when estimating the effect on the selected group (eligible green bonds vs eligible non-green bonds), it also takes into account the change in the additional control group of non-eligible bonds. It can be shown that the DDD estimator is the difference between two DID estimators. The one estimating the difference between eligible green bonds and eligible non-green bonds after the PEPP announcement and that estimating the difference between non-eligible green bonds and non-eligible non-green bonds (Olden and Møen 2022).

To preview our results, we find that whole set of green bonds (regardless of the eligibility to the ECB programmes) faced a reduction in the spread at issuance of 28 basis points after the launch of the PEPP. This reduction is however distributed differently between eligible and non eligible bonds. Non-eligible green bonds benefitted of a yield reduction of slightly more than 20 basis points, while bonds that were at the same time green and eligible

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benefitted of an additional reduction in the range 30-40 basis points. The evidence gathered suggests that central banks' asset purchase programmes might substantially contribute to the channelling of resources towards green project by lowering their funding cost.

The rest of the paper is as follows. Section 2 places the contributions of the paper within the current literature. Section 3 describes the dataset. Section 4 introduces the empirical model and illustrates the results. Section 5 proposes some robustness checks. Section 6 concludes.

2   Related literature

The contributions of the paper span over two different strands of the current literature. The one analysing the effects of ECB corporate purchases and QEs in general, and that concerning the assessment of a possible (negative) premium on green bonds.

The launch of the CSPP, the first corporate quantitative easing by the ECB, in 2016 generated a new wave of interest towards the consequences of unconventional monetary policy measures on market prices and quantities and on non-financial corporations' business developments.

Focusing on secondary trades over a 23-week period around the CSPP announcement, Todorov (2020) finds that the ECB programme substantially increased prices and liquidity of bonds eligible to be purchased. In particular, eligible bond yields dropped on average by 30 basis points after the CSPP announcement. Rischen and Theissen (2021) report a structural change in abnormal returns after the CSPP announcement, especially for eligible bonds that benefitted of a discount of 24 basis points with respect to non eligible bonds. Relying on a novel regression discontinuity design, Li et al. (2021) provide an even smaller estimates in the range 17-22 basis points. Moreover, Pegoraro and Montagna (2022) suggest that the market was very quick in pricing the effect of the CSPP. After accounting for systematic risk exposure

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and for firm-level risk, they show that eligible bond spreads dropped by more than 10 basis points over the first two days relative to non-eligible bonds.

Over the longer time span of six months after the CSPP announcement, Zaghini (2019) estimates that the effect on new eligible bonds reached the 50-70 basis points range. However, this effect weakened significantly up to disappearing in the following months, suggesting the working of the portfolio rebalancing channel. This effect rests on the circumstance that large QEs are similar to a demand shock that crowds out other investors in the targeted segment (Bernanke 2012, D'Amico and King, 2013, Vayanos and Vila 2021). Thus, the CSPP programme, after six months of robust purchases and increasing prices, pushed other investors out of the eligible bond segment towards non-eligible bonds, which are imperfect substitutes and usually have higher expected returns. The rebalancing by investors other than the ECB generated an endogenous increase in the demand for non-eligible bonds able to lower their interest rates by an amount statistically comparable to that faced by eligible bonds. This finding is confirmed by Makinen et al. (2022) over the whole time span in which the CSPP was operating (2016-2018).

As concerns the effect on the bond issuance, De Santis and Zaghini (2021) isolate the CSPP effects by relying on the key eligibility feature of bond euro denomination. Via a DID approach, they estimate an increase in the issuance of euro denominated bonds relative to other foreign currencies of around 14% for eligible corporations with respect to the control group of non-eligible corporations. Along this line, Galema and Lugo (2021) investigate the capital structure of the issuers whose bonds were actually purchased by the ECB under the CSPP. They find that firms effectively targeted increased their relative use of market debt and the maturity of newly issued bonds more than non-targeted issuers.[3]

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[3] A related literature investigated a different spillover effect of the CSPP: NFCs eligible to the programme substituted bank loans with bond debt, this in turn allowed banks to increase the lending to the NFCs which did not benefit from the CSPP. See Grosse-Rueschkamp et al. (2019), Arce et al. (2021) and Betz and De Santis (2022).

Relatively scant is the literature about the PEPP, both concerning the corporate (Bremus et al. 2021; Zaghini 2023) and the sovereign arms (Aymeric and Tripier 2021; Blot et al. 2021; Böninghausen et al. 2022). This is even more surprising given the many contributions about similar policy interventions by the Bank of England and the FED. The Bank of England introduced a new corporate programme (CCFF - COVID Corporate Financing Facility) on 23 March, 2020 to help businesses withstand the COVID 19-related disruption to their cash flows. In addition, it increased the already existing asset purchase programme (APP) to GBP 450 billion. Fatouh et al. (2021) show that these policy measures were timely and effective in easing trading conditions and reducing market volatility. Also the Federal Reserve (FED) responded aggressively expanding for the first time ever its quantitative easing facilities to include also corporate bonds on both the primary (Primary Market Corporate Credit Facility - PMCCF) and secondary market (Secondary Market Corporate Credit Facility - SMCCF). These measures were devised to purchase USD 300 billion of IG corporate bonds (later expanded to USD 850 billion). An increasing recent research has shown that the FED's intervention reduced risk premia, improved liquidity, and led to increased issuance for both investment-grade and high-yield issuers.[4]

A second strand of the literature to which the paper is related is the one assessing the pricing of green bonds. Green bonds are debt instruments, whose proceeds are committed to the financing of low-carbon, climate-friendly projects. In addition, they are the best candidate to satisfy the appetite of investor attending to environmental concerns (BlackRock 2020). Indeed, both theoretical models and investors' surveys suggest that also non-pecuniary motives, specifically pro-environmental preferences, may motivate the holding of green assets (Krueger et al. 2020, Bolton and Kacperczyk

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[4]D'Amico et al. (2020), Kargar et al. (2021), Haddad et al. (2021), Nozawa and Qiu (2021), and O'Hara and Zhou (2021) study the disruptions in the secondary corporate bond market and the improvement in the market functioning following the facilities announcement, Boyarchenko et al. (2022) focus on the primary market.

2021, Giglio et al. 2021, Pastor et al. 2021).

The empirical evidence gathered so far suggests that the pricing of green bonds often include a (negative) premium. For instance, Zerbib (2019) finds that for a set of 110 green bonds priced on global markets between 2013 and 2017 there is a statistically significant negative premium with respect to conventional bonds, even though very limited in magnitude (around 2 basis point). A more recent analysis by Baker et al. (2022) places the premium in a range of 5-9 basis points. Fatica et al. (2021) argue instead that non-financial corporations and especially supranational institutions benefit from a much larger premium (22 and 80 basis point, respectively). At the same time they find that green bonds issued by financial corporations do not enjoy any negative yield differential. Tang and Zhang (2020) reports that stock markets seem to respond positively to the announcement of green bond issuance, whereas Flammer (2021) documents a significant increase in firms' environmental performance after the issuance, that in turn indicates that green bonds are effective in improving companies' environmental footprint. However, both contributions do not find any price difference between green bonds and conventional bonds issued by the same firm.[5]

The only two papers that to our knowledge try to link the ECB monetary policy and the pricing of green bonds are Bremus et al. (2021) and Zaghini (2023). The latter proposes an analysis of the pricing development of bonds issued in the market in which the ECB is committed to purchase (labelled Eurosystem market). The econometric approach is based on the pricing model developed by Sironi (2003) for the primary bond market and covers the CSPP and the early phase of the PEPP. The period studied starts on January 2019 and ends in May 2020, just two months after the PEPP announcement. There are two main findings concerning eligible and green

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[5]Following the empirical implications of the model proposed by Pastor et al. (2021), a different branch of the literature looks at the ESG score of the issuers instead of the green label of the bonds. See for instance Halling et al. (2020), Ferriani (2022), Seltzer et al. (2022).

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bonds that are of interest for our paper. The ECB asset purchases were not (selectively) effective under the PEPP. While it may have avoided a larger deterioration, the worsening in the market conditions that took place after the PEPP announcement was felt by eligible bonds in the same way as all other IG bonds. Over the period from mid-March to end of May 2020 the issuance cost increased by 55 basis points for both the eligible and non-eligible segment. The second finding concerns the set of green bonds: the author reports no evidence of a premium with respect to non-green bonds either up to the PEPP announcement or immediately after. However, he does not take into account the distinction between green eligible and green non-eligible bonds.

The paper by Bremus et al. (2021) looks at the development in the yield to maturity on secondary market trades of green bonds around the PEPP announcement (from January to October 2020). They propose three different DID regressions maintaining the eligible green bonds as the treated group and employing different control samples, that however are always made of green bonds only. In other words, the econometric approach focuses on green bond trades only, entirely neglecting the market development of non-green bonds. The estimated effect of the PEPP strongly depends on the control sample used. It ranges from nil, when the control sample is made of green bonds issued by financial corporations, to 135 basis points, when the control sample is made of green bonds issued by non-financial corporations.[6]

With respect to Zaghini (2023), we have a different research question, a different econometric approach and a longer time span. In particular, we center the focus of our investigation on the PEPP, and we allow for windows around the announcement of different length (6, 9 and 12 months), that are always longer than the two-month period considered by the author. This is important since the primary bond market is not a time-continuous trading

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[6]In a third sample made by green bonds denominated in Swedish crowns the estimated effect is 15 basis points.

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system. This is due to the fact that new issues occur at discrete points in time and are often agreed upon several days/weeks in advance. Thus, the transmission of monetary policy measures takes longer to show in bond prices than on secondary market trades. From Zaghini (2023), we instead take the methodology about how to construct the market in which the ECB is active.

With Bremus et al. (2021) we have a partially overlapping research question. However, the differences in the econometric approach and the market of bond trades are substantial. First we rely on a more homogeneous sample in order to have a better fit between control and treated samples. We then apply a more refined econometric technique which is better suited for the task of correctly identifying the effect of the PEPP on a particular sub-set of the eligible bonds (i.e. those that are eligible and green at the same time). Finally, we rely on the bond pricing on the primary market, since focusing only on bonds regularly traded on the secondary market significantly reduces the sample size and might introduce a selection bias.

3   The Eurosystem corporate market

On April 2016, the ECB set the conditions for eligibility to participate in the CSPP, its first corporate quantitative easing ever. Since then the ECB has only marginally updated them. Even when on March 2020, the ECB introduced more flexibility about procedure and the volume of the purchases within the PEPP, the original eligibility criteria were maintained.[7]

The eligibility criteria are listed below and concern both the bond and the issuer:

- the bond must be eligible as collateral for Eurosystem credit operations;

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[7]The most relevant change to the eligibility framework concerned the expansion of the purchases to non-financial commercial paper, that was announced together with the PEPP on 18 March, 2020. For further details see the ECB press releases:

  www.ecb.europa.eu/press/pr/date/2016/html/pr160421_1.en.html

  www.ecb.europa.eu/press/pr/date/2020/html/ecb.pr200318_1~3949d6f266.en.html

- the bond must be denominated in euro;

- the bond must have a minimum first-best credit assessment of at least BBB- or equivalent (obtained from an external credit assessment institution);

- the bond must have a minimum (remaining) maturity of six months and a maximum (remaining) maturity of less than 31 years;[8]

- the issuer must be a corporation established in the euro area, defined as the location of incorporation of the issuer;

- the issuer must not be a credit institution nor have any parent undertaking which is a credit institution.

From the eligibility criteria, it turns out that while the ECB targets IG bonds only, not all IG bonds are eligible. Provided that the other criteria are fulfilled, when an IG company that is incorporated in the euro area issues euro-denominated bonds they are eligible. When the same firm issues bonds in currencies other than the euro, they are not eligible. For instance, the German company BMW AG issued bonds in eight different currencies in 2019-2021 but only those denominated in euros were eligible for the ECB purchase. Another interesting case is that of IG extra-euro area companies which issued bonds via a financial vehicle incorporated in the euro area. The Japanese Toyota Corp, for example, cannot issue eligible bonds because of the nationality, but it may do so when the bond is issued via the subsidiary Toyota Motor Finance BV, which is incorporated in the Netherlands.

In order to have access to the universe of bonds placed on the primary market, we rely on one of the most used data provider: DCM Analytics by

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[8]After 18 March, 2020 the ECB can purchase marketable debt instruments that have an initial maturity of 365/366 days or less with a minimum remaining maturity of at least 28 days. The six-month minimum remaining maturity requirement continues to apply for marketable debt instruments with an initial maturity of at least 367 days.

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Dealogic. Taking into account two windows of 12 months around the PEPP announcement (March 2019 to March 2021) and the price availability at issuance, we end up with 23,367 bonds. They are placed all over the world from issuers not belonging to the three industry groups of "Government", "Development Banks and Multilateral Agencies" and "Export Credit Agencies". However, the ECB purchases the eligible bonds in a much smaller sub-set (the Eurisystem market) that includes only the 19 domestic euro-area markets and the generic European market, thus we end up with 7,470 bonds.[9]

Table 1 - The Eurosystem market (March 2019 - March 2021)

Country	Parents	Issuers	Bonds	Value	Value %	Eligible	Green
Australia	19	25	79	24	0.7	0	1
Brazil	19	21	74	37	1.2	0	8
Canada	13	14	79	50	1.6	0	4
China	351	434	1,049	324	10.2	0	45
Euro Area	565	710	3,571	1,581	49.8	748	453
Hong Kong	43	53	140	41	1.3	4	9
Japan	26	34	115	50	1.6	16	6
Norway	15	19	110	47	1.5	11	23
Philippines	17	21	33	11	0.4	0	4
Sweden	41	52	352	88	2.8	34	93
Switzerland	30	37	109	56	1.8	36	19
United Arab Emirates	24	27	114	46	1.4	0	3
United Kingdom	160	190	550	260	8.2	52	17
United States	123	148	529	316	10.0	50	23
Rest of the World	230	263	566	241	7.6	41	38
Total	**1,676**	**2,048**	**7,470**	**3,172**	**100**	**992**	**746**

This Table presents some summary statistics of the Eurosystem bond market by country. Parents, Issuers, Bonds, Eligible (bonds), Green (bonds) are reported in units; Value is the amount placed in the market in billions euro. Value % is the percentage of the amount placed by each country. Sources: DCM Analytics, ECB.

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[9]We follow the procedure proposed in Zaghini (2023), that looks at the first two letters of the asset identification code (ISIN) of each bond, that univocally identifies the market in which the bond is placed.

Notwithstanding the geographical construction, the Eurosystem market is an open and international market. Since there are no nationality restrictions for the bond issuance in any of the local markets, that means that they also include foreign extra-euro area issuances from both other European countries and the rest of the world. Looking at the parent level, there are 1,676 corporations (which issued through 2,048 issuers) placing at least one bond over the period March 2019 - March 2021, for a total of 3.2 trillions euro (Table 1). While around one third of them shows a euro-area nationality (565 parents, for almost half of the bonds), the parent companies belong to 75 different countries. In particular, there are 351 corporations from China, 160 from the UK and 123 from the US.

A similar picture applies to the value issued: euro-area companies issued 50% of total value, followed by those from China, the US and the UK (10.2%, 10.0% and 8.2%, respectively). Also important is the role played by Switzerland and the other European countries which together account for another 7% of the total market size. As already explained, the fact that not all eligible bonds are issued by euro-area parents is not surprising: there are 244 bonds issued through euro-area incorporated subsidiaries by parents whose nationality is not from a euro-area country (mainly the UK, the US, Switzerland and Sweden).

Also for the 746 green bonds issued in the Eurosystem market, the euro-area corporations play the largest role with a share of 61%, followed by Sweden at 12.5% and China at 6%. However, if we look at the share of green bonds issued by each country over its own total in the Eurosystem market, we get a different picture: Sweden and Norway show shares above 20%, while the euro area stands at 12.7%, behind Switzerland and barely in front of the Philippines (17.4% and 12.1%, respectively). This evidence suggests that Eurosystem is an elective market for green bonds' placement.

As for the size of the green bond segment, it amounts to 10.7 per cent of whole market and around 7.4 per cent of the total volume. The number of

bonds that at the same time are eligible and green stands at 122 items. They are mainly issued by euro-area corporations (105 vs 17). Around 70% of them (85 bonds) were actually purchased by the ECB, either on the primary or secondary market.

4   The econometric analysis

The empirical analysis of the effect of the PEPP starts from a basic model that relates the bond spread with respect to a risk-free asset to the two main sources of risk of bond features and issuer characteristics:

$$spread_i = \beta_0 + \sum_k \delta_k V_{i,k}^{bond} + \sum_l \delta_l V_{i,l}^{issuer} + \sum_m \delta_m V_{i,m}^{market} + FE_i + \varepsilon_i \quad (1)$$

where $spread_i$ is a generic yield spread of bond i with respect to a risk-free asset, V_k^{bond} are the K variables tracking the bond features and V_l^{issuer} are the L variables characterizing the issuing corporation of bond i. The additional set of M control variables V_m^{market} takes into account the financial market' stress and the macroeconomic conditions. Finally, FE_i are *ad hoc* fixed effects constructed by sets of dummy variables to take into account idiosyncratic shocks.

Note that all variables are taken at the time of issuance of bond i; therefore, for each bond i, the regressors' value is fixed at the time of the placement. Thus, the model is structured as a cross-section and the estimation procedure can be thought of as equivalent to a standard pooled OLS panel estimation. The issuance date is just another characteristic of bond i and can be taken into account by a set of time dummies. A useful feature of the cross-section approach is that it allows a much larger selection of bonds and issuing institutions than a time series analysis. Indeed, many bonds, especially from smaller issuers, are not constantly priced and traded in the

secondary market and thus can not be used in a time series approach.

As the measure of the cost of bond placement for the issuing institution, we rely on the asset swap spread (ASW) at issuance (sourced from Bloomberg), that is the difference between the bond yield and the yield of an asset swap contract of similar characteristics taken as the risk-free benchmark.[10]

As for the selection of the regressors, it is based on the traditional drivers of the risk premium. In particular, as regards the bond features $\left(V_k^{bond}\right)$, the variables taken into account are: the time to maturity at origination, the amount issued (single tranche), the currency of denomination, the coupon frequency and the type of deal (fixed, floating or zero-coupon).

The set V_l^{issuer} characterizing the issuer includes a measure of the creditworthiness of the corporation, the general industry sector and the business nationality.[11] As for the creditworthiness, we rely on the rating provided by the three most important rating agencies: Moody's, Fitch and Standard&Poors. Given the likely non linear relation between the probability of default and the rating, we use a set of dummy variables, one for each rating grade.[12]

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[10]An asset swap contract is a synthetic instrument which allows an investor to swap the payments on a bond (i.e., coupons) to a floating rate payment (risk free rate plus the ASW spread), while maintaining the original credit exposure to the fixed rate bond. In the euro area, it is supposed to perform better than the spread with respect to sovereign bonds, especially in periods of high volatility and when the flight to safety phenomenon pushes the yield of the sovereign benchmarks below the fundamentals.

[11]The 31 sectors provided by DCM Analytics are: Aerospace, Agribusiness, Alcoholic Beverages, Auto/Truck, Banks, Chemicals, Computers & Electronics, Construction/Building, Consumer Products, Defense, Dining & Lodging, Finance other, Food & Beverage, Forestry & Paper, Healthcare, Holding Companies, Insurance companies, Leisure & Recreation, Machinery, Metal & Steel, Mining, Oil & Gas, Professional Services, Publishing, Real Estate/Property, Retail, Telecommunications, Textile, Tobacco, Transportation, Utility & Energy.

[12]The rating of the issuer is first linearized between 1 (CC/Ca) and 20 (AAA/Aaa), so that when the same bond receives more than one assessment from Moody's, Fitch and Standard&Poors they can be averaged. Then the average is transformed into a set of dummy variables. I also add a dummy tracking the firms whose rating is not available at all.

In the set V_m^{market} of variables tracking the financial stress, there are three market indices at the daily frequency: (i) the VSTOXX index, which is a measure of the equity market volatility in the euro area (computed relying on both call- and put-implied volatilities from the DJ Euro STOXX 50 index); (ii) the CISS bond index (Composite Indicator of Systemic Stress), which is the systemic stress indicator for the euro-area financial markets proposed by Hollo et al. (2012); (iii) the iTraxx Europe index (the average of 125 equally-weighted single-name European CDS spreads), which should capture market-wide variation in CDS spreads due to changes in fundamental credit risk, liquidity, and CDS market-specific shock (Acharya et al. 2014). In addition, also at the daily frequency, we include: (i) the index of macro news for the US and the euro-area provided by Citi; (ii) the index of economic policy uncertainty (EPU) by Baker et al. (2016) for the US and the UK; (iii) the nominal effective exchange rate of the euro computed by the ECB with respect to the 19 main trading partners of the euro area.

Furthermore, to take into account idiosyncratic shocks hitting at the country level, we introduce the fixed effects constructed by multiplying quarterly and country dummies.

Following Imbens and Wooldridge (2007), the expansion of model (1) to a DID framework is straightforward. Focusing the set of eligible bonds as the treated group we have:

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\begin{aligned}
ASW_i &= \beta_0 + \beta_1 EB_i + \beta_2 Post_i + \beta_3 Post_i * EB_i + \\
&\quad \sum_{k \,\cup\, l} \delta_j W_{i,j} + \sum_m \delta_m V_{i,m}^{market} + FE_i + \varepsilon_i
\end{aligned}
\tag{2}
$$

where EB is a dummy taking 1 for eligible bonds and 0 otherwise, and $Post$ is a step dummy taking 1 after the PEPP announcement and 0 before. The K+L bond and issuer characteristics are summarized in the W matrix. As usual in the traditional DID analysis, the coefficient of interest is β_3, that quantifies the differential behavior of the treated group with respect to the

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control group in the treatment period (with respect to the previous period).

In order to be a valid control sample for the set of eligible bonds, we need the set of non-eligible bonds to trend in the same way as the eligible set before the PEPP (Imbens and Wooldridge 2007). Figure 1 shows the estimated difference between the ASW spread in the two samples over time. In particular, the coefficients are obtained from a regression of the ASW spread over quarterly time dummies and the quarterly dummies multiplied by the EB dummy tracking eligible bonds. The difference seems to oscillate around -50 basis points before 2020Q1, suggesting that it is legitimate to assume a common trend between eligible and non-eligible bonds up to PEPP announcement.

Figure 1 - Trend assumption (eligible vs non-eligible)
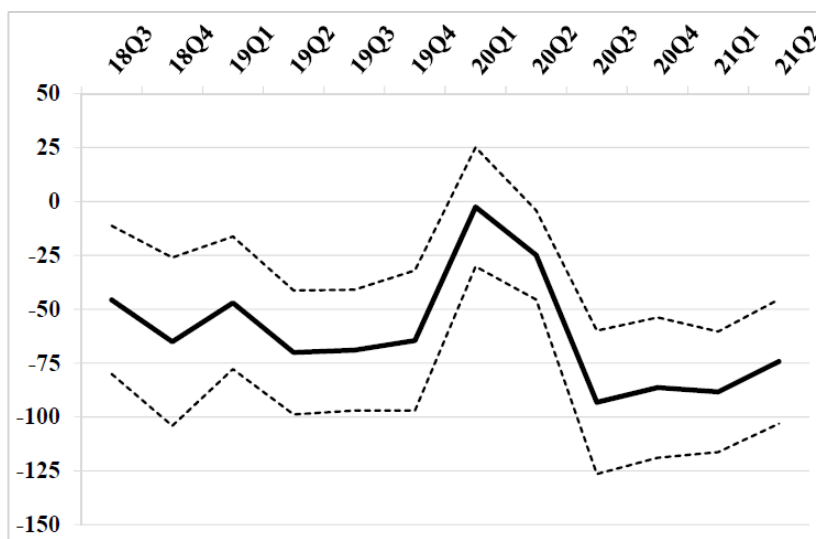
Estimated difference of the ASW spread at issuance between eligible and non-eligible bonds at the quarterly frequency (continuous line); 95% confidence interval (dotted lines); basis points. Source: Bloomberg; DCM Analytics; ECB.

Table 2 reports the coefficient estimations from model (1), when just the EB dummy is added to the controls, and from two regressions from model (2). The windows around the PEPP announcement are set at 9 months. Over the

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whole period, eligible bonds benefitted from a significant negative premium of 22 basis points (column 1). This result is in line with the literature on the ECB corporate asset purchases (Todorov 2020, Li et al. 2021, Rischen and Theissen 2021). Given that eligible bonds are all rated IG, can be always used as collateral for the ECB main refinancing operations and rely on a stronger demand, they usually face a lower placement cost than similar non-eligible bonds.

Table 2 - PEPP effect on eligible bonds

Coefficient	Basic	DID	DID+
Eligible	-21.6159 **	-26.0854 **	-25.8346 **
	(8.3968)	(10.3235)	(10.4257)
Post		67.5987 **	70.292 **
		(28.1024)	(27.4553)
Eligible*Post		7.4050	6.1138
		(13.6899)	(13.7153)
Green			-23.0305 ***
			(5.8691)
Bond controls	YES	YES	YES
Issuer controls	YES	YES	YES
Short-term Market controls	YES	YES	YES
Country*Quarter FE	YES	YES	YES
Observations	5,610	5,610	5,610
R-square	0.7401	0.7405	0.7410

Results from regressions from model (1) and (2) over the period July 2019-September 2020. Eligible is a dummy taking 1 for eligible bonds and 0 otherwise; Post is dummy taking 1 after 18 March, 2020 and 0 before; Green is dummy taking 1 for green bonds and 0 otherwise. Source: Bloomberg, Dealogic DCM Analytics; ECB.

However, when caught in the pandemic period post PEPP, eligible bonds did not perform better that the rest of the sample, maintaining the same differential as before the crisis. The estimated β_3 coefficient in column 2 is not statistically significant. As suggested by Zaghini (2023), this evidence

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can be explained by two circumstances: the change in the market composition and the portfolio rebalancing. As common during crisis periods, a flight-to-safety phenomenon moved financial agents away from the risky HY bonds and towards the safer IG segment, thus making the bond market more concentrated on bonds of similar characteristics (and prices) in the *Post* period. Regarding the second issue, after the starting of the purchases under the PEPP, a sizable share of the market became unavailable because of the large ECB demand, thus investors had to rebalance their portfolio with other assets. The choice was to buy bonds of similar creditworthiness: IG bonds which were non-eligible for the ECB asset purchases. This rebalancing in turn generated an endogenous surge in the demand for non-eligible IG bonds that was able to offset the price difference with respect to eligible bonds in the *Post* period. The result is confirmed in column 3, when the set of green bonds is introduced as an additional control variable.

Given that the segment of eligible bonds did not (selectively) benefit from the introduction of the PEPP, we now investigate whether the exceptional nature of the programme was able to involve green bonds. We thus run a set of regressions as if the green bonds were the treated assets:

$$
\begin{aligned}
ASW_i \;=\; & \beta_0 + \beta_1 GB_i + \beta_2 Post_i + \beta_3 Post_i * GB_i + \qquad\qquad (3)\\
& \sum_{k\,\cup\,l} \delta_j W_{i,j} + \sum_m \delta_m V_{i,m}^{market} + FE_i + \varepsilon_i
\end{aligned}
$$

where GB is a dummy taking 1 for green bonds and 0 otherwise. Again, the coefficient of interest is β_3 that singles out the different price behavior of green bonds over the 9-month period after the PEPP announcement. As done for the set of eligible bonds, we first run a regression checking the ASW development over time. Figure 2 confirms the statistical goodness of the non-green bonds sample as control group under model (3).

From the basic estimation of model (1) reported in Column 1 of Table 3, we have evidence of a statistically significant negative premium (greenium) of

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22 basis points over the 18 months around the PEPP. However, this evidence is better detailed when looking at the DID framework of model (3). The greenium was entirely absent before the PEPP (the coefficient β_1 is not significant in column 2 and 3) and then materialized in the 9-month period of ECB asset purchases. The β_3 estimates suggest a greenium of around 29 basis points. It seems that the new and more flexible features of the PEPP were able to selectively involve a set of bonds different from eligible bonds.

Figure 2 - Trend assumption (green vs non-green)
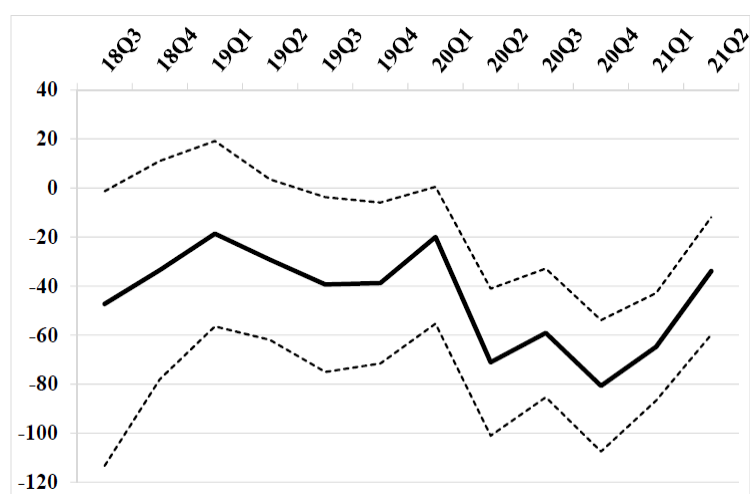
Estimated difference of the ASW spread at issuance between green and non-green bonds at the quarterly frequency (continuous line); 95% confidence interval (dotted lines); basis points. Source: Bloomberg; DCM Analytics; ECB.

Given that the effects of the ECB increased demand take time to appear on the primary bond market, the reported evidence squares well with the results by Zaghini (2023) and Bremus et al. (2021). The greenium was not present before the PEPP or in a very early phase of bond purchases (Zaghini 2023), whereas the ECB purchases under the pandemic programme eased the green bond financing over a longer time span (Bremus et al. 2021).

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Table 3 - PEPP effect on green bonds

Coefficient	Basic	DID	DID+
Green	-22.3326 ***	-5.1189	-5.1405
	(5.7009)	(6.1425)	(6.2560)
Post		73.1357 ***	74.8486 ***
		(25.3770)	(25.8860)
Green*Post		-28.7859 ***	-29.3756 ***
		(9.9902)	(9.8072)
Eligible			-22.7112 ***
			(8.3661)
Bond controls	YES	YES	YES
Issuer controls	YES	YES	YES
Short-term Market controls	YES	YES	YES
Country*Quarter FE	YES	YES	YES
Observations	5,610	5,610	5,610
R-square	0.7402	0.7408	0.7413

Results from regressions from model (1) and (3) over the period July 2019-September 2020. Green is a dummy taking 1 for green bonds and 0 otherwise; Post is dummy taking 1 after 18 March, 2020 and 0 before; Eligible is dummy taking 1 for eligible bonds and 0 otherwise. Source: Bloomberg, Dealogic DCM Analytics; ECB.

Since some of the green bonds issued in the 18-month period under analysis were also eligible for the ECB purchases, the final step consists in checking whether they were differently affected by the PEPP with respect to other (non-eligible) green bonds. In this way only can we disentangle the ECB contribution to the green bond segment.

The analysis has to take into account two different layers of diversification among bonds (in addition to the diversification between the two time periods post and ante the PEPP). The selected econometric approach is that of a difference-in difference-in differences (or triple difference estimator - DDD), which has been recently revised by Olden and Møen (2022).

Analytically:

$$
\begin{aligned}
ASW_i \;=\; & \beta_0 + \beta_1 GB_i + \beta_2 EB_i + \beta_3 EB_i * GB_i + \beta_4 Post_i + \\
& \beta_5 Post_i * GB_i + \beta_6 Post_i * EB_i + \beta_7 Post_i * EB_i * GB_i + \quad (4) \\
& + \sum_{k \, \cup \, l} \delta_j W_{i,j} + \sum_m \delta_m V_{i,m}^{market} + FE_i + \varepsilon_i
\end{aligned}
$$

where the coefficient of interest is β_7. As explained in the Introduction, β_7 is the difference between two DID estimators. The first estimating the difference between eligible green bonds and eligible non-green bonds after the PEPP announcement, the second estimating the difference between non-eligible green bonds and non-eligible non-green bonds over the same time span. In other words, the triple difference estimator β_7 of the change in the ASW spread on eligible green bonds after the PEPP announcement comes net of the change happened to the rest of green bonds, namely those in the set of non-eligible bonds.

Two issues are worth noting from model (4). The first issue concerns the parallel trend assumption. Indeed, the statistical validity of the control group in model (4) involves two sets of bonds, one for each of the two DID estimators in which the DDD estimator can be decomposed. Olden and Møen (2022) show that even if trends were present (before the PEPP) it would be sufficient that the trends were common in both control groups in order to cancel out.[13] However, Figures 3 and 4 show that no trends are at work in our control groups: eligible non-green bonds for the first DID, and non-eligible non-green bonds for the second DID.

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[13] According to Olden and Møen 2022, this hypothesis can possibly be tested by checking the parallel trend assumption for the ratio of the dependent variables in each control group.

Figure 3 - Trend assumption for the DDD estimator (control 1)
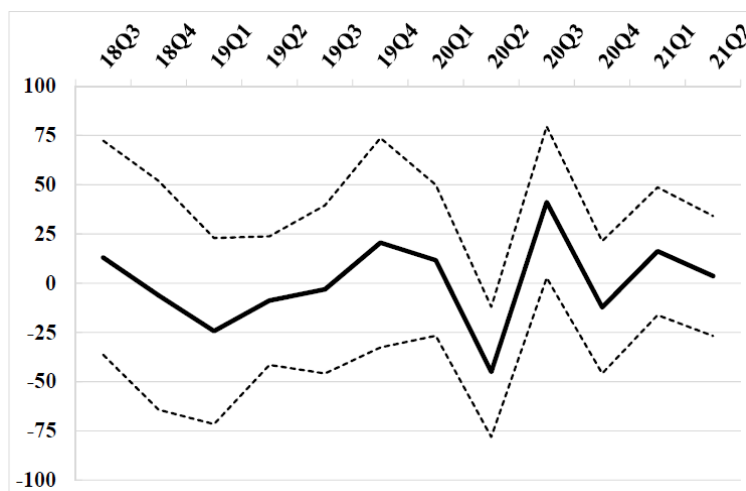
Estimated difference of the ASW spread at issuance between green eligible and non-green eligible bonds at the quarterly frequency (continuous line); 95% confidence interval (dotted lines); basis points. Source: Bloomberg; DCM Analytics; ECB.

Figure 4 - Trend assumption for the DDD estimator (control 2)
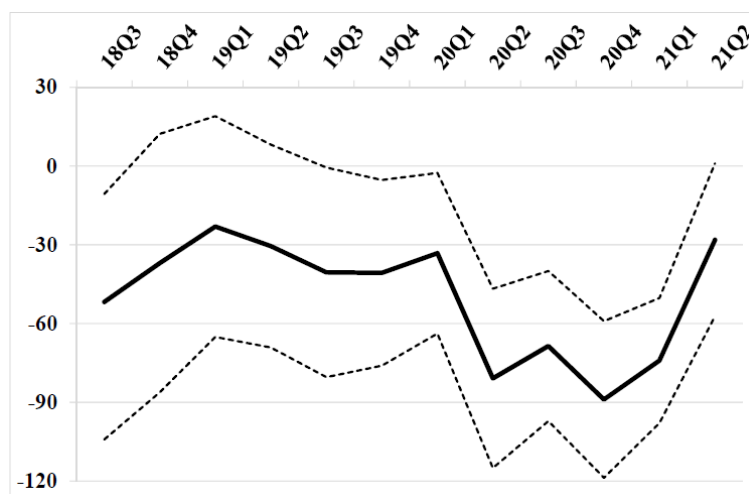
Estimated difference of the ASW spread at issuance between non-eligible green and non-eligible non-green bonds at the quarterly frequency (continuous line); 95% confidence interval (dotted lines); basis points. Source: Bloomberg; DCM Analytics; ECB.

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The second issue concerns the estimate of the total effect on the selected group of eligible green bonds in the *Post* period. We have explained above that the coefficient β_7 provides the additional net effect that allows us to correctly identify the consequences of the ECB asset purchases. Thus this effect does include the changes in the green segment as a whole and in the eligible segment as a whole. Following Olden and Møen (2022), in order to compute the total effect, we have to add three coefficients: β_5, β_6, and β_7. Since eligible green bonds are by definition green bonds, we need to look at the change in the *Post* period of that group (β_5). Analogously, they are by construction eligible, thus we have to add the change in the *Post* period of the set of eligible bonds (β_6). Finally, since neither β_5 nor β_6 include the differential effect of being both eligible and green, we have to add β_7. Thus, in Table 4 we report, in addition to the results of each regression, also the estimate of the total effect given by the sum of the three coefficients and the statistical significance of the T-test.

Model (4) estimation shows that indeed the effect of the PEPP was different within the set of eligible bonds. The estimated β_7 coefficient is statistically significant and negative at 39 basis points (Table 4, column 1), suggesting that eligible green bonds performed much better than eligible non-green bonds. At the same time, this means that while the whole set of green bonds benefitted of a negative premium of 22 basis points in the *Post* period (the β_5 coefficient), those that at same time were also eligible for purchase by the ECB faced a final discount of 51 basis points (namely, $\beta_5 + \beta_6 + \beta_7$), fully reaping the benefits of the increased and diversified demand under the PEPP.

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Table 4 - PEPP effect on eligible green bonds

Coefficient	9-month	12-month	6-month	No banks	Bond IG	CSPP
Green	-12.2576	-16.1763	-6.5862	-12.285	-16.422 *	-43.044
	(7.0789)	(11.3214)	(8.8507)	(12.5136)	(9.6087)	(28.4413)
Eligible	-30.2915 ***	-40.6776 ***	-26.4816 **	-25.0800 **	-23.2082 ***	-45.2175 **
	(10.0412)	(6.2839)	(13.3376)	(10.7334)	(7.6914)	(9.0574)
Green & Eligible	41.0864 ***	40.2109 ***	38.8927 *	31.7503 **	38.7854 ***	63.1963 **
	(11.5938)	(14.4887)	(20.0103)	(12.0787)	(10.5422)	(28.2944)
Post	73.4279 **	81.0118 **	85.1484 *	116.571 ***	52.1135 **	-2.457
	(28.2548)	(31.6551)	(45.3230)	(36.5370)	(20.3901)	(12.5957)
Green*Post	-22.5071 **	-21.3326 *	-30.1940 **	-15.0948	-7.1927	10.6616
	(9.4865)	(12.5923)	(12.2692)	(13.4390)	(10.4939)	(33.2754)
Eligible*Post	10.3452	16.9340	9.3698	-18.1714	23.5131 **	20.5863
	(14.9722)	(11.5443)	(18.5587)	(13.7892)	(9.9404)	(10.4297)
Green*Eligible*Post	-39.0431 **	-28.4032 *	-26.0486	-28.9606 **	-61.5184 ***	-6.5196
	(19.1706)	(16.7374)	(30.3547)	(14.5436)	(18.6803)	(36.7577)
Total effect on E&G bonds	-51.2051 ***	-32.8019 **	-46.8729 *	-62.2269 ***	-45.1980 ***	24.7283
	(15.1737)	(12.6473)	(26.9860)	(13.8875)	(16.8076)	(29.1388)
Bond controls	YES	YES	YES	YES	YES	YES
Issuer controls	YES	YES	YES	YES	YES	YES
Country*Quarter FE	YES	YES	YES	YES	YES	YES
Short-term Market controls	YES	YES	YES	YES	YES	YES
No. observations	5,610	7,469	3,795	3,584	4,503	3,676
R^2	0.741	0.743	0.746	0.729	0.632	0.748

The size of the premium is significant also from an economic point of view. Given that the unconditional mean of the yield at issuance was 2.72% in the 9-month period up to the PEPP, the benefit gained by corporations issuing eligible green bonds after the PEPP stands at 19% of the cost of funding. From a climate change perspective, this evidence suggests that asset purchase programmes can be an effective way of backing segments of the bond market financing green investment and firms' sustainability projects. The cheaper financing conditions of corporations placing green bonds – especially when eligible to the central bank purchases – allow to undertake climate-friendly investments at a lower cost.

5 Robustness

In order to confirm the role of the PEPP in driving the pricing of green bonds, we run several robustness checks concerning the length of the windows around the PEPP announcement and the composition of the control sample. In addition, we run a placebo test to verify that the effect identified for the PEPP is exclusive of this new programme and is not common with the previous CSPP.

The better performance of green bonds within the segment of eligible bonds is confirmed when increasing the length of the windows around the PEPP announcement to 12 months (Table 4, column 2). The entire structure of coefficients' sign, magnitude and statistical significance follows closely that of the 9-month regression. The β_7 coefficient is estimated at the lower level of 28 basis points, making the whole gain in the *Post* period adding up to 33 basis points. When the length of the windows is reduced to 6 months, the structure is again maintained as concerns the sign and the magnitude of the estimated coefficients, but the statistically significance of the β_7 coefficient is lost (column 3). However, the total effect, estimated at 47 basis points, turns out to be significant and lies in between those estimated for the 9-month and 12-month windows.

Given that the purchases under the PEPP are limited to non-banks corporations only, we restrict the control sample of non-eligible bonds to those issued by NFCs, insurances and other non-bank financial institutions. Column 4 shows again that even in this more homogeneous sample the effect of the ECB purchases is different within the group of eligible bonds. Eligible green bond performed better in the *Post* period than eligible non-green by 29 basis points. Over the same period, the overall additional change stands at -62 basis points.

Another possible adjustment of the control sample is suggested by the fact that all eligible bonds have an investment grade rating as concerns the credit risk. Column 5 reports the regression estimates when this restricted sample

is employed. The total effect in the *Post* period for the set of eligible green bonds is aligned with the previous results (45 basis points). We also have an additional insight on green bonds. There is evidence of a greenium of 16 basis points in the sample even before the launch of the PEPP: the β_1 coefficient is statistically significant. This in turn suggests that pro-environmental preferences were already at work before the PEPP and that investors were prone to accept a slightly minor return on green bonds provided that they were of good credit quality

In order to check whether the selective effect on eligible green bonds is associated to the PEPP only, and it is not common also to the standard corporate purchases programme by the ECB, we run a placebo test around the date of the announcement of the CSPP on 12 September 2021. In order not to overlap with the PEPP, we tailor the two windows to the maximum length of 5.5 months. The lack of statistical significance from the last column of Table 4 shows that the segment of green bonds was not involved in any yield change, both as a whole (coefficient β_5) and as a sub-set of eligible bonds (coefficient β_7). This in turn confirms that the PEPP was felt as a different policy measure with respect to more conventional ECB policy interventions.

6 Conclusions

In this paper, we provide evidence that the PEPP, the extraordinary asset purchase programme launched by the ECB to help mitigate the impact of the Corona virus on the euro area, had a significant effect on green bonds. In particular, the segment of bonds that were at the same time eligible to the programme and green enjoyed a discount of 51 basis points.

In order to achieve this result, we implement a two-step analysis. We first rely on two separate difference-in-differences (DID) regressions and then we move to a triple differences estimator (DDD) as recently refined by Olden and Møen (2022). Taking two windows of 9 months around the PEPP announce-

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ment, we show that the set of eligible bonds as a whole did not perform better that the control sample of non-eligible bonds. This results is consistent with the findings in Zaghini (2023) and attributable mainly to a portfolio rebalancing by investors other than the ECB towards non-eligible IG bonds. A second DID regression shows instead that the segment of green bonds as a whole benefitted of a discount of around 20 basis points with respect to non-green bonds, in line with the estimates by Bremus et al. (2021).

Given that the group of green bonds and that of eligible bonds overlap, we end up with four different sets of bonds: eligible green; eligible non-green; non-eligible green and non-eligible non-green bonds. In order to estimate the possibly different impact of the PEPP on the green bonds that were also eligible to the programme, we implement a DDD estimation. In particular, this econometric approach provides an estimate of the selective behavior of eligible green bonds with respect to eligible non-green bonds that takes into account the development over the same time span of the set of non-eligible green bonds with respect to non-eligible non-green bonds. In this way we can correctly identify the ECB contribution.

We find that eligible green bonds showed in the period after the PEPP announcement a better market pricing than eligible non-green bonds. The estimated discount standing at 39 basis points. This premium must be considered additional to the one that the set of green non-eligible bonds witnessed over the same period (22.5 basis points). Also considering the development in the set of eligible bonds, we estimate a total effect of 51 basis points.

All in all, we find support to the ECB role in helping channeling resources towards climate-friendly projects. Even without a declared preference towards green bonds (or low-carbon emitters), the announced increased in flexibility of the PEPP purchases was able to make a difference not within the group of eligible green bonds, but also for the whole market segment of green bonds.

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