DNB Working Paper
No. 590 / April 2018

The impact of the ECB asset purchases on the European bond market structure: Granular evidence on ownership concentration

Martijn Boermans and Viacheslav Keshkov

DeNederlandscheBank
EUROSYSTEEM

The impact of the ECB asset purchases on the European bond market structure: Granular evidence on ownership concentration

Martijn Boermans and Viacheslav Keshkov *

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 590

April 2018

De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

The impact of the ECB asset purchases on the European bond market structure: Granular evidence on ownership concentration*

Martijn Boermans[a,b] and Viacheslav Keshkov[b]

[a] *De Nederlandsche Bank, Amsterdam, The Netherlands*
[b] *Utrecht University School of Economics, Utrecht, the Netherlands*

April 2018

Abstract

This study investigates the impact of the Eurosystem's Public Sector Purchase Programme (PSPP) on the micro market structure of sovereign bonds. In particular, we analyze how the PSPP affected the ownership concentration of PSPP-eligible bonds. In line with portfolio rebalancing models we hypothesize that the entry of relatively new and dominant investor will unevenly displace certain investors who are willing to rebalance their portfolios, thus reducing the dispersion of holdings in the market. Using detailed security-by-security holdings data, we estimate a difference-in-differences model with a matched control group. We find that the announcement of the PSPP did not affect the ownership concentration of sovereign bonds. However, during the implementation phase the asset purchases increased the ownership concentration of the eligible sovereign bonds relative to the control group, potentially due to asymmetric portfolio rebalancing. We argue that quantitative easing had market distortionary effects and our results may explain the growing concerns for bond scarcity, market liquidity dry-ups and price spikes in the European sovereign bond market.

Keywords: quantitative easing, portfolio rebalancing, market concentration, ECB, PSPP, securities holdings statistics, unconventional monetary policy.
JEL classifications: G11; E52; E58.

* Corresponding author: m.a.boermans@dnb.nl

1 Introduction

In January 2015 the President of the European Central Bank (ECB), Mario Draghi, announced the Eurosystem's version of quantitative easing (QE), the Public Sector Purchase Programme (PSPP). During the announcement he explained: "[the Eurosystem] will buy government debt up to the percentage that will allow a proper market price formation (...) [and] wants to create as little distortion as possible". According to the public documentation on the program implementation, the Eurosystem would aim to act as a "market neutral" and 'blind' buyer. In practice, the PSPP announcement implied that the Eurosystem would become a 'dominant' investor in the European sovereign bond market.[1]

In this paper we analyze the market impact of the PSPP. We contribute to the burgeoning literature on the effects of QE by focusing in particular on the micro market structure; an area in this field which has received little attention. Our main question is what the (un)intended consequences are of the entry of a large and relatively new buyer on the market structure. While the primary aim of QE is to reduce bond yields, the asset purchases may also disrupt the existing network of sovereign bond holders. Since the number of bonds available in the secondary market is reduced by the Eurosystem purchases, the Eurosystem must always displace previous holders of the PSPP-eligible assets. We conjecture that this increases ownership concentration as there is no homogeneous response to the Eurosystem purchases from different investors. Certain types of investors are less willing to sell assets to the Eurosystem as they react less strongly to price movements in the sovereign bond markets than other types of investors. Consequently, this group of investors with a strong preference for European sovereign bonds will drive market concentration upwards due to the PSPP.

Our empirical study fits well into the literature on portfolio rebalancing effects. Portfolio rebalancing models explain how the actual purchases under QE affect bond yields.

[1] Speech held on January 22, 2015: Introductory statement to the press conference (ECB).

These models assume that some investors have time-invariant preferences for particular bonds, e.g. with a certain maturity. This 'preferred habitat' leads to market segmentation and imperfect asset substitution among different investors who do not quickly respond to price movements (Vayanos and Vila, 2009). Because some investors continue to have no inclination to sell bonds to central banks, the scarcity of the targeted bonds by the QE program increases, which in turn reduces bond yields and induces portfolio rebalancing among those investors that are more sensitive to price movements (see Gagnon et al., 2011; Joyce et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011). In this paper we argue that the rebalancing effect produces a shift in the micro market structure in terms of ownership concentration that is relevant in itself.

Ownership concentration in the bonds markets matters. First, limited dispersion of ownership reduces market liquidity and can amplify market shocks. There is ample evidence that market concentration is associated with lower market liquidity which reduces the market resilience in both stock markets (e.g. Attig et al., 2006; Jacoby and Zheng, 2010; Rubin, 2007) and bond markets (Boermans et al., 2016; Cai et al., 2018). The reason is that block-holders of stocks and bonds can make it more difficult to trade the assets, obstructing proper price discovery as these concentrated assets become less liquid and more prone to price volatility.

Second, ownership concentration is associated with bond scarcity. A growing stream of papers on bond scarcity due to QE explains how this hampers the liquidity of the financial markets (IMF, 2015; D'Amico et al., 2015; Valiante, 2017; Schlepper et al., 2017). The IMF (2015) (p.38) argues that: "[QE] purchases may also impair market functioning (so-called financial 'plumbing') if they significantly diminish the availability of debt securities (...) [which] may adversely affect market-making for government bond markets". Valiante (2017) further explains that "the ECB determination to buy government bonds in a fragmented market with low net supply will continue to put a strain on liquidity." By contrast, some scholars argue that QE should raise market liquidity. For

example, Christensen and Gillan (2018) argue that the Federal Reserve purchases put the sellers of sovereign bonds in an advantageous position which should increase market liquidity. Ferdinandusse et al. (2017) model this channel explicitly and show that QE may increase market liquidity in the very short term but may erode it in the longer term due to increasing scarcity of sovereign bonds available for purchases by central banks.

Our empirical study analyzes whether the Eurosystem asset purchases increased the concentration of ownership of individual European government bonds eligible for the PSPP. A rise in ownership concentration with the onset of QE is not self-evident, because those investors holding large positions in sovereign bonds can decide to sell to the Eurosystem, thus decreasing the overall concentration. Using a new dataset based on the ESCB securities holdings statistics we are able to assess shifts in the market structure at the individual bond level. As the PSPP can be seen as a natural experiment, we measure how bond concentration was affected by the PSPP by adopting a difference-in-differences estimation with a control group carefully constructed using matching techniques. The data allows us to determine whether QE increased ownership concentration at the granular level. To our knowledge, the potential market distortionary effects of QE on the network structure of sovereign bond ownership have not been analyzed before.

The results show that the PSPP significantly increased the ownership concentration once the actual purchases started. However, before the program implementation (i.e. signalling period 2014Q3-2015Q1) we do not find any significant effects of the PSPP on ownership concentration. It appears there was no increase in ownership concentration of the sovereign bond holdings until the actual start of QE. The implementation of the PSPP raised concentration levels in the short and medium term and had a persistent negative impact on the market. Building upon the literature linking higher concentration to lower market liquidity and inefficient price formation, our findings highlight the unintended consequences of the QE program during the implementation phase. As a side effect, the PSPP had market distortionary effects on the holdings network structure

within the European sovereign bond market.

This paper contributes to the literature by being the first to study how QE affects the underlying network structure of investors. Second, the increased market concentration as a result of QE provides support for other studies on the existence of preferred habitat investors in the euro area (Ferdinandusse et al., 2017; Boermans and Vermeulen, 2018). Third, while the use of difference-in-difference models is widespread to study the impact of QE, our paper is the first one to combine them with matching techniques to construct a control group based on granular data. In addition, for our identification purposes, the individual bond holdings data allows us also to simulate the Eurosystem holdings rather well, based on aggregated public data (Koijen et al., 2016). Finally, given that the PSPP was initiated only recently, we are amongst the first to study the implementation phase effects, showing that at the onset of the program, ownership concentration increased while the pre-implementation phase did not affect the ownership concentration.

The paper is organized as follows: Section 2 connects the literature on QE to ownership concentration. Section 3 presents the granular portfolio holdings data. Section 4 explains our methodology and Section 5 presents the results. Extensions a are covered in Sections 6 and section 7 concludes.

2 Related literature

Our study builds on a growing literature on the impact of QE. From a theoretical perspective, the mechanisms through which QE operates generally fall into two, not mutually exclusive categories. First, the signalling theory explains how the announcement and future commitment to large scale asset purchases by central banks affects market expectations directly in advance of actual purchases (see Bauer and Rudebusch, 2014). The emphasis here is on the 'stock' effect, i.e. the expected size of the asset purchases. The market response would immediately incorporate the news of a QE program, bringing

forward anticipated price effects, thus affecting bond yields directly by lowering expectations of the future short-term interest rates. Before an official announcement, market participants can anticipate the QE program as central banks already provide 'hints' and signals to the markets about their potential policy changes. For concentration, this would imply that even before the asset purchases by the Eurosystem have started, there could have been a significant shift in the micro market structure.

Second, portfolio rebalancing models show that the actual purchases are driving the effects of QE. The main driver is the 'flow' effect generated by the asset purchases themselves. In the portfolio rebalancing models, some investors have a time-invariant preference for certain segments of the bond market. For example, a group of investors prefers to hold bonds with longer maturities (Vayanos and Vila, 2009). This market segmentation gives rise to imperfect asset substitution among different investors causing market frictions. The QE purchases thus only affect investors who are willing to sell, while investors with a 'preferred habitat' to hold sovereign debt drive the scarcity of targeted bonds, which decreases bond yields and induces portfolio rebalancing (see e.g. Gagnon et al., 2011; Joyce et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011; Hamilton and Wu, 2012; Thornton, 2014, for discussions) and results in a 'search for yield' among displaced investors (Becker and Ivashina, 2015; Ammer et al., 2018). Domanski et al. (2017) further show that certain preferred habitat investors in the sovereign bond market must use these bonds to match their durations. Instead of a search for yield, they find that insurers and pension funds in an environment of declining yields and a widening negative duration mismatch will increase their holdings of sovereign bonds. In line with the portfolio rebalancing models, we argue that the asset purchases by central banks displace different groups of investors asymmetrically, thus affecting the dispersion of bond ownership.

The empirical literature building on both signalling and portfolio rebalancing approaches has mainly focused on the impact of QE on bond yields (for an early overview,

see Joyce et al., 2012). First, in line with the signalling theory Krishnamurthy and Vissing-Jorgensen (2011) and Bauer and Rudebusch (2014) document pre-implementation shifts in bond yields related to the announcement of Federal Reserve's asset purchases programs. Further support for signalling effect is presented by Christensen and Rudebusch (2012) and McLaren et al. (2014) for the Bank of England's QE policy announcements and by Oda and Ueda (2007) for Bank of Japan. Second, other empirical studies highlight the importance of the implementation period to explain the effect of QE on bond prices in line with the portfolio rebalancing models (Gagnon et al. (2011), D'Amico et al. (2012) and D'Amico and King (2013) for the Federal Reserve, (Joyce et al., 2012) for the Bank of England, and, Arslanalp and Botman (2015) and Fukunaga et al. (2015) for the Bank of Japan). Lastly, several authors find important effects for both signalling and portfolio rebalancing, see for example Christensen and Rudebusch (2012) and Neely (2015) for the US, Joyce and Tong (2012) for the UK and Ugai (2007) for the early QE program in Japan.

Recently, for the euro area an empirical literature on the impact of the PSPP is emerging, also focussing mainly on bond yields. Altavilla et al. (2015) analyze signalling effects and find that the anticipation and announcement of the PSPP reduced bond yields. De Santis (2016) finds similar results and shows that the impact was larger for the sovereign bonds issued by vulnerable countries. Andrade et al. (2016) also present evidence in line with the signalling theory but also find significant effects on bond yields during the first year of the asset purchases. Arrata and Nguyen (2017) further attribute most of the impact on yields on the pre-implementation period. These papers suggest that for the euro area the most sizeable impact of the PSPP on bond yields was before the program's implementation. These scholars also note that the time period of their analysis is rather limited for studying the implementation phase. Hence, in this paper we studied the possible effects on the market structure both during the announcement and pre-announcement (anticipation) period as well as the implementation period.

Of special interest are several closely related papers using a similar dataset to that used to study the PSPP in the euro area. To start, Koijen et al. (2016) document that euro area investors tend to have a strong home bias in terms of holdings that are eligible under the PSPP. They show that mainly foreign investors sold bonds to the Eurosystem, whereas insurers and pension funds bought these bonds despite the QE program. Ferdinandusse et al. (2017) further suggest that insurers and pension funds are preferred habitat investors in the euro area. Using granular portfolio holdings data they construct a measure of market tightness defined as the share of preferred habitat investors, which is closely related to market concentration. They show that greater tightness is associated with larger price shocks, in line with the general predictions for ownership concentration. In addition, Boermans and Vermeulen (2018) document that certain euro area investors act as portfolio habitat investors, thus driving the impact of QE. Finally, Albertazzi et al. (2016) present evidence for portfolio rebalancing from the PSPP implementation for more vulnerable countries.

Although there is an extensive literature on the impact of QE on bond yields and growing evidence on the portfolio rebalancing channel, there has been little attention, both theoretically and empirically, to possible side effects of QE.[2] To start, as the balance sheet of central banks grows, the number of bonds available in the secondary market decreases monotonically with the actual purchases under QE.[3] Consequently, the assets purchases must always displace previous holders of the PSPP-eligible assets, (un)intentionally changing the composition of investors in sovereign debt market. As Chairman of the Federal Reserve, Bernanke explains: "purchases (...) affect financial

[2]Some other channels through which QE operates may qualify as unintended consequences. Andrade et al. (2016) argue that QE can improve bank balance sheets through the revaluation channel of their sovereign bond portfolios. That is, one side effect of QE is that it disproportionately benefits banks that hold a large share of sovereign debt. This mechanism is referred to as the "capital relief channel" because it is akin to a capital injection. In addition, the Eurosystem's balance sheet expansion implies greater risks of capital losses for the ECB. Finally, there may be concerns over financial stability as compression in interest rate spreads could negatively affect bank profitability.

[3]Note that QE does not only reduce the supply of targeted assets, central banks also 'pay' for these assets by the expansion of reserves.

conditions by changing the quantity and mix of assets held by the public."[4] As a result, QE has a direct effect on what market participants hold or invest in. Further still, for QE to effectively drive bond yields, certain investors must be displaced while preferred habitat investors stick to their holdings (IMF, 2015; Boermans and Vermeulen, 2018). Hence, the underlying mechanism to price movements is a change in the micro market structure, which could translate into shifts in ownership concentration.

A recent burgeoning research agenda also focusses on bond scarcity in the context of QE (IMF, 2015). On the one hand, QE reduces the number of available sovereign bonds ('local supply') (see D'Amico et al., 2012), leading to a 'safety premium channel' (Krishnamurthy and Vissing-Jorgensen, 2011). As prices rise along with scarcity, market participants are forced to use other assets, which further decreases the liquidity of these assets. This may impair the functioning of certain market segments. For example, scarcity of sovereign bonds affects repo markets where these assets are used a primary collateral (D'Amico et al., 2015). Valiante (2017) argues that asset purchases by the Eurosystem in a fragmented market with relatively low net bond supply negatively affected the financial plumbing in repo markets because of scarcity in collateral markets. Using transaction-level data for German sovereign bonds Schlepper et al. (2017) show that the PSPP increased scarcity. Similarly, Strohsal (2017) uses German bond supply data and finds that the bond supply of relatively scarce long-term debt affects yields. D'Amico et al. (2015) provide further evidence on the scarcity channel linked to the implementation of the asset purchases by the Federal Reserve. These papers suggest that QE increased the scarcity of sovereign bonds during the implementation period.

Several papers further show that QE may affect market liquidity in different ways. For Japan, Pelizzon et al. (2017) show that overall the bond scarcity increased which reduced market liquidity, whereas Iwatsubo and Taishi (2017) argue that QE improved market liquidity because of particular auction design features implemented by the Bank

[4]Speech held on August 27, 2010: The Economic Outlook and Monetary Policy.

of Japan. For the United States, Christensen and Gillan (2018) argue that QE enhances the position of sellers in the market as the expected amount of transactions grows. They find that asset purchases improved market liquidity of inflation-protected securities, but Kandrac and Schlusche (2013) find no effects on the market liquidity of Treasury bonds. For the euro area, Schlepper et al. (2017) find that PSPP decreased market liquidity.

In this paper we focus on how QE affects the underlying micro market structure in terms of ownership concentration. Ownership concentration concerns the distribution of holdings across different type of investors. A higher dispersion and a greater number of investors is typically associated with lower concentration. To study the underlying market structure is important because, first, levels of market concentration in various segments of financial markets related to bond investments have increased over the years (e.g. Azar et al., 2017; Bebchuk et al., 2017), heightening concerns over financial stability. Second, at the level of the investor, several scholars have suggested that higher concentration could identify systemically important financial institutions (e.g. Allen et al., 2012). Third, market concentration *in situ* may hamper the functioning of financial markets. To start, higher concentration may reduce market liquidity. If there are fewer players in the markets to sell and buy bonds, liquidity is typically lower. Concentrated ownership thus diminishes the opportunities to trade, which in turn hampers price formation.

Empirically, the negative effect of concentration on market liquidity is well-established. The impact of large block holders has been mainly studied for stock markets. Attig et al. (2006) show that for Canadian firms, higher ownership concentration increases bid-ask spreads of stocks. Jacoby and Zheng (2010) confirm the negative effect of concentration by analyzing blockholder ownership and the number of stockholders on market liquidity for firms listed in the US, where higher concentration is associated with lower market liquidity (see further, e.g. Rubin, 2007; Brockman et al., 2009).

Two related studies analyze the role of ownership concentration in bonds markets for financial fragility. First, Boermans et al. (2016) study how market concentration and

market liquidity aggravate price shocks during periods of financial stress. Using granular data on European sovereign bond portfolio holdings they construct a concentration measure and find that during the Bund Tantrum in 2015, higher concentration explained price spikes. Second, Cai et al. (2018) study the role of ownership concentration in terms of institutional herding for US corporate bonds. They also find that concentration explains price volatility and argue that these effects can be more destabilizing than in stock markets because certain segments of the bond market are highly illiquid.

A related stream of literature focussing on bond markets analyzes how portfolio overlap affects financial stability (see Allen et al., 2012). For insurers, Getmansky et al. (2017) link portfolio overlap to greater systemic risk during the financial crisis. Nanda et al. (2017) further show that highly concentrated bond portfolios increase fire sale risks. For investment funds, Braverman and Minca (2014) show that common holdings increases market volatility. For banks, Hüser et al. (2017) show how portfolio overlap could translate into contagion effects. As they find limited direct portfolio overlap for euro area banks, they argue that contagion may be limited, suggesting that lower market concentration improves financial stability. Combined, these papers suggest that higher concentration makes financial markets more vulnerable.

Our take away from this literature is that we expect that the purchases of sovereign bonds will raise market concentration because those with relatively large positions in these bonds will have a lower responsiveness to price shocks than other investors with smaller positions. As a result, fewer investors will remain and raising the average size of the investment position. Note that this mechanism is not self-evident, because the purchases by the central banks could very well lead to a decrease in market concentration. For example, if the investors with relatively large positions in sovereign bonds are willing to sell to the Eurosystem, the market concentration can decrease. Similarly, the entrance of a new buyer should decrease market concentration if the purchases are accomplished by buying in proportion of existing bond holders, up to a point where the size of purchases

by central banks becomes very large (note that for the Eurosystem this has been capped to 0.25 to 0.33 percent of each bond). Thus, the PSPP can either increase or decrease market concentration. The impact can be measured with the inclusion of the central bank (Eurosystem), which has the benefit that this reflects the central bank as a real agent in the market, or, by only looking at the impact on private investors, which has the benefit that it is informative of how the market positions shifted after the Eurosystem has absorbed certain bonds. In this paper we focus on the first approach and rerun our analysis without the Eurosystem to test the second approach as well.

3 Data

We use data from ESCB Securities Holdings Statistics (SHS) to conduct our analysis. This database contains security-by-security information on the holdings of euro area investors reported on a quarterly basis (ECB, 2015). The main benefit of the SHS data is granularity - each observation in the dataset corresponds to an ownership position in a particular bond identified by its unique International Securities Identification Number (ISIN). As discussed in the previous section, SHS data is being increasingly used to study the impact of QE (Koijen et al., 2016; Albertazzi et al., 2016; Ferdinandusse et al., 2017; Boermans and Vermeulen, 2018).

The data captures both holding-side and issuance-side information. On the holding side, we observe the size of the holding position and information about the holder on a sectoral level, whereby holders are classified as a combination of 'investor sector' and 'holder country' pairs.[5] On the issuance side, we observe the size of the issuance, date of the issue, sector and country of the issuer and further bond-specific characteristics such as yield-to-maturity and coupon rates. In total, we observe sixteen distinct investor

[5]Given this setup, an example of an observation could be a holding position of French social security funds in a German bond. On the holding side, we would observe the social security funds as an 'investor sector', France as a 'holder country', and the size of the holding position as observed value.

sectors from nineteen countries in the euro area in our dataset.[6] We use data over the period 2014Q1-2016Q3.

For our analysis we perform certain cleaning exercises and increase the coverage of data by including a subset of the third-party holdings (TPH). The TPH data contains all the foreign holdings reported by the euro area custodians. But, this data is known to suffer from 'custodian bias', whereby the holder reported by a custodian does not necessarily represent the final holder, especially when held on behalf of the next third-party institution. For that reason, we only include a subset of the TPH data which is unaffected by custodian chains that hide the final holder (see Ferdinandusse et al., 2017). The first subset corresponds to the holdings of euro area households, which are classified as TPH because households are not directly reporting to the SHS database. The second subset corresponds to the holdings by foreign central banks and general government.

Since our data does not include the rest of the foreign holdings that use custodians outside of the euro area, total holdings in our sample are somewhat lower than the issuance size for each given ISIN. This reflects the fact that many of the bonds in our sample are also held by investors outside the euro area. In order to improve the quality of data on the concentration of these bonds, we set a threshold for euro area share of holdings to at least of 30% of issuance size (see Boermans et al., 2016). In practice, following this threshold means that we mainly exclude those bonds that were issued outside of the euro area. We further exclude small bonds with amount outstanding or total aggregated observed holdings below one million euro. As a last step, we add a 'Rest of the World' (ROW) investor as a residual between amount outstanding and observed holdings, which we construct at the individual bond level.[7]

[6] The 16 different investor groups are classified in line with the European System of Accounts 2010 (ESA2010). In particular we observe the following investor sectors: Non-financial corporations, central banks, banks (MFIs), money market funds, investment funds, financial vehicle corporations (SPVs), other financial intermediaries, insurance corporations, pension funds, central government, state government, local government, social security funds, other general government, households, non-profit institutions, other non-financials and specified non-euro area investors.

[7] For example, if we observe three billion euro of total aggregated holdings by euro area investors for

(Insert Table 1 here)

The descriptive statistics of our dataset are represented in Table 1, which provides an overview of the main variables related to the portfolio holdings. We distinguish between bonds by issuance size in terms of the nominal amount outstanding of the principal ($BondSize$), the residual maturity measured in years ($Resid.Mat$), the coupon rate, a dummy on whether the coupon is fixed or not, a dummy for newly issued bonds over the past three months, and seniority and guarantee indicators. Furthermore, we construct an extra dummy for the bond 'eligibility' for PSPP, conditional on all of the official PSPP requirements in line with the ECB decision published in March 2015 and updated throughout the program.[8]

As one can see from Table 1, the subset of eligible sovereign bonds significantly differs from the rest of the euro denominated worldwide bonds on a number of variables. Compared to the other bonds in our sample, eligible bonds tend to have a longer residual maturity and a larger issuance size. They are also issued less frequently and more likely to be senior and have fixed coupon rates with lower yields-to-maturity. The total number of euro area issued bonds in our full sample is 540,990 of which only 5,759 are identified as sovereign bonds eligible for PSPP purchases. In terms of holding size, however the euro area investors held on average 8.838 trillion euro in nominal value of which 3.395 trillion euro was invested in sovereign bonds that became or were eligible under the PSPP.

(Insert Figure 1 here)

To get an overall impression of the evolution of bond holdings throughout the PSPP, Figure 1 shows the relative holdings of the main investors in eligible sovereign bonds at

a particular bond that has an amount outstanding of five billion euro, we keep the bond in our sample as it exceeds the 30% euro area holdings threshold. In the second stage we assign the *ROW* to hold the residual of two billion euro of the bond.

[8] As outlined in the introduction, in this paper we focus only on sovereign bonds eligible under PSPP. It means that we exclude eligible bonds of the supranational institutions and agencies located in the euro area.

the aggregated level. As one can see from the Figure 1 since the onset of the PSPP in 2015Q1 the relative share of central bank holdings has steadily increased to about 20 percent of all eligible sovereign debt. The share of holdings by non-financial investors from the euro area fell steadily and strongly from 25 percent in 2014Q1 to 13 percent in 2016Q3. The share of banks, other financial intermediaries, investment funds and pension funds remained reasonably stable at about 21 percent, 11 percent, 1.5 percent and 3 percent respectively. The share of insurers, however started to grow since the onset of the PSPP in 2015Q from about 16.5 percent to 22 percent in 2016Q3 which is consistent with Domanski et al. (2017). Simultaneously and in line with Koijen et al. (2016), the share of non-euro area investors constituted the largest drop in PSPP sovereign debt holdings, from about 22 percent before the launch of PSPP to about 7.5 percent by the end of 2016Q3.

Taken together, this descriptive data shows that there were significant changes in the holdings structure of the sovereign bond market at the aggregate level, whereby non-financial euro area investors and non-euro area investors reduced their share of sovereign bond holdings and the Eurosystem and euro area insurers increased their relative shares. This observation provides us with an analytical basis to investigate further whether shifts in the aggregate positions also affected the holdings structure at the granular level due to the PSPP. In order to do so, we measure the concentration levels of individual PSPP-eligible sovereign bonds and examine changes over time relative to the similar bonds in our dataset that were not targeted by the PSPP.

4 Method

In this empirical study, we adopt a difference-in-differences methodology in order to identify the potential side effects of the PSPP on ownership concentration. The intuition behind this method is that the PSPP can be considered a natural experiment,

whereby the Eurosystem is targeting a specific group of the euro area bonds.[9] For that 'treatment' group, we can identify a similar control group based on matching procedures to compare the movements in concentration between the two groups. The main advantage of this method is that it controls for any unobserved influencers that could have an impact on concentration throughout the PSPP program. And, given that the parallel trends assumption between the two groups is satisfied, this method allows us to achieve observational causality on the PSPP program side effects.

We apply this methodology in the following order. First, we define the treatment group based on the public eligibility criteria published in the ECB decision of March 2015 and updated throughout the program. Second, given that we do not observe the actual purchases by the Eurosystem, we populate our holdings data with a simulation of PSPP purchases based on the available aggregate amounts. The inclusion of the Eurosystem holdings reflects the idea that the Eurosystem is a relevant market participant that can affect the overall market. We also run our analysis without the Eurosystem to analyze how the market concentration among private investors changed as a robustness test.[10] Third, we select a control group based on propensity score matching. Lastly, we run

[9]One of the main reasons why the PSPP can be regarded as a natural experiment is because the Eurosystem explicitly aimed to act as a market neutral buyer in a particular segment of the bond market. The Eurosystem stated that is would obey to the concept of market neutrality by not suppressing the price discovery mechanism, i.e. avoid interfering with the market price formation mechanism and even went so far that the PSPP portfolio should eventually replicate the duration structure of the outstanding sovereign debt by evenly distribution purchases over amount outstanding (see also Arrata and Nguyen, 2017; Schlepper et al., 2017). The design of the QE policy of the Eurosystem as a 'market neutral' buyer is rather different than the policies implemented by the Federal Reserve, the Bank of England and the Bank of Japan (see Boermans and Vermeulen, 2018). The Federal Reserve mainly brought US treasury bills from households, hedge funds and other non-bank financial institutions including insurers. These investors most likely rebalanced their portfolio holdings towards corporate bonds (Carpenter et al., 2015). The QE purchases of the Bank of England targeted bonds held by particular non-banking sectors. In this market, mainly institutional investors including insurers and pension funds rebalanced their portfolio away from UK sovereigns to corporate bonds (Joyce et al., 2017). Similarly, the design of the Bank of Japan's QE auctions are very different from the market neutral stance of the ECB (Arslanalp and Botman, 2015; Fukunaga et al., 2015). Hence, we argue that the setup of the PSPP justifies well the use of a difference-in-difference approach.

[10]Ex ante, with the inclusion of the Eurosystem as a holder it is not self-evident that the market concentration increases after the purchases. It all depends on how the ownership of bonds is before the program and on how afterwards different investors respond. For example, if ex ante there is a relatively large single holder, the purchases by the Eurosystem would decrease ownership concentration only if it purchases for this relatively holder.

our final diff-in-diff estimation. Varying the time of the analysis allows us to uncover whether PSPP had side effects on market concentration during the implementation, announcement or pre-announcement stage.

4.1 PSPP: Eligible sovereign bonds

As the first step, we describe the boundaries of the bond eligibility for the PSPP in our dataset and show how the eligibility dummy was constructed. PSPP was announced as a program on 22 January 2015 and purchases of 60 billion euro per month started in March 2015. At the announcement, the ECB stated that it would only purchase 'eligible' bonds and provided the list of restrictions on the issuer and bond characteristics. Accordingly, it restricted the issuers to euro area governments, which excludes the cases of Cyprus and Greece, and includes the cases of specific national agencies and supranational institutions. In this paper we focus only on the eligible sovereigns and exclude all bonds issued by national agencies and supranational institutions in the sample. Using a narrower eligibility group leaves us with about 88% of the total PSPP size which in monetary terms amounted to about one trillion euro between 2015Q1 and 2016Q3.

On the bond characteristics, eligible bonds are restricted to have a residual maturity between 2-30 years, euro currency denomination, investment grade (credit quality step 3) and a yield-to-maturity above or equal to -0.2 percent. Accordingly, bonds that are newly issued, matured or crossed the yield-to-maturity threshold throughout the PSPP program represent borderline cases for our treatment group composition. We address those cases by allowing our eligibility dummy to vary slightly over time, such that bonds can exit or re-enter the treatment group, while limiting them from entering a control group in the next periods, to avoid the estimation bias.[11] To use this group for the analysis, we first populate our dataset with holdings data of the Eurosystem using a

[11] It means that our dummy for eligibility may change value from 1 to 0 and 0 to 1 depending on its eligibility for a given period, but it is always restricted from taking a value of 1 for the control group composition. In practice, this occurs very infrequently and does not drive our results.

simulation procedure.

4.2 Eurosystem holdings simulation

In this step, we simulate the Eurosystem holdings of eligible bonds. We cannot simply observe the bonds holdings of the Eurosystem on the granular level, because SHS data is reported at the country-sector level, whereas the Eurosystem comprises an individual investor. Fortunately, we can run a simulation that populates holdings at the individual bond level by utilizing the information on issue limits and real PSPP purchases at the aggregate level. Our simulation procedure is based on the simple premise of 'market neutrality' whereby the Eurosystem purchases are distributed uniformly among all of the eligible bonds in proportion to the available share of amount outstanding.[12]

The starting point of our simulation is a subset of eligible sovereign bonds and their holdings data. For each of those bonds we derive how much 'room' there is left for the Eurosystem given already observed holdings in our dataset, denoted "observed share". Based on this share, we calculate how much of each bond the Eurosystem could potentially purchase, denoted as 'maximum share'. For instance, if 0.85 of the bond issue is already observed, the other 0.15 represents a 'maximum share' available for the Eurosystem. For those bonds which have a higher maximum share, we set the maximum share in line with the legally allowed limits, which is 0.25 prior to 2015Q3 and 0.33 in the next periods.

We then simulate the maximum holdings by the Eurosystem for each individual bond and aggregate them per country in order to compare them with the actual aggregate holdings per country reported by the ECB. With this, our goal is to adjust the maximum share downwards in order to match the exact aggregate amounts. We do so by dividing

[12]In their study, Koijen et al. (2016) use a similar argument to estimate the Eurosystem holdings so our approach is not new and similar to theirs except that they estimate the Eurosystem holdings at an aggregated level across several dimensions while we simulate the Eurosystem purchases at the individual bond level. In addition, we carefully include third party holdings and set a 30% threshold to reduce noise.

the maximum simulated holdings by the actual holdings, denoted 'adjustment ratio'. In the last step, we create a new investor in our dataset, denoted 'Eurosystem'. As a result of simulation, the Eurosystem holds the maximum share times the adjustment ratio, denoted 'final share' which will differ for each individual eligible sovereign bond that we observe in our dataset.

More formally, we start with the following identity under market clearing condition (see also Koijen et al., 2016):

$$BondSize_{i,j,t} = H^{EA}_{i,j,t} + H^{ROW}_{i,j,t} + H^{ECB}_{i,j,t} \tag{1}$$

where $BondSize$ is the amount outstanding of a single bond i, issued by country j at time t, H^{EA} the nominal holdings by the euro area investors, H^{ROW} the holdings of non-euro area investors, here understood as the foreign sector (rest of the world) and H^{ECB} the holdings by the Eurosystem under the PSPP. From our investor-sector, holder-country dataset we know the bond holdings of the euro area investors, H_{EA}. In addition, because third-party holdings are collected, we have partial proxy at the bond level of the holdings of the foreign sector, which we denote $\widetilde{H_{ROW}}$. Hence we can rewrite the identity:

$$H^{ECB}_{i,j,t} = BondSize_{i,j,t} - H^{EA}_{i,j,t} - \widetilde{H^{ROW}_{i,j,t}} + \epsilon_{i,j,t} \tag{2}$$

where we impose the following data restriction to reduce noise:

$$BondSize_{i,j,t} - H^{EA}_{i,j,t} - \widetilde{H^{ROW}_{i,j,t}} \leq 0.30 \tag{3}$$

By taking the summation of the Eurosystem holdings over i we get the positions of the Eurosystem over time t by issuer country j. Hence, we further observe from public data:

$$\sum_{i=1}^{n} H_{j,t}^{ECB} \tag{4}$$

For each summation we determine whether the limits imposed by the ECB on the individual bond level (0.25 and 0.33) are violated and derive the total amount of 'overallocated' Eurosystem holdings. In the next round, we spread them over all PSPP-eligible instruments with a share below the limit, until the simulated purchases closely match the total aggregate amounts while satisfying the individual issue limits.

(Insert Table 2 here)

The results of the simulation are presented in Table 2, which gives a breakdown of the simulated PSPP purchases over time. As we can see, in aggregate our simulated holdings almost exactly replicate the official PSPP holdings. We can also see that maximum share and adjustment ratio grow over time, which reflects that Eurosystem is displacing the previous holders in our dataset and increasingly reaches the legal limits on the individual bonds. Note that as expected, the adjustment ratio increases over time, reflecting increasing bond scarcity for PSPP purchases. Fortunately, the final shares are still relatively low, reaching 0.1 only starting in 2016.[13]

4.3 Difference-in-differences estimation with matching

To assess the impact of PSPP on ownership concentration we employ a difference-in-differences estimator. The Diff-in-diff is a method that compares changes in the outcome of the treated group to the changes in the outcome of the control group before and after the treatment. Many papers in the field use such an approach (Joyce et al., 2017; Pesaran and Smith, 2016; Valiante, 2017) but none with granular data on portfolio holdings. Given that the PSPP can be considered as a natural experiment or nearly exogenous

[13]Appendix 1 presents further details on the outcomes of the simulation with breakdowns of the total simulated Eurosystem holdings by country of the issuer for each time period, both in terms of simulated aggregated Eurosystem holdings and the weighted average maturity of the specific portfolio holdings.

market shock, a diff-in-diff approach is well-suited. This approach aims to ensure that any changes in ownership concentration that we estimate are due to the PSPP and not due to certain unobserved trends which drive concentration. The intuition for this approach is that an appropriate benchmark helps to disentangle the program effect from any other influencers.

This method is valid when the parallel trends assumption is satisfied (Abadie, 2005). This assumption requires both the treatment and control group to have followed a similar trend prior to the treatment. The diff-in-diff assumes that the treated group follows the same trend as the control group in the absence of treatment. All differences afterwards are ascribed to the treatment. For the PSPP, it means that prior to the program, the ownership concentration of the PSPP-eligible bonds and non-eligible bonds has to follow a parallel trend. Hence, the selection of a proper control group is important.[14]

Fortunately, our overall sample of non-eligible bonds is relatively large, meaning that we are able to select comparable bonds for the control group using matching techniques (Ho et al., 2007). First, to achieve good comparability, we perform a 'forced' matching by discarding a large set of bonds that are either fundamentally different from the eligible bonds, or may be subject to contamination from other programs. We exclude all non-euro denominated debt as the dynamics in the foreign debt market may be different (e.g. exchange rate effects). Next, we exclude all securitizations because the ECB ran several programs targeting these assets, that is an ABS purchase program (see e.g. Altavilla et al., 2015). After narrowing our pool of bonds for the control group, we utilize the propensity score matching procedure (PSM) on observable characteristics which are likely to explain the bond eligibility (see Lechner, 2011; Stuart et al., 2014).

The first step in this procedure is to estimate a probit regression on the eligibility dummy to obtain a set of variables on which the two groups will be matched. The results of such probit regression are presented in Table 3. As can be seen, amount outstanding,

[14]Note that matching techniques do not ensure that the parallel trend assumption will be satisfied a priori as we do not match on the outcome variable ownership concentration.

residual maturity, coupon rate and type, guarantee and seniority as well as whether bond was issued recently collectively explain more than 55.5% of the variation in bond eligibility. This is rather high by matching standards, which suggests a good selection of explanatory variables.

(Insert Table 3 here)

The second step is to match the bonds using PSM procedure. PSM assigns a particular propensity score to each bond depending on how closely it approaches the characteristics of an average eligible bond. Our baseline PSM specification uses five nearest neighbors, which means that each individual eligible bond gets five non-eligible matches. Because each non-eligible bond may be used as a control several times, we end up with a rather well-balanced control group of 17,311 non-eligible bonds for a treatment group of 5,694 eligible bonds. PSM also generates weights for each individual bond, which are later used as analytical weights in the matching diff-in-diff regression (see futher Ho et al., 2007; Stuart et al., 2014).[15]

(Insert Figure 2 here)

After our matching procedure we are able to check whether, in the run-up to the PSPP, our constructed control group has a trend in concentration parallel to the treatment group. The graph of the trend is presented in Figure 2. Despite the level difference (eligible bonds are less concentrated than non-eligible bonds), the graph depicts a parallel downward sloping trend prior to 2015Q1 for both of the groups, ceteris paribus.

[15]Appendix 2 presents balancing test results that signify that the matching was able to produce a control group of non-eligible bonds that are comparable on observables to the PSPP-eligible bonds. Weights produced by PSM are always equal to 1 for eligible bonds and can be less or more than 1 for control bonds. The higher the number of times the bond was used for matching, the higher the corresponding weight. Minimum weight in five nearest neighbor procedure we observe is 0.2 and the maximum weight is 24.83, while the average weight is 0.66 (s.d. =1.01). The procedures yield very similar analytical weights to the five nearest neighbors when estimating the PSM with Kernel procedures (baseline and full) and one-nearest neighbors technique. The Pearson correlations across those weights are high (at least 0.72).

Given that we avoided matching on the outcome variable itself, this graph suggests that such control group is an appropriate benchmark to use in the diff-in-diff regression.

The last step of our methodology is to run a diff-in-diff regression. In our case, this is a simple OLS regression on the matched sample weighted by the analytical weights produced by the PSM. The diff-in-diff variables include a 'Treated' dummy for eligibility and an interaction term "Post x Treated", which is 1 for the group of eligible bonds after the start of PSPP and 0 for the three other groups (eligible before PSPP, and non-eligible before and after PSPP). Control variables are similar to those used in the PSM - bond residual maturity, size and type (coupon or fixed, newly issued or not, senior and guaranteed or not). Regressions also include time fixed effects as well as issuer country fixed effects and apply robust standard errors.

For the 'Post' period, we follow a two-step approach to study the role of signalling and implementation separately. The initial anticipation and speculation about sovereign debt purchases by Eurosystem began after the Jackson Hole speech by Draghi in August 2014. Further anticipation of quantitative easing followed in September 2014, together with the announcement of the ABS purchase program. Finally, the program was announced in January 2015, with implementation as of March 2015. Therefore, we define an early signalling period (2014Q3-2015Q1) as well as an 'anticipation period' from 2014-Q2 to 2014-Q4. In addition, we study the long-term effect of the implementation over the 'Post' implementation period 2015Q1-2016Q3. Our sample period starts one year before official PSPP announcement (2015Q1) in order to test for potential signalling effects and it ends with the full start of Corporate Sector Purchase Program (CSPP) implementation (2016Q3) in order to isolate the PSPP effects, i.e. not face contamination of our controls.

To understand the impact of the PSPP on the underlying market structure of the European bond market we study ownership concentration at the individual bond level. Ownership concentration is a measure of the dispersion among bond holders, and, is informative about the network structure of individual bond holdings. More formally, we

estimate the following:

$$HHI_{i,t} = \beta_0 + \beta_1 Post_t * Eligible_{i,t} + \beta_2 Eligible_{i,t} + \beta_k X_{i,t} + \epsilon_{i,t} \tag{5}$$

where market concentration is calculated using the Hirschman-Herfindahl index:

$$HHI_i = \sum_{i=1}^{n} share_i^2 \tag{6}$$

where *share* represents the share of bond i total amount outstanding held by an investor from sector s from holder country j. The average ownership concentration of 17,311 matched non-eligible bonds over the full sample period is 0.54 while that of the PSPP-eligible bonds is 0.37 (see Figure 2).

Our main variable of interest in this equation is the difference-in-difference term $Post{*}Eligible$ which signifies whether after the event period the ownership concentration of the targeted assets by the Eurosystem changed more than the control group for a given period. In a classical difference-in-differences terms, β_1 captures the change in the ownership concentration, from the pre-treatment to the post-treatment period, for the treatment group relative to the control group. A positive coefficient for β_1 would imply that ceteris paribus, the market concentration of the eligible sovereign debt increased.

5 Main results

In this section we analyze the impact of the PSPP during the signalling period and the implementation period using a difference-in-difference model with a matched control group. The results in Table 4 Columns (1) and (2) show that for the signalling period (2014Q2-2015Q1) the ownership concentration of the eligible assets did no change differently from the control group. Columns (3) and (4) further indicate that for the anticipation period 2014Q2-2014Q4 there also was no effect of the PSPP on concentration.

(Insert Table 4 here)

Furthermore, the results in Table 4 suggest that the market concentration of the PSPP-eligible instruments is generally lower than the control group, about 2.76 to 3.06 percentage points. After matching, the bonds with a higher amount outstanding have on average a lower degree of concentration. By contrast, bonds with a longer residual maturity tend to be held in a more concentrated fashion. We also find that higher coupon rates, fixed coupons, newly issued bonds and bonds with underlying guarantees are associated with lower concentration levels and held more broadly across different investors. We find no effect of higher seniority on the dispersion of bond ownership. Overall, our model tends to explain over half of the variation of ownership dispersion at the individual bond level.

For the period of actual purchases, in Table 5 we find that bond concentration increased for the PSPP-eligible assets during the implementation period 2015Q1-2016Q3 against the control group. Column (1) shows that the Eurosystem purchases increased market concentration of these bonds by about 4 percentage points. Columns (2) to (4) use different matching techniques for our control group and tend to confirm this result, although the estimated impact is slightly lower. In contrast to the main results for the signalling period in Table 3, here we find that during the implementation period the individual ownership concentration of the assets targeted by the Eurosystem increased significantly. In economic terms, the estimated increase of about 4 percentage points is somewhat large given that the market concentration of eligible sovereign bonds was 0.37 in 2015Q1.

(Insert Table 5 here)

For the control variables, in Table 5 for the implementation period we find similar contributions to the overall level of concentration for the signalling period. The only exception is that now we find that bonds with a higher seniority tend to have a higher

level of concentration, while the previous results showed no significant role of seniority. Overall, again our estimated model captures more than half of the variation of individual bond concentration levels. To conclude, our empirical findings show no impact of the PSPP until the start of the actual purchases, which increase ownership concentration.

There are nonetheless several potential limitations to this interpretation. First, although we benefit from using an extensive dataset with global bond portfolios we still do not observe individual investor's portfolio positions. Our sectoral decomposition should capture well the aggregate behavior of individual investors when investors within a sector from a given country tend respond to some extent similarly to quantitative easing. Still, from the perspective of systemic risk and financial stability our analysis at the sectoral level is most relevant. Second, Eurosystem holdings are not observed, but does this affect our result? We have shown that our simulation process accurately captures the asset purchases in terms of size and weighted average maturity. Moreover, our findings are the same without the simulated Eurosystem holdings. Third, the use of diff-in-diff strongly relies on a parallel trend assumption, however, for the pre-signalling period (2014Q2-2014Q3) when the market may have started to anticipate the PSPP we are left with only one 'pre' period such that we cannot ensure this assumption is satisfied. Lastly, our constructed control group may have been affected by the treatment, which is a general concern in the literature testing the effects of QE. Our estimation strategy may either underestimate or overestimate the effect of the actual purchases depending on how the portfolio rebalancing works across different investors and asset classes.

6 Extensions

6.1 Short and medium term impact of the PSPP

In this section we analyze the impact of the PSPP over a shorter time frame than in Table 5. The question is what the short and medium term effects of the PSPP on concentration

were, defined as an effect of half a year and one year after the initial implementation. These two periods are also important in light of the announcement of the Corporate Sector Purchase Programme (CSPP) at the end of 2016Q1. This policy led to changes in the PSPP as well as purchases of corporate bonds. The latter are part of our control group and thus concerns over contamination may arise. To prevent the CSPP affecting our results, the shorter and medium term effects provide arguably a clearer test of the impact of the PSPP, albeit over a shorter time frame.

Table 6, Columns (1) and (2) show that in the medium term (2015Q1-2016Q1) the PSPP increased concentration by a range of 3.95 to 4.16 percentage points, which is comparable to the impact found in the main results for the longer term (3.99 to 4.32 percentage points in Table 5). Columns (3) and (4) indicate that the short term impact (2015Q1-2015Q3) before any program adjustments of the PSPP also increased concentration by about 3.71 to 3.75 percentage points. Our interpretation is that the PSPP had a rather direct and persistent effect on the distribution of individual bond ownership and has had a tendency to steadily raise the market concentration.[16]

(Insert Table 6 here)

6.2 Vulnerable and non-vulnerable countries

The impact of the PSPP may differ across vulnerable and non-vulnerable countries. We are interested in whether the increase in concentration is stronger for sovereign debt issued by vulnerable governments.[17] First, we re-estimate the main model and include an additional interaction term for vulnerable issuers in the 'Post $*$ Treated'

[16]The fact that the difference in increased concentration for the medium term (2015Q1-2016Q1) and the longer term (2015Q1-2016Q3) are not so large may be attributed to the CSPP, which potentially also had a similar effect on the market concentration of corporate bonds. If so, our results for the period after 2016Q1 are underestimated.

[17]We define vulnerable sovereign debt as those bond issued by governments from Ireland, Italy, Portugal, Slovenia and Spain. Cyprus and Greece were not eligible under the PSPP and are thus not included in the analysis.

condition in both the nearest neighbor and kernel matched controls for the difference-in-difference estimation. In addition, we analyze subsamples of vulnerable and non-vulnerable countries for expositional purposes.

The results in Table 7 Column (1) and (2) replicate our main finding that the PSPP increased concentration in the targeted sovereign bonds. The interaction with vulnerable sovereigns is positive and significant, suggesting that the level of bond concentration increased even more for the eligible sovereign debt of vulnerable countries. In addition, our expositions of subsamples in Columns (3) to (6) present similar outcomes. Here we find that the estimated coefficient for the 'Post $*$ Treated' tends to be much larger for vulnerable countries. In Column (5) the estimated effect of the PSPP on bond concentration among non-vulnerable countries is even insignificant, albeit positive ($p < 0.10$). From this analysis we conclude that the PSPP increased bond ownership concentration among euro area sovereign debt in general, and even more for vulnerable countries. One explanation is that the portfolio rebalancing channel was more pronounced in these economies (Albertazzi et al., 2016).

(Insert Table 7 here)

6.3 Alternative market concentration measures

Our measure of ownership concentration relies on the application of the HHI. In the literature, some other measures are applied which we can also test. We present only the additional results for the long term implementation period (2015Q1-2016Q3) comparable with our main result from Table 5. First, we define market concentration by counting the number of investor sectors for a given bond (Jacoby and Zheng, 2010). Second, we take a ten percent control cut-off to indicate a blockholder (Attig et al., 2006; Rubin, 2007). Third, we propose studying the degree of home bias as it captures the degree to which non-domestic investors are willing to hold the bond.

The results in Table 8 generally confirm the main results. That is, Column (1) shows that after the implementation of the PSPP the number of investor sectors in eligible sovereigns decreased by about 4.88, thus indicating a higher market concentration. Column (2) suggests that the share of investor sectors with ten percent or more holdings of a single bond increased by 1.88 percentage points, also thus confirming that the dispersion of sovereign bond ownership was reduced by the PSPP compared to other bonds. Finally, for the home bias measure we find not effect. This suggests that the increase in concentration is not explained by domestic investors unwilling to sell to the Eurosystem or even that these domestic investors increased their domestic holdings of PSPP-eligibles. This insignificant result does not contradict our main findings.

(Insert Table 8 here)

6.4 Further robustness checks

For robustness purposes we performed several additional checks not reported here but still worthy of mention. First, the focus of the paper is on the purchases of sovereign debt under the PSPP but we can easily expand the set of eligible bonds with the other PSPP-eligible instruments to include regional agencies and supranational institutions. Doing so yields similar results, i.e. no impact of the PSPP before it implementation, but a significant increase in market concentration as actual purchases were initiated.

Second, our results rely on a measure of market concentration that includes Eurosystem holdings. We can re-estimate the level of ownership concentration excluding the Eurosystem. Again, this yields us similar findings, suggesting that the increase in concentration is not an artifact of our simulation nor solely due to the dominance of a relatively new player, the Eurosytem, becomes dominant, but also because the micro market structure of bond holdings in other sectors became less dispersed.

Third, our treatment group, the eligible PSPP sovereign bonds, changes slightly over time because of changing criteria and market dynamics. In most diff-in-diff models, the

treatment is fixed over time. As a robustness test we assigned a fixed-time eligibility criterium as of January 2015 and did not allow for changes in eligibility status, other than new bonds that are issued could either qualify or not under those original requirements. Our main results are not affected by this time-varying eligibility status.

Fourth, we rerun our analysis using a subsample in which we exclude investor sectors from small countries. Here, we focus only on the five largest investor countries (DE, ES, FR, IT and NL). Doing so does not affect our main findings, although this exercise significantly reduces the number of observations and leads to insignificant results for the short-term effect of market concentration.

Finally, our presented findings are based on matching techniques relying on five nearest neighbors and full Kernel procedures. However, when we apply one-nearest neighbor and Kernel base the main findings are robust. Although the power of the one-nearest neighbor is much smaller (only 7,520 observations) this still leads to a highly significant long-term effect of about 3.01 percentage point of the PSPP implementation on the increased market concentration.

7 Conclusion

While the explicit aim of quantitative easing is to affect yields, our paper analyzes how such policies can have (un)intended consequences for the micro market structure. In particular, we argue that market concentration is amplified by large-scale asset purchase programs. Such result is not self-evident because investors with large positions in PSPP-eligible sovereign bonds prior to QE may very well be those investors selling government debt to the central banks. Taking advantage of portfolio holdings data at the individual security level, the empirical results based on a difference-in-difference model show that the PSPP increased bond market concentration of sovereign bonds when the Eurosystem purchases were initiated. Our study highlights that the actual asset purchases affect

the market concentration, but anticipations and announcements of quantitative easing programs do not affect the dispersion of bond holdings immediately.

Our results emphasize the importance of 'flow' effects and are in line with the portfolio rebalancing channel. The findings suggest that as only certain investors sell bonds to central banks, the investor base of those bonds steadily declines along with the asset purchases. Based on recent insights from the literature on the effects of large-scale asset purchase programs we argue that increased ownership concentration of sovereign bonds could increase the financial fragility. First, the increased market concentration may be the result of growing scarcity of assets as scholars have shown that the actual purchases affect bond scarcity (D'Amico et al., 2015; Schlepper et al., 2017). A second and related factor is that greater scarcity during the implementation period drives down bond yields but negatively affects market liquidity (Pelizzon et al., 2017). Third, these factors combined could well be connected to greater market volatility and may thus hold important lessons for the possible effects of tapering.

References

Abadie, A. (2005). Semiparametric difference-in-differences estimators, *The Review of Economic Studies* **72**(1): 1–19.

Albertazzi, U., Becker, B. and Boucinha, M. (2016). Portfolio rebalancing and the transmission of large-scale asset programs: Evidence from the euro area, *Mimeo* .

Allen, F., Babus, A. and Carletti, E. (2012). Asset commonality, debt maturity and systemic risk, *Journal of Financial Economics* **104**(3): 519–534.

Altavilla, C., Carboni, G. and Motto, R. (2015). Asset purchase programmes and financial markets: Lessons from the euro area, *ECB Working Paper No.* **1864**.

Ammer, J., Claessens, S., Tabova, A. and Wroblewski, C. (2018). Searching for yield abroad: Risk-taking through foreign investment in US bonds, *BIS Working Papers No.* **687**.

Andrade, P., Breckenfelder, J. H., De Fiore, F., Karadi, P. and Tristani, O. (2016). The ECB's asset purchase programme: An early assessment, *ECB Working Paper No.* **1956**.

Arrata, W. and Nguyen, B. (2017). Price impact of bond supply shocks: Evidence from the eurosystem's asset purchase program, *Banque de France Working Paper* **623**.

Arslanalp, M. S. and Botman, D. P. (2015). Portfolio rebalancing in Japan: Constraints and implications for quantitative easing, *IMF Working Paper No.* **186**(15-186).

Attig, N., Fong, W. M., Gadhoum, Y. and Lang, L. H. (2006). Effects of large shareholding on information asymmetry and stock liquidity, *Journal of Banking & Finance* **30**(10): 2875–2892.

Azar, J., Schmalz, M. C. and Tecu, I. (2017). Why common ownership creates antitrust risks, *Mimeo* .

Bauer, M. D. and Rudebusch, G. D. (2014). The signaling channel for Federal Reserve bond purchases, *International Journal of Central Banking* **10**(3): 233–289.

Bebchuk, L. A., Cohen, A. and Hirst, S. (2017). The agency problems of institutional investors, *Journal of Economic Perspectives* **31**(3): 89–102.

Becker, B. and Ivashina, V. (2015). Reaching for yield in the bond market, *The Journal of Finance* **70**(5): 1863–1902.

Boermans, M. A., Frost, J. and Steins Bisschop, S. S. (2016). European bond markets: Do illiquidity and concentration aggravate price shocks?, *Economics Letters* **141**: 143–146.

Boermans, M. A. and Vermeulen, R. (2018). Quantitative easing and preferred habitat investors in the euro area bond market, *DNB Working Paper No.* **586**.

Braverman, A. and Minca, A. (2014). Networks of common asset holdings: Aggregation and measures of vulnerability, *Mimeo* .

Brockman, P., Chung, D. Y. and Yan, X. S. (2009). Block ownership, trading activity, and market liquidity, *Journal of Financial and Quantitative Analysis* **44**(6): 1403–1426.

Cai, F., Han, S., Li, D. and Li, Y. (2018). Institutional herding and its price impact: Evidence from the corporate bond market, *Journal of Financial Economics* .

Carpenter, S., Demiralp, S., Ihrig, J. and Klee, E. (2015). Analyzing Federal Reserve asset purchases: From whom does the Fed buy?, *Journal of Banking & Finance* **52**: 230–244.

Christensen, J. H. and Gillan, J. M. (2018). Does quantitative easing affect market liquidity?, *Federal Reserve Bank of San Francisco Working Paper* **2013-26**.

Christensen, J. H. and Rudebusch, G. D. (2012). The response of interest rates to U.S. and U.K. quantitative easing, *Economic Journal* **122**: 385–414.

D'Amico, S., English, W., López-Salido, D. and Nelson, E. (2012). The Federal Reserve's large-scale asset purchase programmes: Rationale and effects, *The Economic Journal* **122**(564).

D'Amico, S., Fan, R. and Kitsul, Y. (2015). The scarcity value of treasury collateral: Repo market effects of security-specific supply and demand factors, *Mimeo* .

D'Amico, S. and King, T. B. (2013). Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply, *Journal of Financial Economics* **108**(2): 425–448.

De Santis, R. A. (2016). Impact of the asset purchase programme on euro area government bond yields using market news, *ECB Working Paper No.* **1939**.

Domanski, D., Shin, H. S. and Sushko, V. (2017). The hunt for yield: Not waving but drowning?, *IMF Economic Review* **65**: 113–153.

ECB (2015). Who holds what? New information on securities holdings, *Economic Bulletin* **2**: 72–84.

Ferdinandusse, M., Freier, M. and Ristiniemi, A. (2017). Quantitative easing and the price-liquidity trade-off, *Sveriges Riksbank Working Paper Series No.* **335**.

Fukunaga, I., Kato, N. and Koeda, J. (2015). Maturity structure and supply factors in Japanese government bond markets, *Monetary and Economic Studies* **4**: 45–96.

Gagnon, J., Raskin, M., Remache, J. and Sack, B. (2011). The financial market effects of the Federal Reserve large-scale asset purchases, *International Journal of Central Banking* **7**(1): 3–43.

Getmansky, M., Girardi, G., Hanley, K. W., Nikolova, S. and Pelizzon, L. (2017). Portfolio similarity and asset liquidation in the insurance industry, *Mimeo* .

Hamilton, J. D. and Wu, J. C. (2012). The effectiveness of alternative monetary policy tools in a zero lower bound environment, *Journal of Money, Credit and Banking* **44**(s1): 3–46.

Ho, D. E., Imai, K., King, G. and Stuart, E. A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference, *Political analysis* **15**(3): 199–236.

Hüser, A.-C., Hałaj, G., Kok, C., Perales, C. and van der Kraaij, A. (2017). The systemic implications of bail-in: A multi-layered network approach, *Journal of Financial Stability* .

IMF (2015). Euro area policies: Selected issues, *IMF Country Report* **15**(205).

Iwatsubo, K. and Taishi, T. (2017). Quantitative easing and liquidity in the japanese government bond market, *International Review of Finance* .

Jacoby, G. and Zheng, S. X. (2010). Ownership dispersion and market liquidity, *International Review of Financial Analysis* **19**(2): 81–88.

Joyce, M. A., Liu, Z. and Tonks, I. (2017). Institutional investors and the QE portfolio balance channel, *Journal of Money, Credit and Banking* **49**(6): 1225–1246.

Joyce, M. A. and Tong, M. (2012). QE and the gilt market: A disaggregated analysis, *The Economic Journal* **122**(564).

Joyce, M., Lasaosa, A., Stevens, I., Tong, M. et al. (2011). The financial market impact of quantitative easing in the United Kingdom, *International Journal of Central Banking* **7**(3): 113–161.

Joyce, M., Miles, D., Scott, A. and Vayanos, D. (2012). Quantitative easing and unconventional monetary policy–an introduction, *The Economic Journal* **122**(564).

Kandrac, J. and Schlusche, B. (2013). Flow effects of large-scale asset purchases, *Economics Letters* **121**(2): 330–335.

Koijen, R., Koulischer, F., Nguyen, B. and Yogo, M. (2016). Quantitative easing in the euro area: The dynamics of risk exposures and the impact on asset prices, *Banque de France Working Paper No.* **601**.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2011). The effects of quantitative easing on interest rates: Channels and implications for policy, *Brookings Papers on Economic Activity* **2**: 215–287.

Lechner, M. (2011). The estimation of causal effects by difference-in-difference methods, *Foundations and Trends in Econometrics* **4**(3): 165–224.

Lelyveld, I., Schaumburg, J. and Wang, D. (2018). Fire-sale channels, portfolio overlap networks and the credit spread puzzle, *Mimeo* .

McLaren, N., Banerjee, R. N. and Latto, D. (2014). Using changes in auction maturity sectors to help identify the impact of QE on gilt yields, *The Economic Journal* **124**(576): 453–479.

Nanda, V., Wu, W. and Zhou, X. (2017). Investment commonality across insurance companies: Fire sale risk and corporate yield spreads, *Mimeo* .

Neely, C. J. (2015). Unconventional monetary policy had large international effects, *Journal of Banking & Finance* **52**: 101–111.

Oda, N. and Ueda, K. (2007). The effects of the Bank of Japan's zero interest rate commitment and quantitative monetary easing on the yield curve: A macro-finance approach, *The Japanese Economic Review* **58**(3): 303–328.

Pelizzon, L., Subrahmanyam, M., Tobe, R. and Uno, J. (2017). Scarcity and spotlight effects on term structure: Quantitative easing in Japan, *Mimeo* .

Pesaran, M. H. and Smith, R. P. (2016). Counterfactual analysis in macroeconometrics: An empirical investigation into the effects of quantitative easing, *Research in Economics* **70**(2): 262–280.

Rubin, A. (2007). Ownership level, ownership concentration and liquidity, *Journal of Financial Markets* **10**(3): 219–248.

Schlepper, K., Hofer, H., Riordan, R. and Schrimpf, A. (2017). Scarcity effects of QE: A transaction-level analysis in the Bund market, *BIS Working Paper No.* **625**.

Strohsal, T. (2017). Bond yields and debt supply: new evidence through the lens of a preferred-habitat model, *Quantitative Finance* **17**(10): 1509–1522.

Stuart, E. A., Huskamp, H. A., Duckworth, K., Simmons, J., Song, Z., Chernew, M. E. and Barry, C. L. (2014). Using propensity scores in difference-in-differences models to estimate the effects of a policy change, *Health Services and Outcomes Research Methodology* **14**(4): 166–182.

Thornton, D. L. (2014). QE: Is there a portfolio balance effect?, *Federal Reserve Bank of St. Louis Review* **96**(1): 55–72.

Ugai, H. (2007). Effects of the quantitative easing policy: A survey of empirical analyses, *Monetary and Economic Studies* **25**.

Valiante, D. (2017). The 'visible hand' of the ECB's first quantitative easing, *International Economics and Economic Policy* **14**(4): 601–624.

Vayanos, D. and Vila, J. (2009). A preferred-habitat model of the term structure of interest rates, *NBER Working Paper No.* **15487**.

A Appendix 1: Eurosystem holdings simulations

In this Appendix 1 we provide further details on the outcomes of the simulation process. Table A.1 show for each issuer country the total simulated amount of purchases by the Eurosystem over time. The last two rows of the table show the aggregated simulated holdings and the actual holdings.

Table A.2. presents these outcomes in terms of the weighted average maturity of the simulated portfolios. To compare how closely our simulation approaches the actual purchase distribution over maturity curve, we also compare the official weighted average maturity (WAM) to the weighted average maturity of our simulated holdings. The maturity of our bonds is somewhat longer than the actual purchases, with the mismatch slowly increasing over time. It implies that the actual purchases may not have been conducted fully in proportion to the bond amount outstanding. Our simulated results yield an unweighed average WAM across euro area governments of 9.33 whereas the actual purchased stock had an unweighted average WAM of 8.38.

Note that these totals exclude two countries. For Estonia and Lithuania we were not able to allocate the Eurosystem holdings accurately because either the observed share including the Eurosystem holdings reached unity or the Eurosystem maximum share of the simulated holdings for that time period was reached (either 0.25 of 0.33). In addition, it could well be that our observed universe of bonds did not reach the restriction of 0.3 as euro area ownership share. These two countries are dropped from the full sample.

Additional results of the simulation are presented in Table A.2. In line with our restrictions, one can see that observed share has a minimum of 0.3. The average observed share of the PSPP-eligible bonds is much higher at about 0.77. The average maximum share corresponding to that observed share is 0.18, with a legal maximum of 0.33 on the individual bond issue. The adjustment ratio that brings the maximum share in line with the actual purchase stands at about 0.47. It means that the final holdings by

the Eurosystem are on average twice as low as the maximum holdings that we could simulate in our dataset by relying on the limits alone. Once we reach the limit of 1 our set of bonds do not allow for any further PSPP purchases. Taking the actual aggregate holdings into account and using them to populate our granular data allows us to arrive at the accurate simulation results.

(Insert Table A.1 here)

(Insert Table A.2 here)

(Insert Table A.3 here)

B Appendix 2: Quality of the matching: balance tests

Appendix 2 shows the outcome of our matching procedure. Ex ante, as shown in Table 1, the characteristics of PSPP-eligible bonds and non-eligible bonds are very different. Here we present more details on these difference and show how well our matching takes care of minimize the difference across the treatment and control group.

Table B.1 shows the results of the balance test. As can be seen in the 'Matched' rows, practically all ex ante differences disappear because of the matching. Only for the last three dummies (newly issued, seniority and guaranteed) the differences after matching between the PSPP-eligible bonds and non-eligibles remains significant, although the gap is very much reduced.

(Insert Table B.1 here)

Table 1: Descriptives of main variables

Panel A: Full sample	n	mean	s.d.	min	max
BondSize	540,990	16.51	18.53	13.82	24.57
Resid.mat.	540,990	6.74	1.28	0	11.13
Couponrate	540,990	2.33	1.79	0	8.30
Fixedcoupon	540,990	0.59	0.49	0	1.00
Newlyissued	540,990	0.17	0.38	0	1.00
Senior	540,990	0.87	0.34	0	1.00
Guaranteed	540,990	0.20	0.40	0	1.00
Panel B: PSPP-eligible bonds	n	mean	s.d.	min	max
BondSize	5,769	20.81	28.58	13.86	24.49
Resid.mat.	5,769	7.84	0.73	0	9.33
Couponrate	5,769	2.63	1.99	0	8.30
Fixedcoupon	5,769	0.84	0.36	0	1.00
Newlyissued	5,769	0.12	0.33	0	1.00
Senior	5,769	0.96	0.18	0	1.00
Guaranteed	5,769	0.11	0.31	0	1.00

Table 2: Outcome of simulation Eurosystem holdings

Time	PSPP Holdings	Max. share	Adj. ratio	Final share
2015-Q1	42	0.17	0.06	0.01
2015-Q2	173	0.17	0.23	0.04
2015-Q3	300	0.18	0.38	0.07
2015-Q4	431	0.18	0.52	0.09
2016-Q1	501	0.17	0.67	0.12
2016-Q2	642	0.21	0.74	0.15
2016-Q3	679	0.22	0.82	0.18

Table 3: Matching results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BondSize	0.376***	0.374***	0.408***	0.406***	0.406***	0.423***	0.417***	0.426***
	[0.004]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]
Resid.mat.		0.370***	0.384***	0.401***	0.412***	0.448***	0.462***	0.455***
		[0.006]	[0.006]	[0.007]	[0.006]	[0.007]	[0.008]	[0.008]
Couponrate			-0.107***	-0.147***	-0.158***	-0.189***	-0.183***	-0.178***
			[0.004]	[0.005]	[0.005]	[0.005]	[0.005]	[0.006]
Fixedcoupon				0.517***	0.538***	0.534***	0.504***	0.534***
				[0.020]	[0.020]	[0.020]	[0.021]	[0.021]
Newlyissued					-0.328***	-0.379***	-0.380***	-0.386***
					[0.021]	[0.021]	[0.021]	[0.021]
Senior							0.340***	0.393***
							[0.043]	[0.044]
Guaranteed								-0.601***
								[0.024]
Constant	-8.346***	-11.006***	-11.401***	-11.849***	-11.875***	-11.951***	-12.252***	-12.359***
	[0.088]	[0.110]	[0.120]	[0.117]	[0.117]	[0.126]	[0.146]	[0.146]
Observations	595,908	590,765	540,086	540,086	540,086	487,902	487,902	487,902
Pseudo R^2	0.434	0.481	0.497	0.509	0.513	0.542	0.545	0.555

Table 4: Main results: Impact of PSPP on bond concentration, signalling period

	(1)	(2)	(3)	(4)
	Kernel	5 Neighbors	Kernel	5 Neighbors
	Signalling	Signalling	Early Signalling	Early Signalling
$Post * Eligible$	0.0243	0.0226	0.0120	0.0119
	[0.015]	[0.015]	[0.018]	[0.016]
$Eligible$	-0.0276**	-0.0306***	-0.0272**	-0.0284**
	[0.012]	[0.011]	[0.012]	[0.011]
$BondSize$	-0.0790***	-0.0844***	-0.0779***	-0.0862***
	[0.001]	[0.002]	[0.001]	[0.002]
$Resid.mat.$	0.0274***	0.0229***	0.0322***	0.0246***
	[0.004]	[0.004]	[0.004]	[0.005]
$Couponrate$	-0.0113***	-0.0081***	-0.0122***	-0.0077***
	[0.002]	[0.002]	[0.002]	[0.003]
$Fixedcoupon$	-0.1296***	-0.1538***	-0.1371***	-0.1532***
	[0.013]	[0.013]	[0.015]	[0.014]
$Newlyissued$	-0.0311**	-0.0347**	-0.0320*	-0.0461***
	[0.015]	[0.014]	[0.019]	[0.016]
$Senior$	-0.0303	-0.0238	-0.0319	-0.0283
	[0.020]	[0.019]	[0.023]	[0.022]
$Guaranteed$	-0.0167**	-0.0216**	-0.0171*	-0.0226**
	[0.008]	[0.010]	[0.009]	[0.011]
Constant	1.6518***	2.0336***	1.8199***	1.8061***
	[0.042]	[0.052]	[0.041]	[0.054]
Issuer country FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Observations	234,786	8,254	189,810	6,697
R-squared	0.541	0.529	0.532	0.528

Table 5: Main results: Impact PSPP on bond concentration, implementation period

	(1)	(2)	(3)	(4)
	5 Neighbors	Kernel Full	1 Nearest	Kernel Base
Post $*$ *Eligible*	0.0399***	0.0432***	0.0301**	0.0228**
	[0.013]	[0.012]	[0.012]	[0.010]
Eligible	-0.0464***	-0.0395***	-0.0282***	-0.0213**
	[0.012]	[0.011]	[0.010]	[0.009]
BondSize	-0.0834***	-0.0779***	-0.0840***	-0.0818***
	[0.001]	[0.001]	[0.001]	[0.001]
Resid.mat.	0.0121***	0.0147***	0.0191***	0.0135***
	[0.004]	[0.003]	[0.003]	[0.003]
Couponrate	-0.0053***	-0.0074***	-0.0060***	-0.0091***
	[0.002]	[0.001]	[0.002]	[0.001]
Fixedcoupon	-0.1409***	-0.1188***	-0.1121***	-0.1233***
	[0.011]	[0.010]	[0.009]	[0.010]
Newlyissued	-0.0363***	-0.0353***	-0.0409***	-0.0213**
	[0.007]	[0.008]	[0.009]	[0.010]
Senior	0.0398***	0.0281**	-0.0164	-0.0120
	[0.015]	[0.014]	[0.014]	[0.015]
Guaranteed	-0.0296***	-0.0217***	-0.0074	-0.0266***
	[0.007]	[0.006]	[0.009]	[0.006]
Constant	2.0436***	1.8892***	2.2005***	1.7289***
	[0.043]	[0.025]	[0.047]	[0.031]
Issuer country FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Observations	17,311	487,837	7,520	375,136
R-squared	0.522	0.544	0.482	0.556

Table 6: Short and medium term impact of the PSPP

	(1)	(2)	(3)	(4)
	Kernel	5 Neighbors	Kernel	5 Neighbors
	Before 16Q1	Before 16Q1	Before 15Q3	Before 15Q3
Post $*$ *Eligible*	0.0395***	0.0416***	0.0371***	0.0375***
	[0.012]	[0.012]	[0.012]	[0.012]
Eligible	-0.0353***	-0.0419***	-0.0234***	-0.0337***
	[0.010]	[0.010]	[0.009]	[0.009]
BondSize	-0.0775***	-0.0827***	-0.0796***	-0.0852***
	[0.001]	[0.001]	[0.001]	[0.001]
Resid.mat.	0.0163***	0.0113***	0.0219***	0.0201***
	[0.003]	[0.004]	[0.003]	[0.004]
Couponrate	-0.0083***	-0.0054***	-0.0102***	-0.0080***
	[0.002]	[0.002]	[0.002]	[0.002]
Fixedcoupon	-0.1250***	-0.1480***	-0.1225***	-0.1432***
	[0.011]	[0.012]	[0.011]	[0.011]
Newlyissued	-0.0351***	-0.0370***	-0.0283***	-0.0398***
	[0.009]	[0.009]	[0.011]	[0.011]
Senior	0.0069	0.0235	-0.0196	-0.0167
	[0.016]	[0.017]	[0.017]	[0.017]
Guaranteed	-0.0203***	-0.0254***	-0.0194***	-0.0231***
	[0.006]	[0.008]	[0.007]	[0.008]
Constant	1.8837***	2.0446***	1.8494***	1.8686***
	[0.028]	[0.045]	[0.031]	[0.058]
Issuer Country FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Observations	406,187	14,650	321,208	11,311
R-squared	0.544	0.519	0.549	0.534

Table 7: Impact PSPP on bond concentration, vulnerable vs non-vulnerable issuers

	(a)	(b)	(a)	(a)	(b)	(b)
	Dummy	Dummy	Vulnerable	Non-vuln.	Vulnerable	Non-vuln.
$Post * Eligible$	0.0332**	0.0401***	0.0788***	0.0255	0.0669***	0.0341**
	[0.013]	[0.012]	[0.016]	[0.016]	[0.014]	[0.015]
$Eligible$	-0.0463***	-0.0395***	-0.0409***	-0.0476***	-0.0377***	-0.0387***
	[0.012]	[0.011]	[0.015]	[0.015]	[0.014]	[0.014]
$Post * Elig. * Vuln.$	0.0188*	0.0087				
	[0.010]	[0.009]				
$Vulnerable$	0.1662***	0.1443***				
	[0.022]	[0.015]				
$BondSize$	-0.0835***	-0.0780***	-0.0847***	-0.0846***	-0.0788***	-0.0780***
	[0.001]	[0.001]	[0.002]	[0.002]	[0.001]	[0.001]
$Resid.mat.$	0.0119***	0.0146***	-0.0088**	0.0205***	0.0044	0.0197***
	[0.004]	[0.003]	[0.004]	[0.005]	[0.003]	[0.004]
$Couponrate$	-0.0055***	-0.0075***	-0.0007	-0.0082***	-0.0036*	-0.0100***
	[0.002]	[0.001]	[0.002]	[0.002]	[0.002]	[0.002]
$Fixedcoupon$	-0.1409***	-0.1187***	-0.1421***	-0.1447***	-0.1123***	-0.1251***
	[0.011]	[0.010]	[0.012]	[0.017]	[0.010]	[0.014]
$Newlyissued$	-0.0370***	-0.0356***	-0.0271**	-0.0430***	-0.0271***	-0.0400***
	[0.007]	[0.008]	[0.011]	[0.010]	[0.010]	[0.011]
$Senior$	0.0396**	0.0282**	-0.0336	0.0548***	-0.0154	0.0379**
	[0.015]	[0.014]	[0.023]	[0.018]	[0.020]	[0.017]
$Guaranteed$	-0.0291***	-0.0214***	-0.0881***	-0.0197**	-0.0362***	-0.0179**
	[0.007]	[0.006]	[0.017]	[0.008]	[0.010]	[0.007]
Constant	2.0494***	1.8916***	2.2420***	1.9803***	2.1468***	1.9324***
	[0.043]	[0.025]	[0.064]	[0.050]	[0.039]	[0.036]
Issuer country FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
Observations	17,311	487,837	5,969	11,342	192,045	295,792
R-squared	0.522	0.544	0.490	0.539	0.557	0.540

Note: (a) using five nearest neighbor matching weights, (b) using base Kernel matching procedure weights.

Table 8: Alternative measures: Impact implementation period

Alternative Measures	(1)	(2)	(3)
	No. of holders	Share of blockholders (10%)	Ratio home bias
Post ∗ *Eligible*	-4.8883***	0.0188***	0.0186
	[0.941]	[0.005]	[0.012]
Eligible	9.4947***	-0.0145***	0.0085
	[0.831]	[0.005]	[0.010]
BondSize	10.4382***	-0.0404***	-0.0639***
	[0.086]	[0.000]	[0.001]
Resid.mat.	-6.0853***	0.0219***	-0.0094***
	[0.203]	[0.001]	[0.003]
Couponrate	2.0762***	-0.0012*	0.0014
	[0.120]	[0.001]	[0.002]
Fixedcoupon	10.2974***	-0.0490***	-0.1007***
	[0.664]	[0.004]	[0.009]
Newlyissued	3.0888***	-0.0194***	-0.0417***
	[0.601]	[0.003]	[0.007]
Senior	-3.4118***	0.0132***	0.0458***
	[0.935]	[0.005]	[0.015]
Guaranteed	2.0650***	-0.0243***	-0.0955***
	[0.611]	[0.004]	[0.008]
Constant	-138.3613***	1.5013***	1.8890***
	[2.156]	[0.012]	[0.025]
Issuer country FE	YES	YES	YES
Time FE	YES	YES	YES
Observations	487,837	487,837	487,837
R-squared	0.792	0.674	0.528

Table A1: Eurosystem holdings, aggregated by country (simulated)

	2015Q1	2015Q2	2015Q3	2015Q4	2016Q1	2016Q2	2016Q3
AT	1.2	5.0	8.7	12.6	14.8	17.0	18.2
BE	1.5	6.4	11.0	15.9	21.0	28.7	35.1
DE	11.1	46.3	80.1	116.2	148.3	194.9	207.6
ES	5.5	22.7	39.3	56.8	75.2	103.0	126.1
FI	0.8	3.2	5.6	8.1	10.7	14.0	13.6
FR	8.7	36.1	62.6	91.2	121.7	164.8	161.4
IE	0.7	3.0	5.2	7.6	10.0	13.3	15.9
IT	7.6	31.5	54.7	79.2	105.0	144.4	176.9
LU	0.2	0.7	1.0	1.1	1.0	0.9	1.9
LV	0.0	0.3	0.4	0.5	0.6	0.8	0.9
MT	0.0	0.1	0.2	0.2	0.3	0.4	0.4
NL	2.5	10.3	17.8	23.9	29.7	31.3	32.8
PT	1.1	4.5	7.7	11.2	14.8	19.1	21.8
SI	0.2	0.8	1.5	2.2	3.0	3.7	4.3
SK	0.5	2.1	3.4	4.5	5.2	7.1	7.3
Total (simulated)	41.6	173.0	299.2	431.2	561.3	743.4	824.2
Total (actual)	41.7	174.3	301.4	434.8	575.3	782.1	953.3

Table A2: Eurosystem holdings WAM, aggregated by country (simulated)

	2015Q1	2015Q2	2015Q3	2015Q4	2016Q1	2016Q2	2016Q3
AT	7.74	7.46	8.58	9.21	11.50	12.00	12.57
BE	12.84	11.37	13.35	12.87	13.36	14.21	14.18
DE	9.60	9.12	9.85	10.22	13.99	15.85	15.71
ES	9.21	9.28	8.99	8.82	9.10	9.52	9.51
FI	6.57	6.95	7.02	8.25	8.93	9.75	10.59
FR	9.14	9.05	8.84	9.44	10.48	11.25	13.00
IE	7.95	7.74	7.53	7.84	8.29	7.41	9.68
IT	9.54	9.65	9.71	9.36	9.72	9.84	9.78
LU	7.03	6.62	6.41	6.31	7.50	8.24	11.47
LV	6.79	6.47	6.73	6.20	6.40	7.80	7.66
MT	9.46	9.77	9.73	10.13	9.43	8.39	9.30
NL	8.38	8.69	7.74	10.31	12.44	14.26	14.03
PT	7.61	7.95	7.70	8.24	8.35	8.71	8.72
SI	7.62	7.28	8.41	8.06	9.05	8.81	9.71
SK	7.86	8.30	8.37	8.18	8.06	7.86	7.78
Total (simulated)	8.49	8.38	8.60	8.90	9.77	10.26	10.91
Total (actual)	8.51	8.39	8.24	8.25	8.27	8.47	8.52

Table A3: Descriptives of simulation Eurosystem holdings

Variable	Obs	Mean	Std. dev.	Min	Max
Obs. share	3,052	0.77	0.16	0.30	1.00
Max. share	3,052	0.18	0.10	0.00	0.33
Adj. ratio	3,052	0.47	0.30	0.01	1.00
Final share	3,052	0.09	0.09	0.00	0.33

Table B1: Balance test (five nearest neighbor matching results)

		PSPP-eligible	Non-eligible.
BondSize	Unmatched:	20.8	16.3
	Matched:	20.8	20.3
Resid.mat.	Unmatched:	7.8	6.7
	Matched:	7.8	7.7
Couponrate	Unmatched:	2.6	2.3
	Matched:	2.6	2.4
Fixed coupon	Unmatched:	84.0%	57.9%
	Matched:	83.8%	82.9%
Newlyissued	Unmatched:	12.9%	18.1%
	Matched:	12.9%	9.5%
Senior	Unmatched:	96.6%	86.5%
	Matched:	96.6%	91.8%
Guaranteed	Unmatched;	11.5%	21.0%
	Matched:	11.6%	10.3%

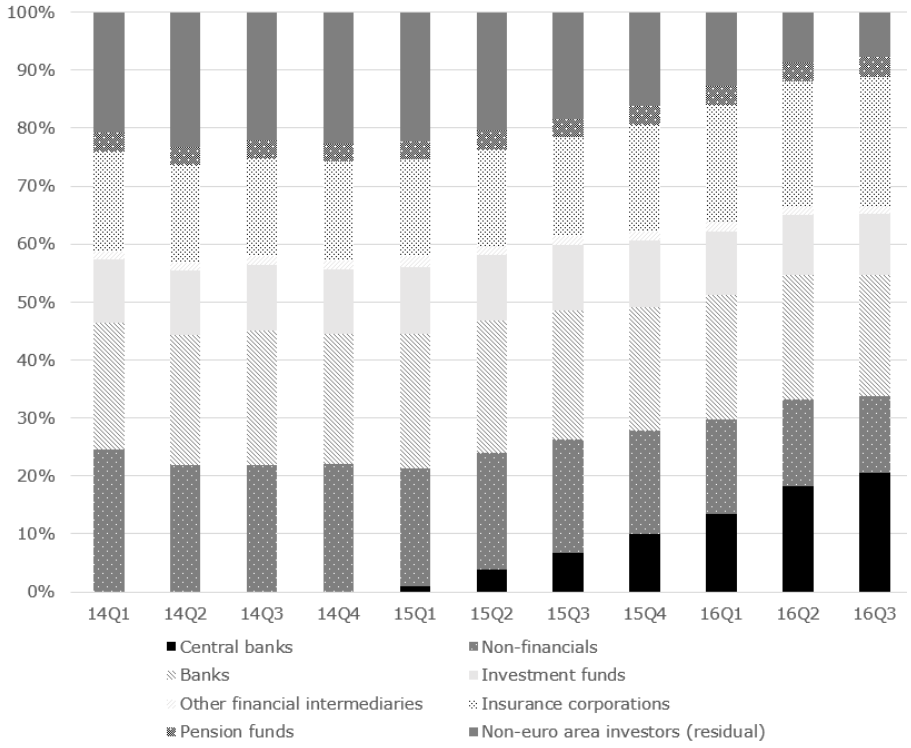

Figure 1: Aggregated shares of sectoral holdings of PSPP-eligible debt over time

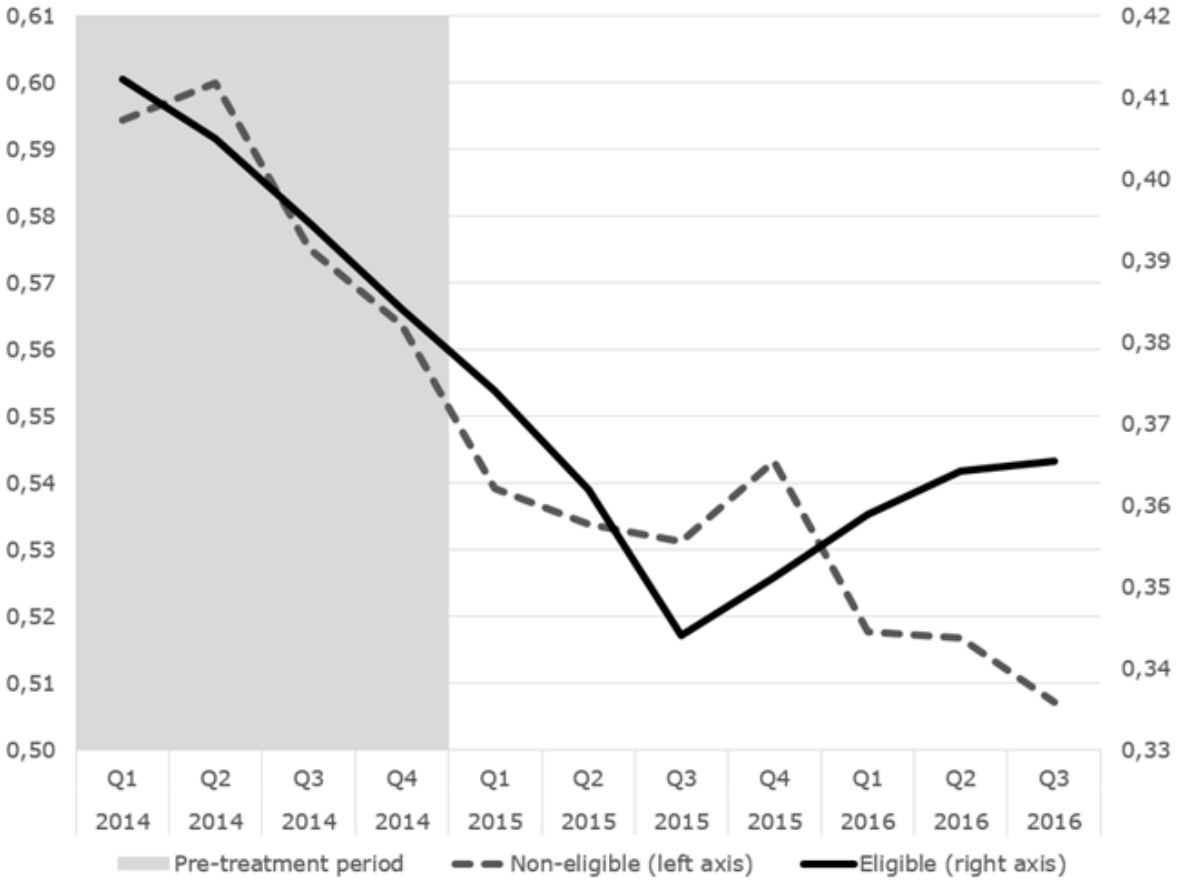

Figure 2: Bond concentration over time, eligibles v.s. non-eiligibles

Previous DNB Working Papers in 2018

No. 583 **Dorinth van Dijk, David Geltner and Alex van de Minne**, Revisiting supply and demand indexes in real estate
No. 584 **Jasper de Jong**, The effect of fiscal announcements on interest spreads: Evidence from the Netherlands
No. 585 **Nicole Jonker**, What drives bitcoin adoption by retailers?
No. 586 **Martijn Boermans en Robert Vermeulen,** Quantitative easing and preferred habitat investors in the euro area bond market
No. 587 **Dennis Bonam, Jakob de Haan en Duncan van Limbergen,** Time-varying wage Phillips curves in the euro area with a new measure for labor market slack
No. 588 **Sebastiaan Pool**, Mortgage debt and shadow banks
No. 589 **David-Jan Jansen**, The international spillovers of the 2010 U.S. flash crash

DeNederlandscheBank

EUROSYSTEEM

De Nederlandsche Bank N.V.
Postbus 98, 1000 AB Amsterdam
020 524 91 11
dnb.nl