Spillover Effects of Sovereign Bond Purchases in the Euro Area*

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This paper investigates cross-border spillover effects from the Eurosystem's Public Sector Purchase Program (PSPP) on euro area government bond returns. We distinguish between the direct effects of domestic bond purchases by national central banks and the indirect effects from bond purchases by national central banks in other euro area countries over the period March 2015–December 2018. The results reveal substantial spillover effects across the euro area, providing evidence for arbitrage within euro area sovereign bond markets. These spillover effects are particularly large for longer-term bonds and for bonds issued by non-core countries. The larger impact of spillovers in these cases can be explained by investors rebalancing towards higher-yielding government bonds.

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1. Introduction

Over the past decade, major central banks have conducted large-scale asset purchase programs.[1] One of these programs is the

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[1]See Dell'Ariccia, Rabanal, and Sandri (2018) for an overview of unconventional monetary policies in the euro area, Japan, and the United Kingdom, and Kuttner (2018) for the United States.

Eurosystem's Public Sector Purchase Program (PSPP), which was launched in 2015 to ease financing conditions across the euro area (EA, hereafter) by lowering government bond yields.[2] This paper investigates the impact of PSPP purchases on individual bond returns for the 10 largest EA countries. In addition, we distinguish between the direct effect of purchases of a specific bond by a country's national central bank and spillover effects from bond purchases by other national central banks in the Eurosystem. We further disentangle these purchases by a breakdown into different maturity segments and country groups. This empirical approach accounts for the unique characteristics of the EA bond markets and examines market arbitrage within the EA. While the unique settings of the EA should be taken into account, our work improves the understanding of spillover effects between government bond market segments (e.g., between bonds of different maturities or between bonds issued in different jurisdictions). In addition, it provides knowledge on the transmission mechanism of large-scale asset purchases and offers insights for the calibration of future purchase programs.

The literature on the effectiveness of the PSPP in the EA has expanded in recent years. Several studies focus on announcement effects, which capture the pricing-in of future central bank purchases, while others investigate the effects of actual purchases. Most studies find that bond purchases significantly reduced yields and raised bond returns in the EA (see Section 2). Our paper builds on De Santis and Holm-Hadulla (2020), who analyze the effects of actual purchase operations on sovereign bond prices using daily PSPP purchase data from March 2015 up to June 2016. These authors find that purchases of a specific bond as well as purchases of domestic

[2]Note that the PSPP is different from the European Central Bank's (ECB's) Pandemic Emergency Purchase Program (PEPP) launched in March 2020 and discontinued at the end of March 2022. While the goal of purchases under the PSPP was to ease general monetary conditions in the EA, the PEPP was introduced as a temporary asset purchase program for private- and public-sector securities, with a purpose to "address illiquidity and heightened volatility in core segments of EA financial markets that threatened to impair the smooth transmission of monetary policy" (Schnabel 2020) and to counter serious risks to the monetary policy transmission mechanism and the economic outlook for the EA posed by the COVID-19 crisis. Evaluating the effects of the PEPP is a promising avenue for future research.

bonds with comparable characteristics (i.e., close substitutes) significantly increase bond prices. De Santis and Holm-Hadulla (2020) do not examine spillovers from purchases by central banks in other EA countries, however.

We contribute to the existing literature in three directions. First, we investigate how the price effects of actual purchases are transmitted across heterogeneous EA bond markets. The EA sovereign bond markets comprise bonds issued by 19 national governments. These government bonds are not perfect substitutes since national bond markets vary in creditworthiness, liquidity, and size, as well as attract different types of investors. In addition, governments have different issuance needs and preferences, while macroeconomic conditions differ considerably between countries. As a result, sovereign bond yields contain credit and liquidity spreads which the European sovereign debt crisis clearly revealed (see e.g., Costantini, Fragetta, and Melina 2014; Bekkour et al. 2015; Paniagua, Sapena, and Tamarit 2017).

Second, we examine the effects of bond purchases using different categories of purchase volumes. We do so by regressing the return of a specific bond on the relative volume purchased of (i) the bond itself, (ii) other bonds issued by the same government (domestic close and distant substitutes), and (iii) bond purchases by other EA countries (non-domestic spillovers). Purchase volumes and bond returns are taken on a monthly frequency. Similar to the previous empirical literature, our identification strategy relies on an instrumental-variable (IV) approach to address a potential simultaneity bias in the estimated relationship between bond returns and central bank purchases, by using exogenous instruments for the own purchases variable. Spillovers from other countries are distinguished based on an individual country's credit risk group and a bond's maturity segment. As an extension, we investigate whether the effects of purchases differ across country groups and maturity segments.

Third, our study contributes in terms of the scope. In contrast to country-specific studies, (e.g., Arrata and Nguyen 2017; Schlepper et al. 2020), our analysis comprises bond purchases in 10 EA countries. Moreover, we cover the entire first phase of net PSPP purchases from March 2015 until the end of 2018, while the related studies are limited to a narrower time interval.

Our findings show that both domestic and non-domestic PSPP purchases significantly increased bond returns, i.e. decreased yields, in the EA. In terms of magnitude, however, the monthly effect of non-domestic purchases on bond returns is substantially larger than the effect of own purchases. This suggests that spillovers from other countries in the EA—i.e., the general purchase pace of the ECB—are a dominant component of the PSPP's effectiveness. It also provides evidence for the importance of arbitrage within the EA government bond markets, despite the segmentation mentioned above. The impact of spillovers is found to be particularly large for both longer-term government bonds and for bonds issued by non-core jurisdictions (Ireland, Italy, Portugal, and Spain). The larger impact of spillovers in these cases can be explained by investors rebalancing towards higher-yielding government bonds.

The rest of the paper is structured as follows. Section 2 reviews the related theoretical literature and previous empirical evidence. Section 3 provides details on the structure and implementation of the PSPP. Sections 4 and 5 describe the methodology and data construction, respectively. Section 6 presents the main empirical results, robustness checks, and extensions. Section 7 concludes with a summary and policy implications.

2. Literature Review

2.1 Channels and Spillovers from Asset Purchases to Bond Yields and Prices

The literature describes several channels through which central bank asset purchases may reduce bond yields. The two prominent ones are the *signaling channel* and the *portfolio rebalancing channel*.[3]

Through the *signaling channel*, central bank communication on asset purchases shapes investors' expectations about future monetary policy and short-term interest rates, which are transmitted to long-term interest rates and asset prices (Joyce et al. 2011; Bauer and Rudebusch 2014; Bhattarai, Eggertsson, and Gafarov 2015;

[3]Quantitative easing may also affect asset prices through other channels, involving liquidity and credit risk (see e.g., Krishnamurthy and Vissing-Jorgensen 2011; Christensen and Gillan 2022).

King 2020). While the *signaling* channel emphasizes the importance of communication and market expectations, tracing primarily the impact of central bank announcements, actual transactions conducted under asset purchase programs can influence bond yields through the *portfolio rebalancing* channel.

The *portfolio rebalancing* channel implies that a purchase-induced price change in one asset spills over to prices of other assets that investors perceive as close substitutes (Vayanos and Vila 2021; Greenwood and Vayanos 2014). Thus, by purchasing government bonds, the central bank changes supply and demand conditions in various market segments beyond the targeted instrument of a specific asset purchase program.

The *portfolio rebalancing* channel is distinct from the direct effects of central bank purchases which influence the price of the asset being bought directly. Krishnamurthy and Vissing-Jorgensen (2013) consider for the transmission of the direct effect the "capital constraints" and the "scarcity" channels. The capital constraints channel is effective when an asset is traded in a narrow and segmented market. When the central bank purchases are large relative to the outstanding amount, a scarcity premium arises which reduces interest rates.

The *portfolio rebalancing* channel asserts that through the indirect effects, transactions in the bond market influence a broader spectrum of asset prices by changing relative yields. These indirect effects can be triggered by other domestic purchases (i.e., domestic purchases of bonds other than the specific bond that is bought under the PSPP) as well as by spillovers from purchases of bonds issued by other countries.

Ferdinandusse, Freir, and Ristiniemi (2020) show with a search theoretical model that the strength of the portfolio rebalancing channel depends on a share of bonds held by preferred habitat investors. These investors have a preference for holding assets of a specific market segment and are only willing to move out of that segment when they receive a risk premium. In a similar vein, Vayanos and Vila (2021) and Greenwood and Vayanos (2014) develop a term structure model where investors have preferences for specific maturities, while risk-averse arbitrageurs integrate markets by trading across different maturities. However, when the group of preferred habitat investors is large, they create a shortage that drives up bond prices and returns and thereby reduces bond yields in specific markets. Meanwhile, arbitrageurs spread the shortage—created by central bank purchases in a particular bond—across maturities and bonds with similar characteristics.

Apart from domestic purchases, spillovers from purchases by central banks in other jurisdictions play a role. Two theoretical studies are relevant in this regard. The first one, by Alpanda and Kabaca (2020), evaluates the international spillovers of large-scale asset purchases (LSAPs) using a two-country (the United States and the rest of the world) dynamic stochastic general equilibrium (DSGE) model. In their model, portfolio balance effects arise from imperfect substitutability between short- and long-term bonds, as well as between domestic and foreign bonds in bond portfolios of each country. Alpanda and Kabaca (2020) show that LSAPs in the United States reduce domestic and foreign long-term bond yields and stimulate economic activity both in the United States and in the rest of the world. The key for this result is the decline in the term premiums abroad through the portfolio rebalancing channel, as relative demand for the rest of the world's long-term bonds increases following LSAPs in the United States.

In a similar framework, Kabaca et al. (2023) examine an optimal allocation of government bond purchases within a monetary union, using a two-region (core and periphery) DSGE model where regions are asymmetric with respect to their economic size and portfolio characteristics. The authors show that a union-wide quantitative easing (QE) affects government asset prices in three ways: first, it directly lowers the term premium of domestic long-term yields; second, lower term premiums spill over through portfolio rebalancing of cross-border assets within the monetary union; third, lower outstanding government long-term debt held by private agents lowers term premiums on these assets. Kabaca et al. (2023) find that a union-wide QE reduces term premiums somewhat more in the core than in the periphery. This is explained by a relatively lower elasticity of substitution between long- and short-term bonds and higher home bias in bond holdings in the periphery compared to the core.

Based on the two studies discussed above, the impact of spillovers may depend on a number of factors, such as the size of asset purchases relative to the pool of substitutable assets, the degree of substitutability of domestic bonds with foreign ones, the risk premium on domestic and foreign bonds, as well as maturity of different assets.

2.2 Effects of Central Bank Purchases on Government Bond Yields and Prices—Evidence

Previous studies show that unconventional monetary policy measures through government bond purchases have a significant and lasting impact on bond yields and other asset prices.[4] The magnitude of the estimated effect varies across purchase programs, countries, applied methodologies, and sample periods.[5] While there is broad evidence showing a significant and lasting effect of central bank purchases on bond yields and prices, different magnitudes are reported across countries due to different characteristics of the purchase programs across countries, different markets being targeted, and different sizes of purchase programs.

Several studies find that announcements of quantitative and qualitative monetary easing measures by the Bank of Japan significantly lowered yields by 10–14 basis points (bps) on average for a 10-year Japanese government bond (see, e.g., Lam 2011; Hausman and Wieland 2014; Arai 2017). Similarly, De los Rios and Shamloo (2017) and De Rezende (2017) conclude that the effects of QE were relatively small in the case of the Sveriges Riksbank's program. They find that 10-year government bond yields in Sweden dropped on average by around 13–17 bps after five Riksbank's announcements involving bond purchases in 2015, with an estimated cumulative total decline of around 46 bps.

The estimates for the effect of QE programs in the United Kingdom on medium- to long-term government bond yields range between −45 and −100 bps (e.g., Joyce et al. 2011; Christensen and Rudebusch 2012; Joyce and Tong 2012; McLaren, Banerjee, and Latto 2014). Several studies for the United States report that

[4]The effects of LSAPs on other market segments, e.g., corporate bonds or bank loans, is beyond the scope of our paper. See, e.g., Albertazzi, Becker, and Boucinha (2021) for transmission effects of the PSPP to other market segments.

[5]See Hohberger, Priftis, and Vogel (2019) and Bhattarai and Neely (2022) for an elaborate overview of the literature on international unconventional monetary policy.

the effect of the Federal Reserve's QE programs on 10-year Treasury bond yields ranges between −30 and −123 bps (Gagnon et al. 2011; Krishnamurthy and Vissing-Jorgenson 2011; Chen, Curdia, and Ferrero 2012; D'Amico et al. 2012; D'Amico and King 2013; Kandrac and Schlusche 2013; Bauer and Neely 2014), although results vary across the studies (Kuttner 2018).

Previous studies for the EA come to mixed conclusions about the QE impact (see Table A.1 in the appendix for an overview). They estimate the PSPP announcement effects on bond yields to range between −45 and −95 bps for an average 10-year government bond (e.g., Andrade et al. 2016; Eser et al. 2019; De Santis 2020; Altavilla, Carboni, and Motto 2021). Meanwhile, the actual PSPP purchases are reported to have led to a significant further reduction in bond yields, ranging between 13 and 63 bps per 10 percent of outstanding amount purchased (Arrata and Nguyen 2017; Koijen et al. 2021). Using the EA daily data for bond prices and purchase volumes, De Santis and Holm-Hadulla (2020) find that central bank purchases of a security amounting to 1 percent of its outstanding amount raised its return by 5.5–7.5 bps on the day of purchase, while Schlepper et al. (2020), based on transaction-level data for German bonds, find that a daily €100 mln purchase volume increased the average bond return by 8.9 bps. The evidence is inconclusive on how asset purchases transmit to bond yields (returns) and which channels contribute the most to the monetary policy transmission.

The empirical literature on spillovers of central bank asset purchases across government bond markets—i.e., the empirical analyses beyond the domestic bond markets—is scant.[6] To the best of our knowledge, two studies—Bauer and Neely (2014) and Neely (2015)—find evidence for such spillovers from the United States to other countries. More specifically, they show that the Federal Reserve's (Fed's) QE announcements significantly reduced international bond yields. For the euro area, Fratzscher, Lo Duca, and Straub (2016) document that unconventional ECB programs (LTROs, SMP, and OMT) resulted in significant international spillovers on bond yields and portfolio flows.

[6] Alpanda and Kabaca (2020) and Kolasa and Wesołowski (2020) provide some theoretical insights on cross-border spillovers.

Our paper contributes to the debate by considering spillovers of the PSPP in the EA. Specifically, we examine how PSPP influences bond returns and to what extent the rebalancing of investors' portfolios spreads the impact to other bond market segments. Such spillover effects may reflect, for instance, search for yield by investors (Becker and Ivashina 2013), externally imposed risk limits or the need to match durations (Domanski, Shin, and Sushko 2015; Koijen et al. 2017). To account for various factors driving spillover effects, we examine purchases on the basis of countries' credit risk group and bonds' maturity segment.

3. The Eurosystem's Public Sector Purchase Program (PSPP)

In the period between March 2015 and December 2018, the Eurosystem expanded its balance sheet by €2575 bln through several QE programs. These purchases comprised more than a quarter of the entire outstanding sovereign debt in the EA and were in same order of magnitude as the QE programs implemented by the Fed, the Bank of England, and the Bank of Japan.

The Eurosystem's QE program—the extended asset purchase program (APP)—includes several subprograms, of which the public sector purchase program (PSPP) was the largest (82 percent of total net APP purchased volume). Under the PSPP, bonds issued by EA central and local governments, agencies, and European institutions were bought in the secondary market. The largest share of purchases involved bonds issued by national governments and agencies, accounting for around 90 percent of total PSPP purchases, compared to 10 percent for bonds issued by European (supranational) institutions.

During our sample period (March 2015–December 2018), the ECB communicated a fixed calendar date on which the APP would end, with the additional qualification that the program could run until the ECB's Governing Council sees a sustained adjustment in the path of inflation consistent with its inflation aim of "below, but close to, 2 percent." Over time, there had been several extensions of the program and adjustments of the net APP purchase pace. In addition, the ECB lowered its main policy rate—the rate on the deposit facility—twice. Table 1 provides an overview of the most

Table 1. An Overview of the ECB's Decisions with Respect to the APP during 2015–18

Announcement Date	Announced Decision	Time Horizon	Announced Volume
January 22, 2015	Start of PSPP; net APP purchases pace set to €60 bln per month	Until September 2016 + SAPI	€1080 bln
November 9, 2015	Increase of the issue share limit to 33% for bonds issued by national authority	Until September 2016 + SAPI	N/A
December 3, 2015	Extension of APP Reinvestment of maturing bonds	Until March 2017 + SAPI	€1440 bln
March 10, 2016	Increase of net APP purchases pace to €80 bln per month Start of CSPP and TLTRO-II from April 2016 Increase of the issue share limit of supranationals to 50%	Until March 2017 + SAPI	€1720 bln
December 8, 2016	Reduction in net APP purchases pace to €60 bln per month Broadening of the criteria for eligible bonds (removal of DFR restriction and inclusion of one- to two-year bonds)	Until December 2017 + SAPI	€2260 bln
October 26, 2017	Reduction in net APP purchases pace to €30 bln per month	Until September 2018 + SAPI	€2530 bln
September 13, 2018	Reduction in net APP purchases pace to €15 bln per month Announced end of net APP purchases by December 2018	End of December 2018	€2575 bln
December 13, 2018	End of net purchases under APP	End of December 2018	€2575 bln
	Interest Rate Decisions		
December 3, 2015 March 10, 2016	Reduce the deposit facility rate (DFR) to –0.3% Reduce the deposit facility rate (DFR) to –0.4%	Forward Guidance on DFR and APP	

Note: SAPI—sustained adjustment in the path of inflation consistent with the ECB's inflation aim.

relevant ECB decisions with respect to the APP during the sample period.

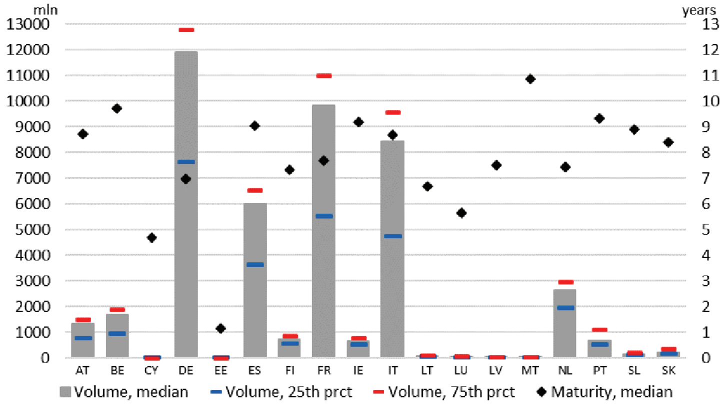
The Eurosystem's purchases were conducted by national central banks (90 percent) and the ECB (10 percent of purchases). The ECB communicated ex ante an aggregate volume target (for the net APP) and published each month purchase volumes disaggregated by jurisdiction and subprogram, to inform market participants about the distribution of conducted purchases. Furthermore, the ECB communicated its intention to use the national central banks' capital key to distribute the planned purchases over different jurisdictions. The capital key is each national bank's stake in the ECB and reflects population and GDP size (equally weighed) of each country in the EA. National central banks bought bonds issued by their domestic governments and supranational institutions, while the ECB conducted purchases in all markets.

The actual purchases per country were in practice not fully aligned with the distribution by the capital key. Typically, this occurred when there were insufficient (liquid) bonds satisfying the eligibility criteria to match the intended volume based on the capital key.[7] Moreover, on a bond level the selection of bonds to be purchased may also be constrained by eligibility rules. Following the intention of market-neutral implementation, national central banks also took into account liquidity conditions of specific market segments or bonds (see Figure 1 for an overview of purchases under the PSPP by country).[8] On a bond level, the eligibility limitations,

[7]For example, Greek government bonds could not be bought, because the credit rating of Greece was too low. In addition, the market liquidity was a limiting factor for smaller countries. Also, the issuer limit (preventing the Eurosystem bond holdings from exceeding 33 percent of the outstanding market debt of a specific country) could have been at the moment a limiting factor for the purchase volume. Finally, also for some smaller countries a limited number of bonds have been bought.

[8]See Cœuré (2015) and Hammermann et al. (2019) for a discussion of the PSPP implementation considerations, such as the interplay between the pursuit of market neutrality, implementation limitations, and market conditions. First, the concept of market neutrality can be perceived in several ways. An important question is to what extent the Eurosystem takes into account market liquidity—which would imply that following the outstanding debt profile is not necessarily market neutral. Market liquidity may differ from one market segment to another. Furthermore, the PSPP was bound by several limitations (issue share limit, issuer limit, and the minimum yield at the deposit facility rate in the first period of the

Figure 1. Overview of Monthly (net) PSPP Purchase Volume and Maturity per Country



Source: ECB.
Note: The left y-axis measures purchase volumes in € mln; the right y-axis measures maturity in years. The median, 25th percentile, and 75th percentile are calculated on the basis of monthly (net) PSPP purchase volumes during March 2015–December 2018. The median maturity of purchased bonds is calculated for the same time period. AT = Austria, BE = Belgium, CY = Cyprus, DE = Germany, EE = Estonia, ES = Spain, FI = Finland, FR = France, IE = Ireland, IT = Italy, LT = Lithuania, LU = Luxembourg, LV = Latvia, MT = Malta, NL = Netherlands, PT = Portugal, SL = Slovenia, and SK = Slovakia.

the market-neutrality principles, as well as country-specific considerations provide the sources of variation in terms of which bonds exactly are being bought, facilitating our empirical analyses.

Purchases in our sample took place almost on the entire spectrum of outstanding government bonds with remaining maturities ranging from 2 years (at a later stage 1 year) up to 30 years and 364 days. Until January 2017, purchases did not take place if bonds traded below the deposit facility rate (DFR). As a result, in several jurisdictions the minimum maturity of purchasable bonds was in practice much higher than two years. In December 2016 the ECB

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program until 2017). These factors constrained the degree of freedom the Eurosystem had in its implementation, which was reinforced by uncertainty about future volume of purchases and new bond issuance by national governments.

lifted the DFR restriction and allowed government bond purchases below the DFR, to the extent necessary.

The Eurosystem's PSPP differs in several ways from QE programs conducted by the U.S. Federal Reserve and the Bank of England. Firstly, and most evidently, the EA bond market consists of multiple national governments, implying a combination of common factors (e.g., single monetary policy) as well as national factors (e.g., budgetary considerations). Second, the Fed and the Bank of England had more explicit maturity objectives and/or communication. While the ECB did not have an explicit duration objective, the Fed operated its maturity extension program and, similarly to the Bank of England, steered and communicated clearly on the allocation of purchase volumes across maturity segments.[9] Third, the extent to which individual bonds were bought also differs. Relatively high issue share limits allowed the Fed and the Bank of England to be more flexible in bond selection. Moreover, the reserves auction system by which the Fed conducted its asset purchases motivates price selection, in comparison to the Eurosystem's purchases, which were to the largest extent conducted on a bilateral basis.

4. Methodology

4.1 Theoretical Motivation

The objective of the paper is to quantify the direct effects of own purchases in a security and to distinguish (indirect) portfolio rebalancing effects from domestic and non-domestic purchases. In essence this can be compared to the estimation of cross-price elasticities for differentiated goods (Berry 1994), with goods being viewed as individual bonds. Ideally one obtains the full cross-price elasticities matrix of all government bonds in the EA. However, due to the existence of thousands of government bonds, estimating such matrix is infeasible.

[9]For more information, see Bank of England (2022); FAQs: Treasury Purchases—Federal Reserve Bank of New York (https://www.newyorkfed.org/markets/treasury-reinvestments-purchases-faq), Federal Reserve Board—Open Market Operations. See https://www.federalreserve.gov/monetarypolicy/openmarket.htm#:~:text=Open%20market%20operations%20(OMOs)%2D%2D,Open%20Market%20Committee%20(FOMC).

In order to identify the different channels through which PSPP purchases may affect bond returns, we impose more structure on the demand function to reduce the number of estimated parameters. This is similar to the approaches proposed in Portes and Rey (2005) and Koijen and Yogo (2019) for reducing the dimensionality in demand systems. Specifically, to capture the direct effect, the purchases in the single bond b are considered. In order to capture the portfolio rebalancing effect from other domestic purchases, we aggregate the purchases in all domestic government bonds except bond b. Similarly, to capture the price elasticity of non-domestic purchases, we aggregate the central bank purchases in non-domestic government bonds, that is, bonds issued by other jurisdictions than country j.

Based on previous empirical evidence and theoretical papers, we expect that domestic and non-domestic purchases would increase bond returns (while lowering yields). In the absence of a clear guidance from the literature on the magnitude of different effects from purchases, we remain agnostic about the expected size of price elasticities to different types of purchases.

4.2 Baseline Model

We use the panel data set for 10 EA countries with information on individual bonds issued by these countries, at monthly frequency over the period March 2015–December 2018 (see Section 5.1 for data description). Our methodological approach is comparable to De Santis and Holm-Hadulla (2020) and follows the related literature in using panel data regression techniques to analyze the effects of central bank purchases. The baseline model is specified as

$$\begin{aligned} r_{bjt} = {} & \beta * own\_purch_{bjt} + \gamma * oth\_dom\_purch_{bjt} \\ & + \theta * nondom\_purch_{bjt} + u_t + \mu_b + \varepsilon_{bjt}, \end{aligned} \tag{1}$$

where r_{bjt} denotes the monthly return of a specific bond b (issued by jurisdiction j) in month t, defined as the log change in its price level from end-of-month $(t-1)$ to end-of-month t, in percentage.

We use bond returns as our dependent variable in line with previous studies (e.g., D'Amico and King 2013; Kandrac and Schlusche 2013; De Santis and Holm-Hadulla 2020). own_purch_{bjt} denotes own relative purchases of bond b in month t. This variable captures the direct effect of central bank purchases on bond returns through the capital constraints and/or scarcity channels (Krishnamurthy and Vissing-Jorgenson 2013). $oth\_dom\_purch_{bjt}$ is net relative purchases of domestic substitutes (close and distant) for bond b in month t. $nondom\_purch_{bjt}$ denotes non-domestic purchases, i.e., monthly net relative purchases by EA central banks other than the central bank in country j. To the best of our knowledge, our paper is the first in the literature to explicitly control for and examine the impact of non-domestic purchases on bond returns in the EA. Construction of different purchases variables is described in Section 5.2. β, γ, and θ are vectors of parameters on the respective purchases variables.

u_t denotes time fixed effects, capturing monthly time-specific common factors such as central bank announcements, market expectations, changing economic indicators, global and regional (European) financial conditions, and geopolitical events, among others.[10] μ_b denotes unobserved time-invariant bond-specific fixed effects, which capture the characteristics of the bond such as its original maturity, coupon rate, and type (inflation linked or not), among others. ε_{bjt} is an idiosyncratic error term with mean 0 and variance $\sigma^2_{\varepsilon,bjt}$.[11] Standard errors are clustered at the bond level to account for heteroskedasticity and autocorrelation in the error term.[12]

This set-up allows distinguishing the direct effect of central bank purchases on the return of a particular bond being purchased (captured by β), as well as the indirect effects of other domestic and non-domestic purchases (captured by γ and θ, respectively) that might affect a bond *b's* return through the portfolio rebalancing channel. The use of relative purchase variables (in percent of outstanding amounts) is justified by the assumption that the scarcity induced by a given amount of central bank purchases depends inversely

[10]We include time fixed effects to ensure that variation between bonds is captured by the regression and not by the (communicated) overall purchase pace of the PSPP. In case there was no variation across bonds, the regression would not show any effect of the purchases.

[11]The cross-sectional dimensions b (bond) and j (country) in our panel data set are nested, i.e., multiple bonds are issued by one country. Therefore, bond-specific effects automatically control for country-specific effects.

[12]The post-estimation tests show that there is no remaining (second-order) serial correlation in the residuals.

on the total size of the respective market segment (De Santis and Holm-Hadulla 2020).

4.3 Instrumental-Variables Approach

Empirical studies on the effects of central bank asset purchases face a potential identification problem: the ordinary least squares (OLS) method may produce inconsistent estimates if the allocation of overall purchase volumes to individual bonds by a purchasing central bank depends on the observed bond returns in the market on a given purchase day (Arrata et al. 2020; De Santis and Holm-Hadulla 2020). In this case, bond returns and purchases would be jointly determined, resulting in a potential simultaneity bias in the estimated relationship between them. As such, the effect of PSPP might be underestimated if this endogeneity problem is not properly addressed.

Existing studies for the EA and the United States solve this problem by employing an instrumental-variable (IV) approach. For example, De Santis and Holm-Hadulla (2020) apply the IV estimation based on a natural experiment, using "blackout periods" embedded in the PSPP legal set-up, to identify exogenous variation in daily central bank purchase volumes. Arrata et al. (2020) follow a similar approach, additionally using the PSPP eligibility rules to create instruments for purchases. Arrata and Nguyen (2017) build an instrument from a set of variables indicating specialness and liquidity/scarcity of each bond in the French bond market. Koijen et al. (2021) construct each country's predicted government bond purchases by using its capital key in the EA. For the U.S. data D'Amico and King (2013) instrument the LSAP amounts with purchased securities' characteristics prior to the announcement of the program, such as remaining maturity, percentage of issue held by the Fed, and on-the-run dummy.[13]

[13]Other papers propose alternative strategies to deal with identification problems for the price impact of central bank purchases. These approaches arguably provide a clear source of variation. For instance, Krishnamurthy, Nagel, and Vissing-Jorgensen (2018) use differences in corporate credit default risk from securities denominated in U.S. dollars to identify the redenomination component of sovereign euro-denominated bond yields. Di Maggio, Kermani, and Palmer (2020) use rules on the eligibility of mortgages for central bank purchases to

Compared to these studies, we address the identification problem in the following way. First, we use monthly (instead of daily or intraday) bond purchases and monthly bond returns. This setting partly alleviates the simultaneity bias that is inherent in daily data, since price differences are less likely to persist on a monthly basis; if they did, dealers would only be able to buy these bonds to a certain extent, as they would need to fulfill a relatively large volume objective. Note that monthly total purchases are predetermined at the start of the month, so the purchase volume during a month is not sensitive to developments during this month. For example, on March 10, 2016 the ECB announced that it would increase monthly net APP purchases as of April 2016 from €60 bln to €80 bln per month. This implies that the risk of monthly purchases being correlated with a common factor during the month is small, thereby decreasing the risk of a simultaneity bias.

Next, we propose two instrumental variables to deal with the endogeneity of own purchases. For this purpose, we use the three eligibility criteria based on the legal and technical rules imposed by the Eurosystem on the PSPP purchases. First, eligible securities must have a residual maturity of between 2 and 30 years. The lower threshold of two years was relaxed to one year from January 2017 onwards. Second, the yield on eligible securities must be higher than the DFR. This rule was set before the start of the PSPP and relaxed from January 2017 onwards, implying that the Eurosystem could also buy bonds with yields below the DFR. Third, the Eurosystem (i.e., the ECB and national central banks) cannot hold more than 33 percent of a bond issued by a national authority. We construct a dummy variable $Eligible_{bjt}$ that takes the value one when a specific bond b issued by country j is considered eligible to be purchased based on the eligibility criteria 1 and 2, and zero otherwise. The second instrumental variable $Deviation_{bjt}$ is constructed using criterion 3 as a difference between the 33 percent threshold and the relative cumulative purchases of a specific bond b. Thus, this variable measures the distance from the volume of the specific

study the impact of LSAPs by the Fed on the refinancing activity. Rodnyansky and Darmouni (2017) use the relative prevalence of mortgage-backed securities on the banks' books before the launch of QE in the United States to identify the exposure of banks to LSAPs.

bond already purchased by the central bank and the allowed purchase limit of 33 percent. These variables are suitable instruments in our context, as they provide exogenous variation in the amount of bonds bought under the PSPP and are themselves not affected by the market constellation of bond returns.

The first-stage regression in the two-stage least-squares (2SLS) set-up writes as follows:

$$own\_purch_{bjt} = \delta_1 * Eligible_{bjt-1} + \delta_2 * Deviation_{bjt-1} + \varphi_t + \vartheta_b + \omega_{bjt}, \tag{2}$$

where own_purch_{bjt} denotes the own purchases variable; φ_t and ϑ_b are month and bond fixed effects, respectively; and ω_{bjt} is an error term. We use one-month lags of the instruments, as own purchases of bond b in current month t are likely to be determined by this bond's eligibility and the distance of cumulative purchase in this bond so far from the 33 percent allowed limit, as of the end of the previous month. Based on the estimated coefficients $\widehat{\delta_1}$ and $\widehat{\delta_2}$, the fitted values of the own purchases variable are computed. Subsequently the second-stage regression, specified in Equation (1), replaces the own purchase variable with its fitted values from Equation (2) to obtain the estimates of the slope coefficients β, γ, and θ.[14]

5. Data

5.1 Data Description

Our sample period covers the first phase of net asset purchases conducted under the PSPP and runs from March 9, 2015 (the day PSPP was launched) until December 31, 2018. We use monthly data on PSPP purchases of individual government bonds as summed-up daily purchases over each corresponding month. Each PSPP transaction has the assigned trade and settlement dates, the book value, the nominal amount, and the International Securities Identification Number (ISIN) identifier. We merge the monthly purchase data with end-of-the-month data from Bloomberg on prices and yields of individual government bonds across all EA countries and with

[14] All the reported 2SLS IV regressions in our paper are estimated using the `xtivreg` packages in Stata.

data on individual bond characteristics from the Centralized Securities Database (CSDB). The latter include quarterly data on issuer country, issuer sector, outstanding amount, issuance date, maturity date, and coupon type.

We exclude purchases of government agencies and supranational institutions from our sample. Thus, we keep only bonds issued by the government (central and regional) in each country. In addition, we drop the data for nine EA countries that had no or few purchases within the PSPP and/or whose markets are relatively illiquid (Cyprus, Estonia, Greece, Latvia, Lithuania, Luxembourg, Malta, Slovakia, and Slovenia). This results in a sample comprising 10 EA countries (Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal, and Spain).[15] These countries account for over 98 percent of the PSPP net sovereign debt purchases during the sample period. The final sample consists of about 33,000 observations for around 1,000 individual government bonds. The panel is unbalanced, as not all bonds were purchased every month during the sample period. Table 2 provides an overview of the bond coverage in our sample, reporting per jurisdiction the number of bonds and the median nominal outstanding amount of these bonds, based on the data for the first (March 2015) and the last (December 2018) month in our sample.

5.2 Construction of Purchases Variables

In order to examine the effects of domestic and non-domestic purchases on bond returns, we use monthly relative net purchases, measured as the nominal amount (in € mln) of central bank net purchases of a specific bond (group of bonds), in percent of the total nominal outstanding amount issued (in € mln) of the corresponding bond (group of bonds). We distinguish "domestic purchases" (all purchases by country j's central bank of bonds issued by the country j's national authority) and "non-domestic purchases" (all purchases by the rest of the Eurosystem, i.e., all other EA central banks without country j's central bank).

[15] In a sample selection we consider the universe of government bonds issued by national governments in the EA. The selection of bonds is based on excluding bonds issued by the smallest countries in the EA as well as Greece due to liquidity concerns and eligibility rules. See also the discussion in Section 3.

Table 2. Number of Bonds and (median) Outstanding Amount in Our Sample, per Country

Jurisdiction	March 2015		December 2018	
	Number of Bonds	Nominal Amount Outstanding in €mln (Median)	Number of Bonds	Nominal Amount Outstanding in €mln (Median)
Austria (AT)	63	100.0	81	100.0
Belgium (BE)	142	71.0	172	50.0
Germany (DE)	130	7,124.4	185	2,000.0
Spain (ES)	162	604.0	237	163.7
Finland (FI)	19	5,000.0	19	5,000.0
France (FR)	84	15,388.0	82	20,565.5
Ireland (IE)	23	4,941.4	29	4,023.0
Italy (IT)	117	14,878.8	138	14,891.3
Netherlands (NL)	30	13,876.9	32	13,765.1
Portugal (PT)	35	600.0	39	1,000.0

We split domestic purchases into "own purchases" (purchases by country j's central bank of a specific bond b issued by country j) and "other domestic purchases" (purchases by country j's central bank of bonds other than bond b issued by the same country j). Let Q_{bjt} denote the nominal amount of central bank purchases of bond b in month t, issued in country j, OA_{bjt}—the nominal outstanding amount issued of bond b in country j. Then own purchases (own_purch_{bjt}) are constructed as follows:

$$own\_purch_{bjt} = \frac{Q_{bjt}}{OA_{bjt}} \times 100. \tag{3}$$

"Other domestic purchases" are further divided into close and distant substitutes. For this purpose, we group bonds in each country into six mutually exclusive maturity segments K based on the bond's remaining time to maturity in years, using the following intervals: 0–1 year, 1–2 years, 2–5 years, 5–10 years, 10–20 years, and over 20 years. The upper bounds of the intervals (except for the last one) are closed, so that the same bond cannot appear in two segments at the same time. "Domestic purchases of close substitutes" are defined as all purchases by country j's central bank of all bonds other than bond b_0, issued in the same country j and located in the same maturity segment K as bond b_0. "Domestic purchases of distant substitutes" are defined as all purchases by country j's central bank of all bonds other than bond b_0, issued in the same country j and located in different maturity segments K than bond b_0. Let N_j denote the universe of bonds issued in country j. "Other domestic purchases" ($oth\_dom\_purch_{bjt}$) are then constructed in the formulas (4)–(5) as follows:

$$close\_substitutes_{bjt} = \frac{\sum_{\substack{b=1 \\ b\neq b_0}}^{N_j} Q_{bjt}}{\sum_{\substack{b=1 \\ b\neq b_0}}^{N_j} OA_{bjt}} \times 100 \text{ if } K_{bjt} = K_{b_0jt}, \tag{4}$$

$$distant\_substitutes_{bjt} = \frac{\sum_{\substack{i=1 \\ b\neq b_0}}^{N_j} Q_{bjt}}{\sum_{\substack{b=1 \\ b\neq b_0}}^{N_j} OA_{bjt}} \times 100 \text{ if } K_{bjt} \neq K_{b_0jt}. \tag{5}$$

Next, we construct purchase variables indicating non-domestic purchases. We start from "total non-domestic purchases" ($nondom\_purch_{bjt}$), denoting all monthly net relative purchases by other central banks than the central bank in country j_0, formalized as

$$nondom\_purch_{bjt} = \frac{\sum_{\substack{j=1 \\ j\neq j_0}}^{J} \sum_{b=1}^{N_j} Q_{bjt}}{\sum_{\substack{j=1 \\ j\neq j_0}}^{J} \sum_{b=1}^{N_j} OA_{bjt}} \times 100. \tag{6}$$

We decompose total non-domestic purchases using two dimensions: risk group and bonds' maturity segment. First, we distinguish lower/higher credit risk groups and assign each country in our sample to one of them. For this purpose, we allocate countries to one of the five credit rating categories, using S&P ratings of individual EA countries during 2015–18: (i) AAA (Germany, the Netherlands); (ii) AA (Austria, Belgium, Finland, France); (iii) A (Ireland); (iv) BBB (Italy, Spain); and (v) BB (Portugal). The lower credit risk group includes rating categories (i) and (ii) with six countries (Austria, Belgium, Finland, France, Germany, and the Netherlands); the higher credit risk group includes rating categories (iii)–(v) and consists of the four remaining countries (Ireland, Italy, Portugal, and Spain). We use this distinction to construct "same group (SG) non-domestic purchases" (all purchases by other countries that are within the same risk group R as country j_0) and "different group (DG) non-domestic purchases" (all purchases by other countries that are in the different risk group R than country j_0), formalized as follows:

$$SG\_nondom\_purch_{bjt} = \frac{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} Q_{bjt}}{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} OA_{bjt}} \text{ if } R_{bjt} = R_{bj_0t} \quad (7)$$

$$DG\_nondom\_purch_{bjt} = \frac{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} Q_{bjt}}{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} OA_{bjt}} \text{ if } R_{bjt} \neq R_{bj_0t}. \quad (8)$$

Finally, we use the bond grouping by maturity segments, as described above, and decompose total non-domestic purchases into "same maturity (SM) non-domestic purchases" (all purchases of bonds issued by other countries and located in the same maturity segment K as bond b_0 issued by country j_0), and "different maturity (DM) non-domestic purchases" (all purchases of bonds issued by other countries and located in the different maturity segments K than bond b_0 issued by country j_0), constructed as

$$SM\_nondom\_purch_{bjt} = \frac{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} Q_{bjt}}{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} OA_{bjt}} \text{ if } K_{bjt} = K_{b_0j_0t} \quad (9)$$

$$DM\_nondom\_purch_{bjt} = \frac{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} Q_{bjt}}{\sum_{\substack{j=1 \\ j \neq j_0}}^{J} \sum_{b=1}^{N_j} OA_{bjt}} \text{ if } K_{bjt} \neq K_{b_0j_0t}. \quad (10)$$

Note that each purchases variable is normalized by the nominal outstanding amount of a corresponding bond (group of bonds), hence all purchase variables have different denominators.[16] This

[16]The numerator and the denominator for all purchases variables are taken at the same month t. To check whether variation in the denominator might be

implies that the purchases variables (e.g., domestic and non-domestic) and their estimated effects on the bond return cannot be summed up to calculate the combined impact. To gauge and compare the economic size of the effect across different purchases, we use one standard deviation in the purchases variables based on their descriptive statistics for the estimation sample. Figure 2 provides an overview of the constructed purchases variables.

As a robustness check, we use duration risk-weighted net purchases instead of unweighted purchases, to test if purchases of government bonds with a higher duration risk have a stronger effect on returns than purchases of bonds with a lower duration risk (see Section 6.3).

5.3 Descriptive Statistics

Table 3 presents the descriptive statistics of the variables used in our empirical analysis. For the average bond, monthly own purchases of a specific bond by individual EA central banks constituted on average 0.245 percent of the nominal outstanding amount of this bond. Monthly domestic purchase volumes of close substitutes, relative to their nominal amount outstanding, were somewhat larger than domestic purchases of distant substitutes (0.574 percent compared to 0.526 percent). Regarding the total non-domestic purchases, during 2015–18 on average monthly they were equal to 0.531 percent of total outstanding amount of the corresponding bonds in our sample.[17] The largest in terms of relative monthly volume were non-domestic purchases by countries of bonds within the same maturity segments as bond b purchased by country j's central bank. The univariate unit-root Fisher-type tests for unbalanced panel data show that all variables are stationary (results available on request).

driving results, as a robustness test, we lag the denominator by one month. The estimated coefficients are very similar to the baseline ones (available on request). Thus, we are confident that it is the variation in the numerator (the purchases) that drives the empirical results, and not the denominator.

[17]Purchases of bonds, conducted abroad, range between 0.49 percent and 0.53 percent of the total outstanding amount of these bonds, from a perspective of an individual country in our sample.

Figure 2. Overview of Purchases Variables Constructed for the Model Estimation

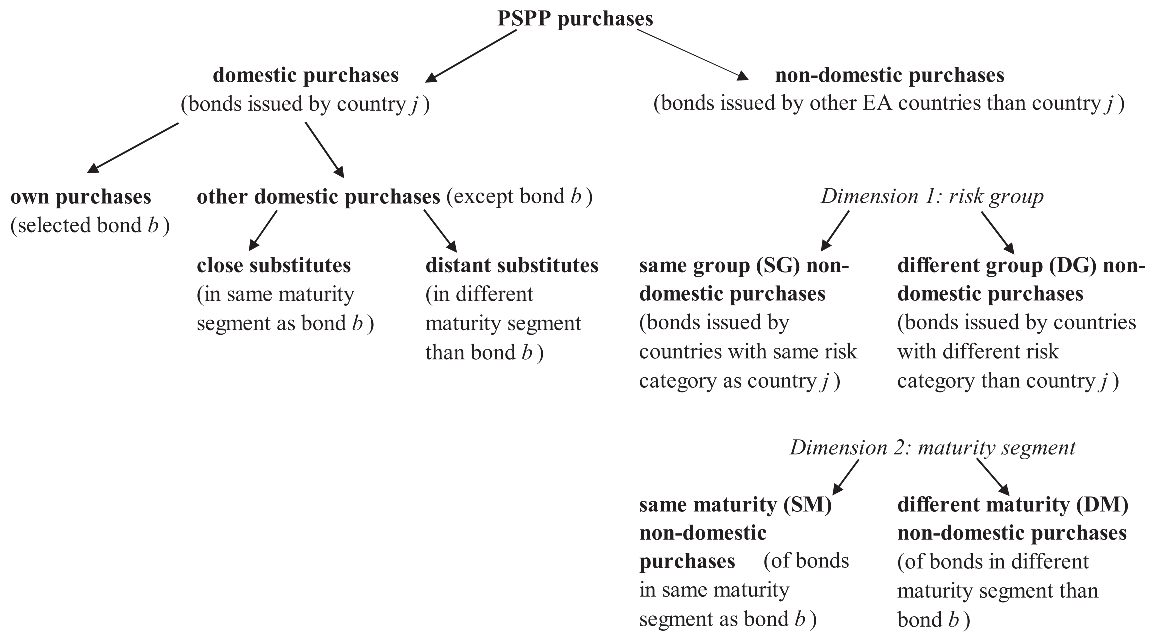


Table 3. Descriptive Statistics for 10 EA Countries over March 2015–December 2018

Variable	Mean	St. Dev.	25th Percentile	75th Percentile
Bond Return (in %)	–0.098	2.357	–0.595	0.541
Own Purchases	0.245	0.754	0.000	0.024
Domestic Close Substitutes	0.574	0.579	0.089	0.851
Domestic Distant Substitutes	0.525	0.303	0.334	0.681
Non-domestic Purchases	0.531	0.256	0.420	0.642
Same Risk Group Non-domestic Purchases	0.534	0.264	0.414	0.674
Different Risk Group Non-domestic Purchases	0.525	0.254	0.412	0.667
Same Maturity Non-domestic Purchases	0.556	0.392	0.251	0.808
Different Maturity Non-domestic Purchases	0.513	0.257	0.390	0.631

Note: The table reports the descriptive statistics for the variables used in the 2SLS regressions reported in Table 4, columns 3–6. The mean, standard deviation (St. Dev.), and 25th and 75th percentiles are reported for the sample included in these regressions. N=32,683. All purchases are measured in percent of the nominal amount outstanding of a corresponding bond (group of bonds) issued by EA countries in the sample.

6. Empirical Results

6.1 Main Analysis

Table 4 presents our main results for the full sample. The findings from the 2SLS IV estimates point to statistically significant effects of all types of purchases on bond returns. Based on the specification including only the own purchases, time and bond fixed effects as explanatory variables (column 2), monthly central bank purchases of a specific bond equal to 1 percent of its outstanding amount raise this bond's return by 0.13 percentage point (pp) on average over the sample.[18] This result is in line with De Santis and Holm-Hadulla (2020, Table 1, columns 1–3), although the magnitude of the estimated coefficient on the own purchases variable is smaller in our case. This is plausibly due to methodological and sample differences: unlike the cited paper based on daily data over March 2015–June 2016, we use monthly data over a longer period (March 2015–December 2018) as well as different instruments in the IV approach.

Next, we add other domestic purchases as explanatory variables, that is, domestic purchases of close and distant substitutes (column 3). The estimated coefficient on the own purchases variable remains significant, albeit smaller in magnitude (0.104). Purchases of close substitutes—bonds in the same maturity segment as a specific bond b—have a similar direction of impact as own purchases, implying an increase in the bond's return, while purchases of distant substitutes are associated with lower return on the bond in a different maturity segment. Price elasticities differ also in terms of size, with the coefficient on distant substitutes purchases being statistically significantly larger in absolute value compared to the coefficient on close substitutes purchases.

[18]Note that it is not possible to evaluate the cumulative effect of purchases over the entire sample period using our empirical setting. That is, the average monthly effects cannot be simply summed up over 46 months to produce the total effect of the PSPP on bond returns. In order to estimate a cumulative effect of the PSPP, one would need a different model with cross-sectional data on total purchased stocks as of the end of 2018 and a bond return change between the start and the end of the first phase of the PSPP implementation. Such analysis is beyond the scope of our paper, as we investigate the market arbitrage due to the PSPP and not the total effectiveness of the PSPP.

Table 4. Main Estimation Results—Effects of PSPP Purchases on Bond Returns

	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Own Purchases	0.028**	0.130***	0.104**	0.106**	0.106**	0.078*
	(0.011)	(0.048)	(0.047)	(0.048)	(0.047)	(0.047)
Close Substitutes			0.044*	0.118***	0.109***	0.054**
			(0.027)	(0.037)	(0.034)	(0.029)
Distant Substitutes			–0.665***	–0.252*	–0.300**	–0.384***
			(0.100)	(0.154)	(0.136)	(0.109)
Non-domestic Purchases				5.354***		
				(1.020)		
Same Group Non-domestic Purchases					1.391***	
					(0.329)	
Different Group Non-domestic Purchases					3.699***	
					(0.504)	
Same Maturity Non-domestic Purchases						1.153***
						(0.118)
Different Maturity Non-domestic Purchases						2.090***
						(0.338)
No. of Observations	32,819	32,809	32,683	32,683	32,683	32,683
No. of Bonds	997	997	995	995	995	995
R-squared (Overall)	0.279	0.278	0.278	0.276	0.276	0.272
Kleibergen-Paap rk Wald F-statistic	—	256.81	248.78	246.08	246.19	245.46
Stock-Yogo Critical Values	—	19.93	19.93	19.93	19.93	19.93

Note: The table reports the estimation results of Equation (1) where a monthly bond return is a dependent variable. Standard errors in parentheses are clustered on the bond level. ***, **, and * indicate statistical significance at 1 percent, 5 percent, and 10 percent levels, respectively. Column 1 shows the results of the fixed-effects panel OLS regression, while columns 2–6 show the second-stage results of the 2SLS IV regressions where own purchases variable is instrumented in the first-stage equation (2). Stock-Yogo critical values are reported for 10 percent maximal Wald test size distortion.

Column 4 includes total non-domestic purchases to control for spillovers from purchases by the rest of the Eurosystem. The coefficient estimate on the non-domestic purchases variable is sizable and statistically significant at the 1 percent level. Purchases of bonds by other EA countries amounting to 1 percent of total outstanding amount issued of these bonds increase a specific bond's b return by 5.35 pp on average over the sample. This implies that bond returns are significantly affected by both domestic and non-domestic purchases, which provides evidence for rebalancing within the EA government bond markets. Noteworthy, the coefficient on own purchases (0.106) is much smaller in magnitude and statistically significantly different from the coefficient on non-domestic purchases (5.354), indicating a substantially higher price elasticity of a bond to non-domestic spillovers than to own purchases.

To interpret the economic size of the coefficient, we use a one standard deviation (st. dev.) increase in purchases variables as reported in descriptive statistics in Table 3. Based on the data and the estimated coefficients in our baseline specification (Table 4, column 4), a one st. dev. increase in monthly own purchases under the PSPP raised a bond return by 7.99 bps, ceteris paribus. In addition, during a typical month a one st. dev. increase in domestic purchases of close substitutes further increased the bond b's return by 6.83 bps. The effects of own and close substitutes purchases were somewhat offset by domestic purchases of distant substitutes—one st. dev. increase in the latter reduced the bond return by 7.64 bps. Lastly, monthly non-domestic purchases equal to one st. dev. of total outstanding amount of purchased bonds raised the return of a specific bond b by 137 bps (1.37 pp), which is a relatively large economic impact, accounting for over half of a standard deviation in the bond return variable (Table 3).

Several observations can be made based on these findings. First, coefficient estimates differ substantially in size across the variables. This suggests that the price elasticity of bond returns to PSPP purchases depends on the type of purchases considered. Second, the size of the effect of own purchases on the return of a specific purchased bond is rather small. Third, purchases of close and distant substitutes seem to push the bond return in opposite directions, in some way offsetting each other. Fourth, the coefficients for non-domestic purchases as well as their economic effect are considerably larger than for own purchases of a specific bond. These findings suggest that the general purchase pace under the PSPP across all involved EA countries was of great relevance for the effect on all bond returns. Moreover, it points to an important role of arbitrage in the EA government bond markets.

Distinguishing non-domestic purchases by different dimensions does not alter our conclusions about their importance. We observe that purchases by countries from a different risk group raise the return of a domestic bond b stronger than purchases by countries in the same risk group, which is visible both from the coefficients (column 5) and from the calculated economic effect (94 bps for different group purchases versus 37 bps for same group purchases). The same holds when we compare non-domestic purchases by maturity—a one st. dev. increase in non-domestic purchases in a different maturity segment raised a bond b's return slightly more (54 bps) than purchases in the same maturity segment (45 bps).

6.2 First-Stage Regression and Alternative Instruments

This section discusses the results of the first-stage regressions in the 2SLS IV estimation of the own purchases variable on exogenous instruments and a full set of month and bond fixed effects, formalized in Equation (2). For each specification we report model diagnostics that indicate if included instruments are strong and valid, based on Sanderson-Windmeijer (S-W) weak IV statistic (conditional F-test), Stock-Yogo (S-Y) critical values, and Hansen's J test of overidentifying restrictions.

We start by including only the eligibility dummy as an instrument in Table 5, column 1, which comes out significant with an expected positive sign. In column 2 we estimate a first-stage equation with the eligibility dummy and the deviation from 33 percent limit included as instruments. The results confirm the significance of both instruments. In line with our conjecture, the larger the distance is of cumulative purchases in a specific bond b up to current month from the 33 percent allowed limit—that is, the less scarce a bond is in the market—the more of this bond a central bank can buy in the next month. The conditional F-test statistic (S-W) improves substantially; it is high and well above the S-Y critical values for relative bias and Wald-test size distortions, indicating that the instruments are strong. In addition, a test of overidentifying restrictions fails to

Table 5. First-Stage Regression of PSPP Purchases on Instrumental Variables

	(1)	(2)	(3)
Eligible_{bjt-1}	0.279***	0.283***	
	(0.037)	(0.033)	
Eligible_{bjt-1} (Excluding Criterion 2)			0.268***
			(0.036)
Deviation_{bjt-1}		0.046***	0.046***
		(0.002)	(0.002)
Bond-Specific Fixed Effects	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes
No. of Observations	32,813	32,809	32,809
No. of Bonds	997	997	997
R-squared (Overall)	0.053	0.023	0.023
Sanderson-Windmeijer Weak IV Statistic	57.32	256.81	250.40
Stock-Yogo Critical Values	16.38	19.93	19.93
Hansen's J Test of Overidentifying Restrictions	0.00	1.10	21.49
P-value	Exactly Identified	0.29	0.00

Note: The table reports the first-stage estimation results of the 2SLS IV regression, with the first-stage regression specified in Equation (2) where own purchases is a dependent variable. Standard errors in parentheses are clustered on the bond level. ***, **, and * indicate statistical significance at 1 percent, 5 percent, and 10 percent levels, respectively. Sanderson-Windmeijer weak IV statistic corresponds to Sanderson-Windmeijer conditional F-statistic for the endogenous regressor; Stock-Yogo critical values are reported for 10 percent maximal Wald test size distortion.

reject the null hypothesis of joint instrument validity. Thus, we find no evidence of consistency problems in the IV estimates and can conclude that the selected instruments are valid. This assessment is supported by high Kleibergen-Paap rk Wald F-statistic, reported in Table 4 for the second-stage regressions. The validity of instruments is also reflected in the size of the coefficient on the instrumented own purchases variable, which becomes five times larger in absolute value in the 2SLS regression (Table 4, column 2) compared to the OLS estimate (Table 4, column 1). This indicates that not addressing the endogeneity problem leads to the underestimation bias in the OLS specification, which is effectively alleviated by our IV approach.

As a robustness check, we constructed an alternative instrumental variable for eligibility, excluding the second restriction which mandates the yield level to be higher than the DFR. This restriction might be less exogenous as yields at the end of a previous period determine whether a bond is eligible or not but could also be correlated with yields in the next period. In addition, the DFR restriction became ineffective from January 2017 onwards.[19] The results of the first-stage regression using this alternative specification (Table 5, column 3) are very similar to the baseline IV specification in column 2, with the coefficient estimate for the eligibility dummy in column 3 becoming slightly smaller in absolute value. The model diagnostics is worse in this robustness check, as a Hansen's J test of overidentifying restrictions rejects the null hypothesis of joint instrument validity. The results of the second-stage regressions based on different instrumental specifications used in Table 5 show that dropping the DFR restriction in the eligibility dummy does not qualitatively change our findings about the impact of purchases on bond returns (results available on request). We conclude that using the eligibility instrument excluding the DFR restriction does not offer a better and stronger (econometrically) IV identification. Therefore, the baseline IV specification in Table 5, column 2 remains our preferred choice.

6.3 Robustness Analysis

In order to test the robustness of our main results, we conduct several sensitivity checks by modifying the sample as well as the construction of our dependent and explanatory variables. The estimation results from all robustness checks using the baseline specification (Table 4, column 4) are reported in Table 6.

First, we apply winsorizing of bond returns variable at the 1st and 99th percentile of its distribution to prevent the outliers related to technical aspects (such as end-of-year effects, inflation-linked features, and other non-plain-vanilla bonds) from distorting the regressions. We include the winsorized bond returns as a dependent variable in column 1. The results are robust to outliers in the bond return, as the effects of purchases are very close to the baseline,

[19] We thank an anonymous referee for pointing this out.

Table 6. Robustness Checks—Effects of PSPP Purchases on Bond Returns

	Winsorized Bond Return	Bond Yield Change	Excl. Days to Maturity ≤ 90	Excl. Outstand. Amount $<$ €100 mln	Risk-Weighted Purchases
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Own Purchases	0.064*	–0.008**	0.108**	0.115**	0.113**
	(0.045)	(0.004)	(0.048)	(0.053)	(0.050)
Close Substitutes	0.087**	0.003	0.115***	0.056	0.039*
	(0.035)	(0.003)	(0.037)	(0.039)	(0.024)
Distant Substitutes	–0.318**	0.066***	–0.274*	–0.400**	–0.159***
	(0.147)	(0.014)	(0.156)	(0.169)	(0.061)
Non-domestic Purchases	4.325***	–0.277**	5.339***	4.536***	5.844***
	(0.936)	(0.089)	(1.032)	(1.098)	(0.621)
No. of Observations	32,683	32,683	32,107	26,895	32,683
No. of Bonds	995	995	988	839	995
R-squared (Overall)	0.309	0.458	0.280	0.272	0.273
Kleibergen-Paap rk Wald F-statistic	246.08	246.08	242.87	226.81	135.89
Stock-Yogo Critical Values	19.93	19.93	19.93	19.93	19.93
Hansen's J Test of Overid. Restrictions	0.01	2.73	0.00	1.27	3.32
P-value	0.92	0.10	0.99	0.26	0.07

Note: The table reports the second-stage estimation results of the 2SLS IV regression specified in Equation (1) where the own purchases variable is instrumented in the first-stage equation (2). Standard errors in parentheses are clustered on the bond level. ***, **, and * indicate statistical significance at 1 percent, 5 percent, and 10 percent levels, respectively. Bond and month fixed effects are included (not shown). Column 1 uses as a dependent variable the winsorized bond returns variable with cutoffs at the 1st and 99th percentiles of its distribution. Column 2 replaces bond returns with bond yield changes as a dependent variable. Column 3 excludes observations for bonds with maturity up to 90 days. Column 4 drops observations for bonds with nominal outstanding amounts below €100 mln. Column 5 uses duration risk-weighted purchases instead of unweighted purchases. Stock-Yogo critical values are reported for 10 percent maximal Wald test size distortion.

although the coefficient estimate on the own purchases variable becomes smaller.

Second, we replace monthly bond returns with monthly bond yield changes as a dependent variable (column 2). The coefficients on own purchases and non-domestic purchases have the expected negative sign, suggesting that PSPP purchases—both domestic and by the rest of the Eurosystem—significantly reduced bond yields. These findings are consistent with our results for bond returns and in line with the related literature. Compared to De Santis and Holm-Hadulla (2020) the size of the estimated impact of own purchases is smaller in our case, likely due to the above-mentioned differences in the sample, data frequency, and IV approach.

Third, we exclude observations for bonds with a maturity of less than or equal to 90 days, as those are more likely to exhibit outliers or extreme bond returns. The estimation results for this modified sample shown in column 3 remain broadly unchanged compared to the baseline.

Fourth, we check sensitivity of outcomes to the inclusion of bonds with relatively small issuance volumes. For this purpose, we re-estimate the baseline specification while dropping bonds whose nominal outstanding amount is below €100 mln. The findings (Table 6, column 4) are close to the main ones. Thus, bonds with small issuance do not distort our estimates.

Lastly, we include duration risk-weighted net purchases instead of unweighted ones to test if purchases of bonds with a higher duration risk have a stronger effect on returns than purchases of bonds with a lower duration risk. We construct risk-weighted variables by multiplying net purchases with the remaining time to maturity in years (divided by 10 for comparability) and subsequently construct purchases variables using formulas (3)–(10). The coefficient estimates have similar signs as in the baseline specification, while magnitudes changed somewhat (column 5). Specifically, the effects of non-domestic and own purchases became larger, suggesting that duration risk extraction matters for the impact of PSPP on bond returns. Meanwhile, coefficients on other domestic purchases halved in size compared to the baseline.

These robustness checks confirm that the baseline results carry through in several modifications and do not alter the main conclusions. The model diagnostics for all 2SLS regressions in

Table 6 show that selected instruments remain strong and valid: the Kleibergen-Paap rk Wald F-statistics are well above the S-Y critical values, while the test of overidentifying restrictions does not reject the null hypothesis of joint instrument validity.

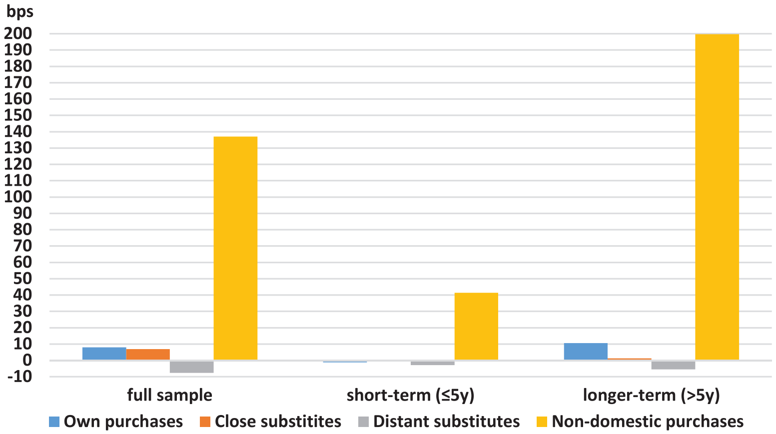
6.4 Extensions: Maturity Segments

The effects of central bank asset purchases on bond returns may vary across maturity segments—for instance, due to preferred habitat investors. To test this prior we split the sample into two groups of government bonds based on their remaining time to maturity at month *t*. We distinguish short-term bonds (remaining maturity up to five years), capturing the short end of the yield curve, and the longer-term bonds (over five years), capturing the medium- and long-term parts of the curve. We re-estimate baseline specifications (4–6) as in Table 4 for each subsample.

The results (see Table A.2 in the appendix) offer several insights. First, the estimated effects of purchases on bond returns are more pronounced—both in absolute value and in statistical significance—for longer-term bonds, in line with a higher duration risk extracted from this market segment. This holds for both domestic (own and substitutes) purchases and non-domestic ones. Second, there is no evidence on the impact of own purchases on bond returns in the short-term subsample, while there is a positive significant effect from non-domestic purchases for this segment. Third, domestic purchases of close substitutes do not have a significant effect on bond returns in either subsample, while distant substitutes have a negative impact, albeit weakly significant.

Figure 3 shows that a one st. dev. increase in non-domestic purchases raises a return of a bond in the longer-term maturity segment by 200 bps (2 pp), which is almost five times as large as the impact for the bond return in the short-term maturity segment (41 bps). In terms of economic effect of own purchases, the estimated price elasticity implies that a one st. dev. increase in own purchases raises a bond return in the longer-term segment by 10.6 bps. Based on this analysis, we can deduce that the full sample results are mainly driven by bonds in the medium- and long-term parts of the yield curve, while the impact on bonds in the short-term end of the curve seems to be less pronounced.

Figure 3. Effects of One St. Dev. Increase in Purchases, by Maturity Segments



Note: The figure plots the effects (in bps) on a bond return of one st. dev. increase in own purchases, other domestic purchases (close and distant substitutes), and non-domestic purchases under the PSPP, calculated as coefficient estimate*1 st. dev. in purchases variable. The coefficient estimates are based on column 4 in Table 4 (full sample), and columns 1 and 4 in Table A.2 in the appendix (subsamples by maturity segment).

6.5 Extensions: Core versus Non-core Countries

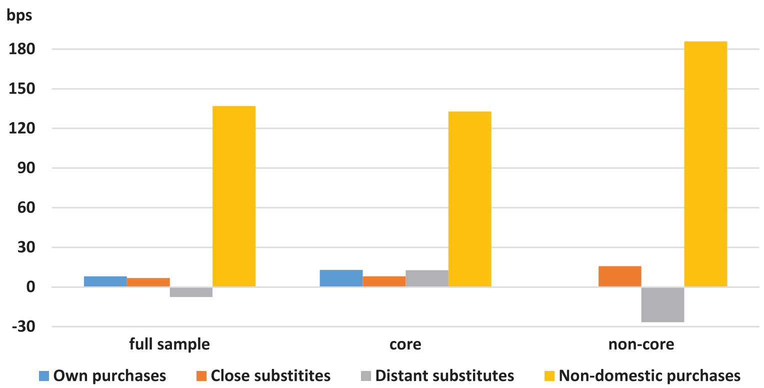
As another extension, we analyze whether the impact of bond purchases under the PSPP differs between country groups by estimating the models separately for the core (Austria, Belgium, France, Finland, Germany, the Netherlands) and the non-core EA countries (Italy, Ireland, Portugal, Spain). The results (Table A.3 in the appendix) show that the effects of purchases differ substantially between the core group (columns 1–3) and the non-core one (columns 4–6), both in terms of the sign and the magnitude. In particular, an increase in own purchases of bond b issued by countries in the core group is associated with a much stronger rise in bond returns in this country group, while the impact of own purchases in the non-core group is insignificant. Such outcome may be related to the smaller credit risk component of bonds issued in the core jurisdictions, which increases the impact of own purchases. Moreover, better market liquidity in core countries can also contribute to stronger upward effects on the return of bonds that are being purchased. This is also in line with Kabaca et al. (2023), who find in a theoretical setting that a monetary union-wide QE reduces somewhat more term premiums of bonds issued in the core region than for bonds issued in the non-core region.

The estimated coefficients on close substitutes purchases for non-core countries are twice larger than for the core group. Perhaps this compensates for the weak effect of own purchases in the former group, with purchases in the same maturity segment having a stronger impact due to investors' portfolio rebalancing into similar bonds. The effect of distant substitutes differs across two subsamples: these purchases raise bond returns in the core countries, thus complementing the close substitutes purchases, while decreasing the bond returns in the non-core group, thus offsetting the effect of close substitutes.

The important result we find, which is novel in the empirical literature on PSPP, is the stronger impact of non-domestic purchases on bond returns in the non-core countries. Purchases by other countries equal to 1 percent of total outstanding amount of bought bonds raise the bond return by 5.2 pp in the core countries and by 7.2 pp in the non-core ones. The effect becomes particularly sizable when we split non-domestic purchases by the risk group (columns 2 and 5). The estimated coefficient on non-domestic different group purchases is almost three times larger in the non-core group than in the core one. The results for non-domestic purchases by bond maturity segment are rather comparable across the country groups.

Figure 4 shows the economic effects of a one st. dev. increase in purchases variables for two country groups. In line with the estimated coefficients, the economic size differs across the country groups, with a larger effect on a bond return of own purchases for the core jurisdictions (13 bps) than the non-core (–0.6 bps). Substantial differences in the economic impact are observed for non-domestic purchases: a one st. dev. increase in total non-domestic purchases raises a bond return in the core countries by 133 bps (1.3 pp) and by 186 bps (1.9 pp) in the non-core. These results suggest that the general pace of the PSPP was relatively more effective for raising bond returns in the EA non-core economies, in line with the observed data.

Figure 4. The Effects of One St. Dev. Increase in Purchases, by Country Groups



Note: The figure plots the effects (in basis points) on a bond return of one st. dev. increase in own purchases, other domestic purchases (close and distant substitutes), and non-domestic purchases under the PSPP, calculated as coefficient estimate*1 st. dev. in purchases variable. The coefficient estimates are based on column 4 in Table 4 (full sample), columns 1 and 4 in Table A.3 in the appendix (subsamples by country group).

This is also plausible from a theoretical point of view. When risk-free rates decrease, risk premiums are likely to decrease as well—for instance, because of improved debt sustainability. Since risk premiums are larger for non-core countries, the potential for increasing bond returns through the portfolio rebalancing channel is larger in these jurisdictions. The already low yields in the core countries may therefore trigger investors to rebalance their portfolios towards higher-yielding sovereign bonds issued by the non-core countries, thereby creating additional demand for those bonds and boosting their returns. In addition, the non-core jurisdictions may benefit relatively more than the core countries from the improved market liquidity and anticipation of increased European risk-sharing and reduced borrowing costs due to the PSPP. The latter can be partially due to the signaling channel of central bank purchases—PSPP signals a reduction of liquidity and credit risk in the entire EA and may be viewed as a commitment of the ECB to keep short-term interest rates at the effective lower bound for a longer time (e.g., King 2020).

7. Conclusions

This paper investigates cross-border spillover effects from the Eurosystem's PSPP on EA government bond returns. We provide evidence on how PSPP purchases of an individual bond, of bonds with a similar or different maturity, as well as purchases by the rest of the Eurosystem affected bond returns. The overall findings show that PSPP purchases had a significantly positive effect on bond returns. This holds not only for own purchases of a specific bond but also for other bond purchases within a particular country or across other EA countries.

The finding that the impact of bond purchases spreads across countries and maturity segments complements earlier research by showing the important role that arbitrageurs play in EA government bond markets. If these markets were completely fragmented, bond purchases in one EA country would have no effect on bond returns in other EA countries, ceteris paribus. The large cross-border effects, documented in this paper, suggest that arbitrageurs affect bond prices across EA government bond markets following large-scale PSPP bond purchases.

Our results have several policy implications. First, PSPP purchases have been effective in pushing down yields, while simultaneously raising bond returns, which is an important criterion for conducting central bank asset purchase programs in the first place. The effect appears to be most pronounced for bonds with longer maturities and lower credit ratings, which can be explained by the larger duration and credit risk extraction in these cases. The relatively large impact of non-domestic purchases in these market segments can be attributed to spillovers from higher-rated low-maturity bonds due to investors rebalancing their sovereign bond portfolio towards higher-yielding sovereign bonds.

Second, the results suggest that the precise distribution of government bond purchases over different countries may have a limited impact on the overall transmission of the ECB's monetary policy across EA countries as long as the arbitrage functions well in the bond markets. With arbitrageurs at work, it appears to be less relevant which bonds are being bought—as long as the overall volume is purchased. While not explicitly tested in this paper, the effect of the distribution of bond purchases might, however, also have an impact via the expectations channel after public ECB announcements. Moreover, the transmission of bond purchases across countries may depend on market liquidity and may be hampered in times of financial stress. There could also be limitations when purchases are concentrated in a few bond issues or in one particular maturity segment. In particular, price distortions would arise when purchases crowd out arbitrageurs and preferred habitat investors fully dominate these bond holdings. Preventing these potential market distortions can justify spreading bond purchases across a large number of bonds when conducting the PSPP.

Finally, our empirical framework can be applied for evaluating other (past, ongoing, and future) asset purchase programs in the EA. The important aspect that we add to the literature—i.e., considering spillover effects from bond purchases by central banks in other EA countries—potentially matters for the effectiveness of central bank purchase programs and, therefore, needs to be taken into account. In this sense, the Eurosystem's Pandemic Emergency Purchase Program (PEPP) can be an important testing ground for new research on the effectiveness of asset purchase programs in the EA.

Appendix

Table A.1. Effects of PSPP in the Euro Area: Empirical Evidence

Study	Time Period	Country Sample	Empirical Approach	Estimated Effect
PSPP Announcements—Effect on 10-Year Bond Yield				
Altavilla, Carboni, and Motto (2021)	9/2014–3/2015	Euro Area	Event Study Daily Data	–65 bps
Andrade et al. (2016)	3–12/2015	Euro Area	Event Study Daily Data	–45 bps
Eser et al. (2019)	1/2015–6/2018	Euro Area	Term Structure Model Monthly Data	–50 bps (Initial Announcement) –95 bps (Overall)
De Santis (2020)	9/2014–10/2015	10 Euro Area Countries	Panel Error Correction Model Daily Data	–72 bps
PSPP Actual Purchases—Effect on 10-Year Bond Yield				
Arrata and Nguyen (2017)	3/2015–3/2016	France	OLS, IV Regressions Cross-Sectional Data	Per 10% of Amount Outstanding Purchased: –13 bps (OLS) –26 bps (IV)
Koijen et al. (2021)	2015:Q1–2017:Q4	Euro Area	2SLS Regressions Quarterly Data	Per 10% of Amount Outstanding Purchased: –63 bps on Average; Between –38 and –83 bps across Countries
PSPP Actual Purchases—Effect on Average Bond Return				
De Santis and Holm-Hadulla (2020)	3/2015–6/2016	Euro Area	2SLS Regressions Daily Data	Per 1% of Amount Outstanding Purchased: +5.5 to +7.5 bps
Schlepper et al. (2020)	9/2015–10/2016	Germany	Panel Regressions Intraday and Daily Data	Per €100 mln Purchased: +8.9 bps

Table A.2. Effects of PSPP Purchases on Bond Returns, by Maturity Segment

	Short Term (Up to Five Years)			Longer Term (Over Five Years)		
	(1)	(2)	(3)	(4)	(5)	(6)
Own Purchases	–0.016	–0.009	–0.008	0.138**	0.133**	0.167***
	(0.023)	(0.022)	(0.023)	(0.065)	(0.063)	(0.068)
Close Substitutes	0.002	–0.002	–0.016	0.022	0.007	0.064
	(0.013)	(0.014)	(0.011)	(0.046)	(0.043)	(0.046)
Distant Substitutes	–0.090*	–0.113*	–0.148***	–0.192	–0.291	–0.241
	(0.055)	(0.059)	(0.039)	(0.243)	(0.206)	(0.183)
Non-domestic Purchases	1.650**			7.706***		
	(0.786)			(1.483)		
Same Group Non-domestic Purchases		0.100			2.156***	
		(0.378)			(0.448)	
Different Group Non-domestic Purchases		1.287**			4.898***	
		(0.556)			(0.667)	
Same Maturity Non-domestic Purchases			0.076*			2.835***
			(0.040)			(0.257)
Different Maturity Non-domestic Purchases			0.705***			6.359***
			(0.258)			(0.630)
No. of Observations	11,800	11,800	11,800	20,883	20,883	20,883
No. of Bonds	505	505	505	643	643	643
R-squared (Overall)	0.086	0.094	0.090	0.415	0.415	0.416
Kleibergen-Paap rk Wald F-statistic	79.74	78.27	77.81	140.66	141.59	139.16
Stock-Yogo Critical Values	19.93	19.93	19.93	19.93	19.93	19.93

Note: The table reports the second-stage estimation results of the 2SLS IV regression specified in Equation (1) where a monthly bond return is a dependent variable and the own purchases variable is instrumented in the first-stage equation (2). Standard errors in parentheses are clustered on the bond level. ***, **, and * indicate statistical significance at 1 percent, 5 percent, and 10 percent levels, respectively. Bond and month fixed effects are included (not shown). Stock-Yogo critical values are reported for 10 percent maximal Wald test size distortion.

Table A.3. Effects of PSPP Purchases on Bond Returns, by Country Group

	Core Countries			Non-core Countries		
	(1)	(2)	(3)	(4)	(5)	(6)
Own Purchases	0.160***	0.158***	0.121**	–0.009	–0.012	–0.010
	(0.057)	(0.057)	(0.059)	(0.077)	(0.076)	(0.075)
Close Substitutes	0.133***	0.112***	0.087***	0.292***	0.279***	0.185**
	(0.028)	(0.026)	(0.024)	(0.095)	(0.095)	(0.074)
Distant Substitutes	0.400***	0.286**	0.309***	–0.959***	–1.033***	–1.189***
	(0.130)	(0.119)	(0.096)	(0.254)	(0.259)	(0.204)
Non-domestic Purchases	5.232***			7.175***		
	(1.006)			(1.622)		
Same Group Non-domestic Purchases		1.918***			1.631***	
		(0.413)			(0.492)	
Different Group Non-domestic Purchases		8.267***			23.386***	
		(1.556)			(2.985)	
Same Maturity Non-domestic Purchases			1.267***			0.895***
			(0.161)			(0.162)
Different Maturity Non-domestic Purchases			2.144***			1.308***
			(0.404)			(0.499)
No. of Observations	18,454	18,454	18,454	14,229	14,229	14,229
No. of Bonds	556	556	556	439	439	439
R-squared (Overall)	0.326	0.327	0.322	0.316	0.318	0.316
Kleibergen-Paap rk Wald F-statistic	163.73	162.93	159.19	106.04	105.75	106.57
Stock-Yogo Critical Values	19.93	19.93	19.93	19.93	19.93	19.93

Note: The table reports the second-stage estimation results of the 2SLS IV regression specified in Equation (1) where a monthly bond return is a dependent variable and own purchases variable is instrumented in the first-stage equation (2). Standard errors in parentheses are clustered on the bond level. ***, **, and * indicate statistical significance at 1 percent, 5 percent, and 10 percent levels, respectively. Bond and month fixed effects are included (not shown). Stock-Yogo critical values are reported for 10 percent maximal Wald test size distortion.

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