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Abstract

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JEL Classification: N/A

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Inspecting the Mechanism of Quantitative Easing in the Euro Area*

Ralph S.J. Koijen† François Koulischer‡ Benoît Nguyen§ Motohiro Yogo¶

July 27, 2019

Abstract

Using new data on security-level portfolio holdings by investor type and across countries in the euro area, we study portfolio rebalancing during the European Central Bank's (ECB) purchase programme that started in March 2015. To quantify changes in risk concentration, we estimate the evolution of the distribution of duration, government, and corporate credit risk exposures across investor sectors and regions until the last quarter of 2017. Using these micro data, we show that 60% of ECB purchases are sold by non-euro area investors, and we do not find evidence that risks get concentrated in certain sectors or geographies. We estimate a sector-level asset demand system using instrumental variables to connect the dynamics of portfolio rebalancing to asset prices. Our estimates imply that government yields declined by 47bp, on average, but the estimates range from -28bp to -57bp across countries.

Keywords: Quantitative Easing, Flow of Risk, Portfolio Rebalancing, Risk Concentration.

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In response to growing concerns about a prolonged period of low inflation, the European Central Bank (ECB) announced the expanded asset purchase programme on January 22, 2015. The objective is to increase inflation to a level close to, but below, 2%. The initially announced size of the purchase programme was €60 billion per month until September 2016, starting in March 2015. The programme has subsequently been expanded in various ways.

Central banks in Japan, the United Kingdom, and the United States, among others, have implemented similar quantitative easing (QE) programmes when interest rates reached levels close to zero. The recent literature has explored various channels through which unconventional monetary policy can affect asset prices, inflation, and economic growth more broadly. To quantify the importance of various channels, the standard approach is to use event studies and to measure the response of various asset prices around key policy announcements.[1]

We extend this literature by looking at prices and portfolio rebalancing jointly using new data on security-level portfolio holdings for all major investor sectors, including banks, insurance companies and pension funds, and mutual funds, and for all countries in the euro area. For each sector in a particular country, we observe the quarterly holdings of government bonds, corporate bonds, asset-backed securities (including covered bonds), and equities, both in and outside of the euro area. We link these portfolio holdings to detailed data on prices and security characteristics. We also observe the ECB's security-level holdings and purchases, both from the ongoing asset purchase programme as well as the legacy holdings from earlier programmes. We use these data to quantify which investors sell to the ECB, how investors' portfolio rebalancing impacts the distribution of financial risk exposures across investors and geographies, how it impact government yields, and which investors, again differentiated by investor type and geography, experience the largest appreciation of their asset portfolio.

Our sample is from 2013Q4 to 2017Q4. To summarize the initial conditions, we first document the portfolio holdings and risk exposures before the announcement of the asset purchase programme using data from 2013Q4 to 2014Q4.[2] For all securities in an investor's portfolio, we measure the euro-area duration, government and corporate credit, and equity risk exposure.[3] In addition, we summarize the holdings by euro-area investors of foreign, that is, securities issued outside the euro area or securities issued in foreign currency. By imposing market clearing, our framework measures how aggregate risks are shared across investors before the programme was announced.

[1] See for instance Gagnon, Raskin, Remache, and Sack (2011) and Krishnamurthy and Vissing-Jørgensen (2011) for the United States and Krishnamurthy, Nagel, and Vissing-Jorgensen (2017) for Europe.

[2] A summary of these facts is presented in Koijen, Koulischer, Nguyen, and Yogo (2017).

[3] Begenau, Piazzesi, and Schneider (2015) study the dynamics of banks' risk exposures to interest rate risk and credit risk. Our data allow us to also measure risk exposures to government and equity risk and we can measure exposures for other institutions than banks, such as mutual funds, insurance companies, and pension funds.

We then measure how investors rebalance their portfolios during the programme. Our security-level data allow us to measure which investors sell to the ECB for narrow groups of securities that are differentiated by issuer country and maturity. We develop a simple regression framework, based on the market clearing condition in changes, to exactly decompose how different investors sell in response to purchases by the ECB.

We also use the same risk accounting framework, but now applied in changes, to understand how the programme affects the distribution of risk exposures across investors and to explore whether risks get concentrated in certain sectors or geographies. To safeguard the confidentiality of our data, we report our results at the level of two regions that we classify as vulnerable countries (Italy, Spain, Portugal, Greece, Cyprus, and Ireland) and non-vulnerable countries (all other countries), following Altavilla, Pagano, and Simonelli (2017), but the underlying estimates use our more granular country-level data.

To relate investors' rebalancing to government bond yields, we estimate a sector-level asset demand system in which we model the demand curves of investors as a function of prices (or bond yields), bond characteristics, and latent demand that captures investors' expectations or constraints beyond the characteristics included in the model. Koijen and Yogo (2019) provide a micro foundation for this empirically-tractable model of asset demand curves. In particular, they show that this specification is consistent with a model in which investors have mean-variance preferences. In addition, investors assume that returns follow a factor model and both expected returns and factor loadings are affine functions of a set of characteristics.

As prices are endogenous to latent demand, we develop an instrumental variables estimator using a unique feature of the purchase programme. While we cannot use the aggregate time variation, as it is correlated with economic conditions in the euro area, the allocation of those purchases to different bond markets contains an exogenous component as the assignment is based on the capital key. The capital key is a formula based on GDP and population shares, both receiving equal weight.[4] Using heterogeneity in the size of the purchases relative to the size of the bond market gives us exogenous cross-sectional variation in demand shocks (or, equivalently, residual supply) across countries.

Our approach complements the event study approach that has been explored extensively in the literature to estimate the impact of purchase programmes. This approach estimates price responses on a small number of important policy announcement days. A potential drawback of this empirical strategy is that investors may anticipate (parts of) the purchase

[4]It is important to note that the capital key uses the level of GDP and not GDP per capita. If one would still be concerned about endogeneity of GDP shares, we could instead use population shares only to construct the instrument as we have done in an earlier version of the paper.

programme and that expectations adjust gradually in response to the flow of macroeconomic and financial news. Our empirical strategy does not require the selection of these days and uses an instrument based on the capital key instead.

Using our new security-level holdings and purchase data, we document five new insights:

1. All institutions in vulnerable countries, including insurance companies, pension funds, and mutual funds, have a strong home bias in their fixed income portfolios compared to the same institutions in non-vulnerable countries. As such, the feedback loop between the financial sector and governments, which received a lot of attention among regulators, is not limited to banks, but extends to institutions that safeguard households' long-term savings.

2. The foreign sector sells most in response to the programme (approximately €0.60 per euro purchased), followed by banks (approximately €0.30 per euro purchased) and mutual funds (approximately €0.10 per euro purchased). Long-term investors, such as insurance companies and pension funds, do not sell in response to the programme and, if anything, tend to buy some of the same securities as the ECB. The foreign sector sells bonds issued in vulnerable and non-vulnerable countries at roughly the same rate, and do not reinvest their proceeds elsewhere in the euro area.

3. We do not find evidence of risk concentration or large-scale rebalancing across asset classes. For duration risk, if anything, the programme appears to reduce mismatch risk.

4. Our first-stage estimates of the demand system imply that government yields declined by 47bp, on average, as a result of the programme, but the estimates range from -28bp to -57bp across countries. We connect these price responses to the demand curves of different sectors. The estimates imply to substantial heterogeneity across investors with the foreign sector's demand being most elastic with respect to prices. A recent generation of asset pricing models explicitly models intermediaries and how they may matter for purchase programmes.[5] Our results highlight the importance of investor heterogeneity in absorbing demand shocks.[6] As most models feature on a single class of intermediaries, an important direction for future research is to allow for more heterogeneity among intermediaries.

[5]See for instance He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), and Brunnermeier and Sannikov (2016).

[6]See Coimbra and Rey (2019), Koijen and Yogo (2019), and Greenwood, Hanson, and Liao (2018) for models with richer heterogeneity across institutions.

5. We conclude by using the price estimate, combined with the sensitivity of investors' portfolio to movements in the euro-area yield curve, to measure the valuation impact on investors' portfolios.[7] As institutions (banks, mutual funds, and insurance companies and pension funds) in non-vulnerable countries hold longer-duration portfolios compared to vulnerable countries and because they are larger, they benefit more. The total valuation effect equals €377 billion, of which €179 billion went to investors in non-vulnerable countries, €67 billion to investors in vulnerable countries, and the remaining €131 billion to investors outside of the euro area.

Theories of Quantitative Easing: The Dynamics of Risk Exposures and Asset Prices

We group different theories to interpret our results into three categories. First, Wallace (1981) and Eggertsson and Woodford (2003) derive irrelevance results similar to Modigliani and Miller (1958) for corporate capital structure. If markets are complete, households can unwind any exposures coming from changes in the central bank's portfolio. As a result, consumption, inflation, and asset prices are unaffected by the QE programme. The model in Eggertsson and Woodford (2003) features a representative household. In a model with heterogeneous investors, the same economic mechanism suggests that only the investors that are exposed to the trading gains and losses of the central bank (via taxation) adjust their portfolios.[8]

Second, QE can have a positive effect on asset prices and growth through various channels. Eggertsson and Woodford (2003) argue that QE programmes may be used to signal future monetary policy.[9] By buying long-term bonds, the central bank could have an incentive to keep interest rates low until the bonds mature to avoid large mark-to-market losses. The second channel through which prices and portfolios change is the "portfolio balance channel." If the central bank purchases government bonds, it reduces the amount of duration and government credit risk in the hands of investors, which lowers risk premia (Vayanos and Vila (2009)).[10] In response to lower risk premia in government bond markets, investors optimally rebalance their portfolios and increase prices (and lower risk premia) of other risky assets. Depending on how investors substitute across various risk factors or characteristics (such as maturity), other asset prices are affected (Krishnamurthy and Vissing-Jørgensen (2011)). We

[7] As we do not have information on the structure of the liabilities, we cannot estimate the impact on the overall funding positions of various intermediaries.

[8] In the United States, Carpenter, Demiralp, Ihrig, and Klee (2015) show using data from the Flow of Funds that the household sector (which includes hedge funds) is an important group selling to the Fed. In Japan, Saito and Hogen (2014) document that the foreign sector sells in response to QE programme.

[9] See also Mussa (1981) and Clouse, Henderson, Orphanides, Small, and Tinsley (2003).

[10] See also Greenwood and Vayanos (2014) and Greenwood, Hanson, and Vayanos (2016).

use our risk accounting framework to measure directly how investors change their exposures to key risk factors.

Brunnermeier and Sannikov (2016) develop a model in which an increase in asset prices can relax the financial constraints faced by institutions and increase their lending activity, which in turn affects inflation and economic growth. We use our detailed holdings data to show how eligible securities are distributed across investor sectors and geographically and how much different investors benefit from QE.

The third category of theories highlights potential financial stability concerns as a results of QE. If successful, the yields of safe assets and the funding costs of intermediaries decrease. In response, investors may decide to take on (excessive) levels of leverage, leading to financial fragility (Woodford, 2011, Coimbra and Rey, 2019). In addition to leverage, investors may take on additional forms of risk, such as liquidity and credit risks (Stein, 2012). Of course, in part, this is precisely the objective of QE. However, risks may get concentrated in certain sectors, which may lead to financial instability. Although such risk shifting incentives are perhaps best addressed through capital and risk regulation of banks and insurance companies, regulation may be slow to adjust. Our risk accounting framework can be used to monitor the dynamics of risk exposures and risk concentration across countries and institutional sectors.

1. Asset Purchase Programmes in the Euro Area

We summarize the asset purchase programmes that the ECB implemented since the euro crisis in the fall of 2009. The first covered bond purchase programme (CBPP1) of €60 billion was implemented from July 2009 until June 2010. From November 2011 to October 2012, the ECB implemented a second covered bond purchase programme (CBPP2) of €16.4 billion. The securities markets programme (SMP) was implemented from May 2010 until September 2012 and was used to buy government bonds from vulnerable countries through secondary markets. The size of the SMP portfolio at its peak was around €210 billion. The securities purchased as part of these programmes will be held until maturity and we observe the legacy holdings of the SMP. In September 2014, the ECB added a purchase programme for asset-backed securities (ABSPP) and a third covered bond purchase programme (CBPP3).

In January 2015, the ECB announced the extended asset purchase programme (EAPP), which is the main focus of our paper. The EAPP has three components: it extends the ABSPP and CBPP3 and adds the public sector purchase programme (PSPP). The PSPP purchases bonds of euro-area governments, agencies, and European institutions. The PSPP has been modified several times. We summarize the key dates, and subsequent modifications, in Table I.

Table I: Expanded Asset Purchase Programme (EAPP): Key Policy Announcements. The table summarizes the key announcement dates and policy changes of the EAPP.

Date	Policy Announcement
Sep. 4, 2014	Deposit facility rate (DFR) decreased to -0.2% as of September 10, 2014.
Jan. 22, 2015	Announcement of the EAPP. Total monthly purchases of €60 billion from March 9, 2015 until the end of September 2016. Eligible public sector assets must have a remaining maturity between 2 and 30 years and a yield to maturity above the DFR. Issuer limit and Issue limit set at 33% and 25% respectively.
Jul. 16, 2015	Expansion of the list of government agencies eligible for purchases.
Sep. 3, 2015	Issue share limit increased to 33% except for bonds with specific CACs. Effective as of November 10, 2015.
Dec. 3, 2015	(1) DFR decreased to -0.3% as of December 9, 2015. (2) EAPP is extended until the end of March 2017. (3) Reinvestment of the principal payments from the purchases. (4) List of eligible assets is enlarged to include euro-denominated marketable debt instruments issued by regional and local governments located in the euro area.
Mar. 10, 2016	(1) DFR decreased to -0.4% as of March 16, 2016. (2) Monthly purchases under the EAPP to be expanded to €80 billion starting on April 1, 2016. (3) ECB launches Corporate Sector Purchase Programme (CSPP). Purchases to be included in the combined monthly purchases and will begin in late June 2016. (4) The issuer and issue share limits for securities issued by eligible international organizations and multilateral development banks is increased to 50%.
Apr. 21, 2016	Publication of technical details on CSPP purchases.
Dec. 8, 2016	(1) Purchases of €80 billion per month decreased to €60 billion as of April 2017. (2) EAPP is extended until the end of December 2017. (3) The minimum maturity threshold for eligibility is decreased to 1 year. (4) Purchases of securities under the EAPP with a yield to maturity below the DFR will be permitted to the extent necessary.
Jan. 19, 2017	Publication of technical detail on purchases below the DFR.
Oct. 26, 2017	(1) From January 2018 the net asset purchases are intended to continue at a monthly pace of €30 billion until the end of September 2018. (2) ECB publishes additional data on redemptions as well as information about reinvestments and role of private sector purchase programmes.
Jun. 14, 2018	(1) After September 2018 the monthly purchases will be reduced to €15 billion until the end of December 2018 and net purchases will then end.
Dec. 3, 2018	Five-yearly adjustment of capital key.
Dec. 13, 2018	The new capital key will guide the reinvestments.

The combined purchases were announced to be €60 billion per month starting in March 2015. The initial programme was supposed to end in September 2016. The programme would lead to Eurosystem purchases of €1.14 trillion, which amounts to approximately 15% of the euro area's GDP. The stated objective of the programme is to stimulate economic activity by lowering the borrowing costs of firms and households in an environment where the main policy rates are close to their effective lower bound. Ultimately, this should help restoring inflation at a level close to, but below, 2%.

Before the start of the PSPP, the purchases of the ABSPP and CBPP3 programmes amount to €10 billion a month. In addition, the ECB announced that the PSPP was split into purchasing bonds of supranational institutions[11] located in the euro area (12%) and governments (88%). Assuming that the ABSPP and CBPP3 purchases continue at the same pace, this corresponds to purchases of €6 billion of supranational bonds and €44 billion of government bonds (Claeys, Leandro, and Mandra, 2015).

These €44 billion of purchases are allocated to bonds issued by different euro-area governments according to the "capital key," which is a country's share of the ECB's capital. The capital key weight of a country is an equal-weighted average of its GDP and population shares.[12] The purchases are held by national central banks and the ECB. For 20% of the purchases, losses are shared via the ECB according to the capital key. Throughout the paper, we refer to ECB purchases as the sum of all purchases by Eurosystem central banks.

The ECB specified a set of eligibility criteria for bonds that are purchased as part of the PSPP. The bonds need to be investment grade (corresponding to a credit rating of at least BBB), with additional criteria for countries operating under an EU/IMF Eligible Asset Rating adjustment program. The bond maturities need to be between 2 and 30 years, and up to 33% (25%) of an issuer (issue) can be purchased.[13] In addition, the yield to maturity has to be above the deposit facility rate, which was equal to -20bp at the launch of the programme. The deposit facility rate is the interest banks receive for depositing money with the central bank overnight.

Bonds issued by certain national agencies is also eligible, such as for instance the bonds of the Landeskreditbank Baden-Württemberg Foerderbank. Across maturities, the ECB intends to act as "market neutral" as possible, which we interpret as buying (approximately)

[11]Supranational institutions in the euro area include the European Financial Stability Facility, the European Investment Bank, the European Stability Mechanism, the European Union, the European Atomic Energy Community, the Council of Europe Development Bank, and the Nordic Investment Bank.

[12]The ECB adjusts the shares every five years and whenever a new country joins the EU. The adjustment is made on the basis of data provided by the European Commission.

[13]The issue-level limit may be raised on a case-by-case basis. The issuer limit of 33% is a means to safeguard market functioning and price formation as well as to mitigate the risk of the ECB becoming a dominant creditor of euro area governments.

in proportion to the outstanding maturity distribution between 2 and 30 years.

2. Data Description

2.1. Portfolio Holdings and Asset Characteristics

We use data on security-level portfolio holdings of euro-area investors from the Securities Holding Statistics (SHS).[14] Securities in our sample are identified by a unique International Securities Identification Number (ISIN). The data are collected on a quarterly basis from custodian banks in the euro area since 2013Q4, which is the first quarter of our sample. The last available quarter at the time of writing is 2017Q4.

Investors in the SHS are defined by sector and by country of domicile. There are six aggregate sectors: households, monetary and financial institutions (MFI), insurance companies and pension funds (ICPF), other financial institutions (OFI), general government, and non-financial corporations.[15] OFI includes important intermediaries such as mutual funds and hedge funds. We will refer to MFI as banks and to OFI as mutual funds, which are the largest representatives of these groups. We group non-financial corporations and general government as a sector labeled "Other" as we mostly focus on banks, mutual funds, insurance companies and pension funds, the ECB, and the foreign sector. The countries are the 19 member states of the euro area.[16] The total holdings reported in the SHS correspond to approximately €27 trillion during our sample. The assets covered include both government and corporate bonds, equities, mutual fund shares, asset-backed securities (ABS), and covered bonds.

We merge the SHS with data on the securities held by the ECB as part of the SMP, the CBPP3, and the PSPP. Holdings are observed at the same level of detail and frequency as the SHS so that the combined data sources provide a unique overview of the portfolios of public and private investors in the euro area.

To protect the confidentiality of our data, we compute the duration risk held by the ECB using publicly-available data. If the weighted-average maturity of the ECB's portfolio is available, we select a sample of government bonds with maturities in a one-year window around it and compute the weighted-average duration of these bonds. For covered bonds and ABS, we take the duration of the market portfolio based on these securities.

Our main data source for security characteristics is the Centralised Securities Database (CSDB). The CSDB contains information on more than six million active debt securities,

[14] We refer to EU Regulation 1011/2012 for more information on SHS.

[15] The sector definitions follow the European System of Accounts 1995 (ESA 95) standard.

[16] The list of countries is Belgium, Germany, Ireland, Greece, Spain, France, Italy, Cyprus, Luxembourg, Malta, The Netherlands, Austria, Portugal, Slovenia, Slovakia, Finland, Estonia, Latvia, and Lithuania.

equities, and mutual fund shares issued by companies globally. The data are from both public and commercial sources and the database is managed by the ESCB (ECB, 2010). A key variable used in CSDB is price, which is the market price when available. For debt securities for which prices are unavailable, for instance, when a bond does not trade, the price is estimated using the reference information of the security.

We complement the CSDB with data on credit ratings given by Standard and Poor's, Moody's, Fitch, and DBRS. These are the four rating agencies recognized as "External credit assessment institutions" by the Eurosystem, which publishes also a mapping between the different rating scales. We use the long-term asset-level credit rating. If this rating is unavailable, then we use, in order of priority, the short-term asset level credit rating, the long-term issuer rating or the short-term issuer rating. In assigning ratings, we follow the priority rule used by the Eurosystem.[17] When we have ratings from multiple agencies, we apply the rules defined in the guidelines (first-best rating for non-ABS securities and the second-best rating for ABS).

2.2. Security Types

We study the direct holdings of debt instruments and equities. We account for all indirect holdings of securities through mutual funds as part of the mutual fund sector. We group securities into broad categories as summarized in Figure 1. We use the CSDB characteristics to classify securities, unless mentioned otherwise.

First, we distinguish "euro-area" and "non-euro-area" securities. Euro-area securities are defined as euro-denominated securities issued in the euro area. It is useful to make this distinction for some of our calculations as we do not always have data on the total amount of debt outstanding for securities issued outside of the euro area (at both face and market value). However, we always have accurate data on holdings of euro-area investors for securities issued inside and outside of the euro area.

For euro-area securities, we separate equity and fixed income securities and we consider a finer breakdown of debt securities. We define government debt as debt issued by the general, central, state or local government sectors. Non-government debt is issued by the remaining issuer sectors. We divide government debt into "PSPP eligible" and "PSPP ineligible," depending on whether a bond satisfies the eligibility criteria outlined in Section 1. In addition, we also classify a bond as PSPP eligible if the Eurosystem purchase data show that a bond has been purchased as part of the PSPP.

[17] Guideline 2015/510 of the ECB on the implementation of the Eurosystem monetary policy framework, Art.82/83/84 "The Eurosystem shall consider ECAI issue ratings in priority to ECAI issuer or ECAI guarantor ratings."

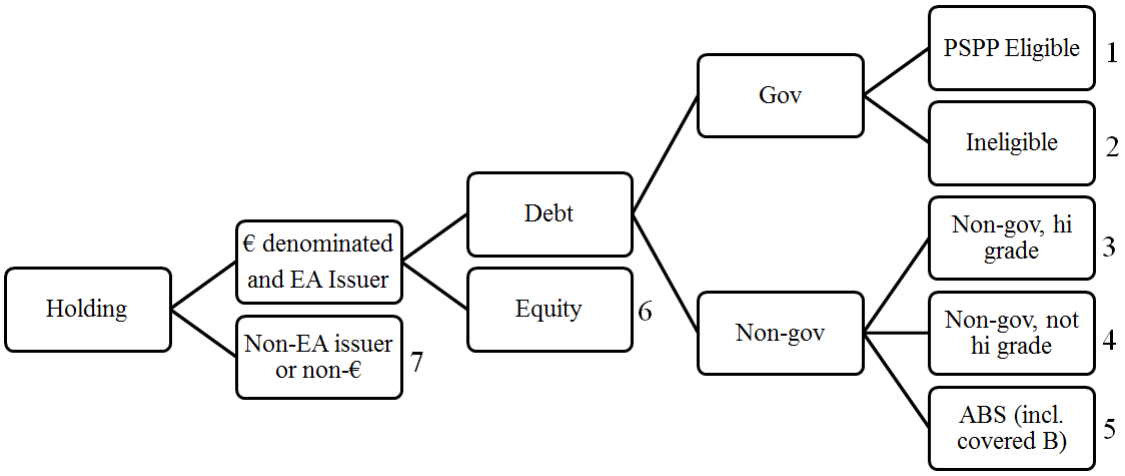


Figure 1: Summary of security types.

We split non-government debt into corporate bonds and collateralized debt, which includes ABS and covered bonds. To distinguish standard corporate bonds from ABS, covered bonds, medium-term notes, and commercial paper, we use data on asset type from the Eurosystem collateral database. If this information is missing, we rely on the CSDB to determine the type of debt.[18] We omit commercial paper as we do not focus on the very short end of the yield curve.

We use data on credit ratings to group corporate bonds into investment grade and speculative grade. If bonds are unrated, we classify them as speculative grade. Panel A of Table II summarizes the definitions of the asset categories.

2.3. Investor Types

In addition to the investor sectors defined in Section 2.1, we construct the holdings of the "foreign sector," which are all non-euro area investors, as the difference between the total amount outstanding of a given security from the CSDB and the aggregate holdings of euro-area investors. Combined with the holdings data from the SHS and the data on Eurosystem purchases, we consider in total seven investor types as summarized in Panel B of Table II.

Within the euro area, investors differ along two dimensions. First, several sectors are subject to some form of risk regulation, such as banks and insurance companies. Second, investors differ in terms of the maturity structure of their liabilities. For instance, banks have

[18]Standard bonds are defined as debt types D.1, D.11, D.15, D.16, D.164, D.18. Covered bonds correspond to asset types 9, 10, 12 and 13 in the ECB collateral database and debt types D.21, D.23 and D.233 in CSDB. Medium term notes are asset types 02 in the collateral database or debt types D.3 and D.32 in CSDB. Commercial paper is asset type 03 in the collateral database and debt types D.7, D.72, D.74 and D.742 in CSDB.

Table II: Definitions of asset categories and investor sectors.

Panel A: Definition asset categories

Category	Description
1	PSPP-eligible government bonds, € denominated, and euro-area issuer.
2	PSPP-ineligible government bonds, € denominated, and euro-area issuer.
3	High-grade corporate debt (incl. medium-term notes), € denominated, and euro-area issuer.
4	Low-grade corporate debt (incl. medium-term notes), € denominated, and euro-area issuer.
5	Asset backed securities (incl. covered bonds), € denominated, and euro-area issuer.
6	Equity, € denominated, and euro-area issuer.
7	Non-euro-area issuer or in a currency other than euros.

Panel B: Definition investor sectors

Sector	Description
1	Household sector (HH).
2	Insurance companies and pension funds (ICPF).
3	Monetary financial institutions, such as banks (MFI).
4	Other financial institutions, such as mutual funds (OFI).
5	Foreign investors.
6	Other (General government and Non-Financial Corporations).
7	Eurosystem holdings in the framework of the PSPP, CBPP, and the SMP.

short-term liabilities that may be subject to runs, while insurance companies have long-term liabilities that cannot be withdrawn easily in most countries.[19] The combination of long-term liabilities and risk regulation leads to fairly inelastic demand by insurance companies and pension funds for long-term bonds.

For some of the calculations, we separate countries into two groups based on their exposure to the European sovereign debt crisis following Altavilla et al. (2017). The first group includes the vulnerable countries: Italy, Spain, Portugal, Greece, Cyprus, and Ireland. The second group consists of the non-vulnerable countries: Austria, Germany, France, the Netherlands, Estonia, Luxembourg, Latvia, Slovakia, Finland, Malta, Slovenia, Belgium, and Lithuania.

2.4. Potential Shortcomings of the Data

We are aware of two potential shortcomings of our data. First, as is typically the case in measuring cross-border holdings, we cannot measure securities positions of euro-area institutions that are held through offshore institutions, and institutions located outside of the

[19] France is an exception in the euro area where insurance liabilities are more similar to demand deposits.

euro area (see Milesi-Ferretti, Strobbe, and Tamirisa (2010) and Zucman (2013) for further discussions). Second, we have accurate holdings of cash securities, but we do not observe derivatives positions. Abad, Aldasoro, Aymanns, D'Errico, Rousova, Hoffmann, Langfield, and Roukny (2016) use new data on OTC derivatives in the euro area that can potentially be merged with our data to get a comprehensive view based on both cash and derivatives positions.

3. Institutional Portfolio Holdings Before the Purchase Programme

We summarize in this section the heterogeneity in portfolio holdings before the announcement and implementation of the PSPP as a point of reference.

3.1. Securities Holdings

In Table III, we report the holdings by sector and geography for each asset category. We compute the average market value of portfolio holdings from 2013Q4 to 2014Q4, which is before the PSPP was announced.

The top panel summarizes the holdings by sector for investors in non-vulnerable countries, the middle panel for investors in vulnerable countries, and the bottom panel presents the holdings of the ECB and the foreign sector. Each of the columns corresponds to an asset category and the final column summarizes the total holdings. The final column indicates that, as measured by assets under management, investors in non-vulnerable countries are are more than twice as large as investors in vulnerable countries.

Insurance companies and pension funds invest a large fraction of their portfolios in fixed-income instruments and in particular in eligible government bonds. In terms of corporate bonds, their portfolios are tilted towards investment-grade corporate bonds. These allocations are consistent with standard asset-liability management.

Banks also invest a large share of their portfolios in eligible government debt. Also, they are the largest investor in ABS and covered bonds. The corporate bond portfolios in non-vulnerable countries are tilted towards investment-grade corporate bonds, while the opposite is true in vulnerable countries. We explore this fact in more detail below.

Mutual funds invest a large fraction of their assets in equity and notably foreign securities. This implies that mutual funds play an important role in providing global diversification benefits for euro-area households and institutions. The foreign sector mostly holds government bonds and euro-area equity. About a third of their allocation to government bonds is invested in ineligible bonds, which includes short-maturity bonds (residual maturities shorter than two years) but also bonds with yields that are below the deposit facility rate (for instance,

Table III: Holdings by investor type, geography, and asset category.

The table reports the average market value of holdings, computed before the announcement of the PSPP, from 2013Q4 until 2014Q4. The asset categories are defined as: Eligible Govt. (i.e., PSPP eligible government bonds), Ineligible Govt. (i.e., PSPP ineligible government bonds), IG-Corp. (i.e., Investment grade corporate bonds), SG-Corp. (i.e., Speculative grade corporate bonds), ABS&CB (i.e., ABS and covered bonds), Equity (i.e., euro-area equity), and Foreign (i.e., Non-euro area assets). The top panel reports the holdings for investor sectors in non-vulnerable countries. the middle panel for vulnerable countries, and the bottom panel for the ECB and the foreign sector. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016). All figures are in billion of euros.

Riskiness	Sector	Eligible Govt	Ineligible Govt	IG Corp	SG Corp	ABS & CB	Equity	Foreign	Total
Non-vulnerable	Banks	827	451	443	143	702	127	650	3,343
	Mutual Funds	577	211	281	234	190	901	2,415	4,809
	ICPF	940	170	362	201	191	137	481	2,482
	Household	19	16	100	146	12	466	146	905
	Other	126	82	34	45	26	768	87	1168
	Total	2,489	930	1,220	770	1,122	2,398	3,780	12,709
Vulnerable	Banks	542	394	140	230	587	72	262	2,227
	Mutual Funds	161	133	40	47	25	156	808	1,370
	ICPF	340	97	70	45	38	29	64	683
	Household	174	73	120	237	5	199	70	878
	Other	113	44	11	23	2	257	38	488
	Total	1,328	741	381	582	657	713	1,243	5,645
	Foreign	2,298	1,499	278	539	359	2,853	-	7,826
	ECB	114	17	0	0	30	0	0	161

in the case of Germany).

The ECB holds a small portfolio of government bonds and covered bonds due to the earlier purchase programmes, namely the CBPP and the SMP, before the start of the PSPP. During this period, the ECB does not invest in corporate bonds or equity. The holdings of ineligible government bonds is a consequence of a bond's residual maturity dropping below two years at some point or the yield falling below the deposit facility rate, rendering it ineligible.

The holdings of eligible government debt across institutions play a central role in theories that show that asset purchase programmes can relax financial constraints of compromised institutions (Brunnermeier and Sannikov, 2016). We directly estimate the benefit of the PSPP to different institutions and across geographies in Section 5.4.

In addition, banks' holdings of government debt has been flagged as a potential concern for financial stability as losses to the government impact the banking sector, which may feed back into the fiscal position of the government (Altavilla et al., 2017). While the literature on

"doom loops" has focused on the banking sector, we show that the home bias in government debt applies to other intermediaries as well.

Table IV reports the holdings of PSPP-eligible debt by investor sector and geography. The first column reports the market value of eligible debt held (in billions of euros). The second column reports the share in percent of an investor's portfolio invested in eligible government debt. The third column reports the share in percent of the investment in eligible debt for which the holder and issuer country coincide, that is, the home bias PSPP-eligible debt.

Table IV: Holdings of PSPP-eligible government debt by sector and country group.

The table reports for each investor sector and country group three statistics on the holdings of PSPP-eligible debt. The first columns reports the market value of the holdings in billions of euros. The second column reports the share of a sector's portfolio invested in PSPP-eligible government debt (in %). The third column reports the share of a sector's PSPP-eligible debt portfolio invested in the same country (in %), which is the home bias. Each statistic is an average from 2013Q4 until 2014Q4. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016).

Riskiness	Sector	Holdings (bn €)	Share eligible (%)	Home bias (%)
Non-vulnerable	Banks	827	25	55
	Mutual funds	577	12	19
	ICPF	940	38	52
	Household	19	2	68
	Other	126	11	72
	Total	2,489	20	47
Vulnerable	Banks	542	24	84
	Mutual funds	161	12	65
	ICPF	340	50	85
	Household	174	20	96
	Other	113	23	97
	Total	1,328	24	85
	Foreign	2,298	-	-
	ECB	114	83	-

In both regions, insurance companies and pension funds invest a larger share of their portfolios in eligible government debt than the other sectors. The main insight from Table IV is, however, that all institutions in vulnerable countries have a stronger home bias, compared to non-vulnerable countries. Banks invest 84% of their PSPP-eligible government debt portfolio in their own country, insurance companies and pension funds 85%, and even mutual funds 65%. This implies that concerns about doom loops apply to the financial sector more broadly, and not just banks.

Acharya and Steffen (2015) discuss various reasons why banks in vulnerable countries invest heavily in own-country government debt. First, banks can borrow cheaply from the

ECB and invest in high-yielding government bonds, thereby earning the "carry." This trade may be attractive to banks as it is considered to be riskless under the Basel regulations. However, as any government bond has a zero risk weight, the carry trade does not imply home bias. More importantly, mutual funds are not subject to the same risk weights, yet their portfolios have a similar home bias as those of regulated institutions.

Second, in the presence of limited liability, it may be optimal for financial institutions to invest in own-country government bonds as the states of the world in which the bonds default align with those in which the institutions fail as well (Diamond and Rajan, 2011). As mutual funds are all-equity firms, this argument does not explain the home bias for these institutions.

Financial repression provides a third possible explanation if financial institutions are encouraged or forced to buy bonds of their own government to lower government borrowing costs, see Becker and Ivashina (2017) and Ongena, Popov, and Horen (2019). While it may appear at first sight that this theory cannot explain the home bias of mutual funds, it is worth noting that most mutual funds in the euro area are offered via banks. The pressure on banks may therefore motivate mutual funds to tilt their portfolios towards the government debt of their own country.

Our findings are important from a financial stability perspective. Policy discussions tend to focus on the bank-government feedback loop. Given that insurance companies, pension funds, and mutual funds play a central role in saving for retirement, the failure of a sovereign would not only have an adverse effect on the banking sector, but also on the accumulation of retirement savings.

3.2. Risk Exposures of Investment Portfolios: Measurement

In addition to holdings and flows, we also estimate the distribution and dynamics of risk exposures to euro-area financial market risks across investors. We distinguish five dimensions of risk: (i) euro-area duration risk, (ii) euro-area government credit risk, (iii) euro-area corporate credit risk, (iv) euro-area equity risk, and (v) foreign risk.

For each of these risks, we define (linear) risk measures to quantify exposures. For euro-area interest rate risk, we use duration. We measure the duration of government bonds, both eligible and ineligible, corporate bonds, ABS, and covered bonds.[20] To compute duration, we need to know the yield-to-maturity, the coupon rate, and the payment frequency of the coupons.

For government credit risk, we measure the risk exposure using the credit rating of all government bonds. For each country, we use the ISIN-level rating when it exists, and otherwise

[20] We assume that the duration of floating-rate bonds is zero.

the long-term debt rating of a country. We then map each rating to the 5-year cumulative default probability using estimates in Moody's (2015) and take the average probability of default as our risk measure.

We measure corporate credit risk exposure analogously. We aggregate the holdings across all corporate bonds, ABS, and covered bonds. We map the ratings to default frequencies using estimates for 5-year cumulative corporate default probabilities reported in Moody's (2015).[21]

For equity risk, we report the total investment in equities as a share of the overall portfolio value. This assumes that the equity exposure of fixed income securities, once we control for rating and duration, is zero and that all stocks have a beta equal to one. For foreign risks, we simply measure the portfolio share. In all cases, we report the average risk measures from 2013Q4 until 2014Q4.

3.3. Portfolio Risk Exposures

We report the risk exposures by holder country group and sector in Table V. The first column reports the duration based on all bonds, including bonds issued outside of the euro area (i.e., based on asset category 1 to 5 and 7). The second column reports the euro-area duration risk (i.e., based on asset category 1 to 5). By comparing both columns, we find that these numbers generally coincide other than for mutual funds in vulnerable countries. The difference for the foreign sector is consistent with euro-area firms issuing debt in, for instance, U.S. dollars, which is held primarily by investors outside of the euro area.

Across institutional sectors, we find that insurance companies and pension funds hold the longest duration portfolios. The duration for insurers and pension funds is about twice as large as for banks. The euro-area duration is lower for banks, mutual funds, and insurance companies and pension funds in vulnerable countries compared to non-vulnerable countries, which in part reflects the supply of bonds outstanding.

Home bias combined with higher government risk exposures of debt in vulnerable countries explains the difference in government risk exposures across vulnerable and non-vulnerable countries. Also, the ECB purchased debt of vulnerable countries as part of the SMP, which leads to government exposure before the start of the PSPP.

The exposure to corporate credit risk is also higher for institutions in vulnerable countries, although the difference is less extreme than for government risk. The ECB's portfolio, which

[21] In interpreting the numbers, it is important to keep in mind that a bond's rating can be low because of its exposure to either aggregate or idiosyncratic risk (or both). As we do not have the information required to decompose risk exposures, we assume that a bond's exposure to aggregate corporate credit risk is linear in its default probability.

Table V: Risk Exposures of Investors' Portfolios.

The table reports the average risk characteristics from 2013Q4 until 2014Q4. Duration and euro-area duration are expressed in years. The government credit risk exposure is measured by the 5-year cumulative probability of default for either governments or firms as reported in Moody's (2015) and we use the ISIN-level rating when it exists, and otherwise the long-term debt rating of a country. For euro-area equity and foreign risk exposure, we report the fraction in percent of an investor's portfolio invested in either asset category. The top panel reports the risk exposures for investor sectors in non-vulnerable countries and the middle panel for investors in vulnerable countries. The bottom panel reports the risk exposures of the portfolios of the foreign sector and the ECB (as so far as related to purchase programmes). ECB duration risk is imputed from public data on maturity and duration data on representative bond portfolios. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016).

Riskiness	Sector	Dur.	EA Dur.	Government	Corporate	Equity	Foreign
Non-vulnerable	Banks	3.2	3.2	0.4	0.5	4	19
	Mutual Funds	5.2	5.1	0.6	1.2	19	50
	ICPF	6.8	7.2	0.3	1.0	6	19
	Household	2.6	2.6	0.5	1.7	51	16
	Other	4.1	4.2	0.2	1.2	66	7
Vulnerable	Banks	2.4	2.4	1.5	1.5	3	12
	Mutual Funds	5.7	3.8	1.3	1.9	11	59
	ICPF	5.3	5.4	1.3	1.6	4	9
	Household	3.6	3.6	1.3	2.2	23	8
	Other	4.8	4.8	1.6	2.1	53	8
	Foreign	-	4.9	0.5	1.3	-	-
	ECB	3.5	3.5	1.5	0.6	0	0

only includes covered bonds during our sample, and the portfolio of banks in non-vulnerable countries are the safest before the start of the PSPP.

3.4. The Distribution of Risk Exposures

In Table VI we report how the total risk is distributed across the different investor sectors for each of the risk factors. By definition, each of the columns (excluding the subtotals) aggregates to 100.

Insurance companies and pension funds bear 26% of all euro-area duration risk, the foreign sector 31%, and banks 20%. The banks' risk exposure is surprisingly high given the relatively short duration of their liabilities. Vulnerable countries are most exposed to government risk, which is a direct consequence of the home bias in their government debt portfolios, see Table IV. Banks in vulnerable countries bear 23% of all government credit risk, while they only bear 7% of the duration risk. Compared to banks in non-vulnerable

Table VI: The Distribution of Risk Exposures.

The table shows the distribution of risks across investors, normalized to 100 for the total risk outstanding. We report the average from 2013Q4 until 2014Q4. The top panel reports the risks for investor sectors in non-vulnerable countries and the middle panel for investors in vulnerable countries. The bottom panel reports the risks of the portfolios of the foreign sector and the ECB. ECB duration risk is imputed from public data on maturity and duration data on representative bond portfolios. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016).

Riskiness	Sector	EA Dur.	Government	Corporate	Equity	Foreign
Non-vulnerable	Banks	13	7	14	2	13
	Mutual Funds	12	7	13	15	48
	ICPF	21	6	13	2	9
	Household	1	0	5	8	3
	Other	2	1	2	13	2
	Total	49	21	47	40	75
Vulnerable	Banks	7	23	22	1	5
	Mutual Funds	2	6	3	3	16
	ICPF	5	9	4	1	2
	Household	4	5	7	3	2
	Other	2	4	1	4	0
	Total	20	47	37	12	25
	Foreign	31	28	18	48	0
	ECB	1	3	0	0	0

countries, which are more than 50% larger than banks in vulnerable countries, banks in vulnerable countries bear almost four times the government risk. We estimate that the ECB only bears 1% of the euro-area duration risk and 3% of all government credit risk as a result of the earlier SMP.

The exposure to corporate credit risk is more equally split across country groups, with sectors in non-vulnerable countries bearing 47% of all risk and sectors in vulnerable countries bearing 37%. The foreign sector bears 18% of all euro-area credit risk. However, the risk exposures in vulnerable countries are concentrated in the banking sector (22% of 37%), while the risk exposures are almost equally split among banks, mutual funds, and insurance companies and pension funds in non-vulnerable countries. Hence, in vulnerable countries, both government and corporate credit risks are concentrated in the banking sector.

The picture is quite different in terms of exposures to euro-area equity risk and foreign risk. The foreign sector bears almost half of all euro-area equity risk and institutions in non-vulnerable countries bear another 40%, where mutual funds account for the largest share (15% of 40%). For foreign risk, we normalize the overall holdings to 100% for all euro-area investors as we do not observe the holdings of foreign investors in securities issued outside of

the euro area. As expected, non-vulnerable countries are most exposed to foreign risk (75% versus 25%) and in both country groups, most of the risk is concentrated in the mutual fund sector.

4. Portfolio Rebalancing and the Dynamics of Risk Exposures

We study portfolio flows and the dynamics of risk exposures during the PSPP from 2015Q2 until 2017Q4. In addition to broad portfolio flows, our main contribution in this section is to use our detailed micro data to establish a close connection between the securities purchased by the ECB and the investors, differentiated by geography and institutional type, who sell those same securities.

4.1. Portfolio Rebalancing Across Asset Categories

We first compute how investors rebalance their portfolios for each of the asset categories. For investor i and security n, we measure rebalancing at time t, T_{int}, as

$$T_{int} = (Q_{int} - Q_{in,t-1})\, P_{nt}, \tag{1}$$

where Q_{int} denotes the number of securities and P_{nt} the price. This definition measures active rebalancing and is not impacted by price effects. We then aggregate the overall rebalancing activity by asset category in a given quarter. In Table VII, we report the cumulative rebalancing in billions of euros from 2015Q2 to 2017Q4. As a point of reference, Table B.1 summarizes the average rebalancing during the quarters before the PSPP from 2013Q4 until 2014Q4.

From 2015Q2 to 2017Q4, the ECB purchases €1,878 billion. The total supply of government debt increases by €539 billion, implying that investors need to sell €1,349 billion for markets to clear. Quite strikingly, the majority, namely €-917 billion, was sold by the foreign sector. In the period leading up to the programme, the foreign sector was a net buyer of euro-area government debt. This finding is surprising from the perspective of the neutrality theorems, which imply that sectors that are affected by changes in the timing or risk exposures of the central bank's portfolio (through taxation or adjustments in subsidies) should rebalance their portfolios.[22] It seems unlikely that the foreign sector is most exposed to the gains and losses in the central bank's portfolio. However, our finding is consistent with estimates from Japan based on aggregate statistics from the Flow of Funds, see Saito and Hogen (2014). One possible interpretation is that the foreign sector's demand is more elastic

[22]Since the consumption plans are unaffected by asset purchase programmes if the neutrality theorems apply, the exchange rate should not be affected either.

Table VII: Portfolio Rebalancing During the PSPP.

The table shows the cumulative rebalancing from 2015Q2 to 2017Q4 by asset category (EUR billion). The holdings are the euro-area government debt holdings as measured in terms of market value as of 2015Q2. The share sold is the rebalancing in government debt relative to the holdings (in percentage points). The top panel reports the rebalancing for investor sectors in non-vulnerable countries and the second panel for investors in vulnerable countries. The third panel reports the rebalancing of the foreign sector and the ECB. The bottom panel reports net issuances. The flows are reported in billions of euros. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016).

Riskiness	Sector	Govt	Corp	ABS & CB	Equity	Foreign	Holdings	Share sold (%)
Non-vulnerable	Banks	-275	-139	-178	-15	-292	1259	-22
	Mutual funds	-76	55	-51	178	175	826	-9
	ICPF	92	-7	-33	-1	126	1169	8
	Household	-14	-68	-4	1	-1	28	-50
	Other	15	-6	-7	67	9	208	7
Vulnerable	Banks	-192	-98	-40	11	-14	927	-21
	Mutual funds	-58	32	-9	22	303	302	-19
	ICPF	177	47	-9	15	110	471	38
	Household	-62	-183	-3	21	-28	208	-30
	Other	-29	-13	-4	-11	13	148	-20
	Foreign	-917	-122	-140	-	-	3715	-25
	ECB	1,878	130	184	0	0	-	-
	Total	539	-371	-294	-	-	-	-

Table VIII: Foreign sector rebalancing by asset class and issuer country riskiness

The table shows the cumulative rebalancing from 2015Q2 to 2017Q4 by asset category (EUR billion) for the foreign sector. The holdings pre-QE are measured in terms of the average market value from 2013Q4 to 2014Q4. The share sold is the rebalancing in government debt relative to the holdings (in percentage points). The flows are reported in billions of euros. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016).

Issuer risk	Asset type	Prior holdings	PSPP rebalancing	Share sold %
Non-vulnerable	Government bonds	2,995	-690	-23
	Corporate bonds	669	-108	-16
	ABS & CB	198	-70	-35
Vulnerable	Government bonds	803	-227	-28
	Corporate bonds	147	-14	-9
	ABS & CB	161	-69	-43

with respect to price. As yields decline in response to the PSPP, they reallocate capital to other regions or asset classes that offer more attractive risk-return tradeoffs. Euro-area investors, by contrast, have euro-denominated liabilities that result in more inelastic demand for securities in the euro area, even though they may have elastic demand across countries within the euro area.

We split the sales of the foreign sector by bonds issued by governments in vulnerable and non-vulnerable countries. To put their rebalancing behavior into perspective, we scale the sales by their holdings right before the start of the programme in 2015Q2. As shown in Table VIII, the foreign sector sells across both geographies approximately in proportion to their prior holdings. The same is true in the other fixed-income asset classes.

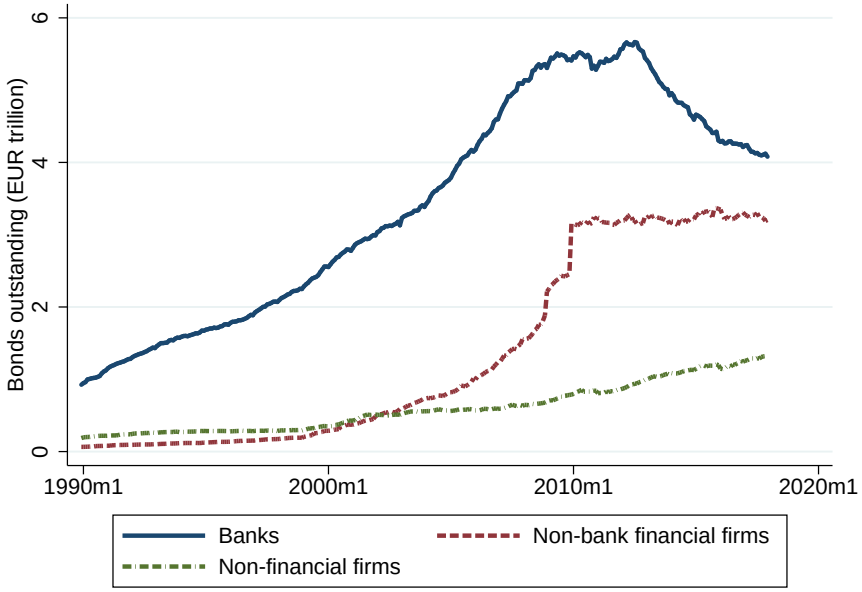
The banking sector sells €-467 billion and mutual funds €-134 billion of government bonds. Insurance companies and pension funds in fact buy €269 billion of government bonds with a larger share purchased by long-term investors in vulnerable countries. Inelastic demand, or even upward-sloping demand curves, of insurance companies and pension funds may be due to their desire to hedge the interest rate risk associated with their long-dated liabilities in a low-rate environment (Domanski, Shin, and Sushko, 2017).

For corporate bonds, net issuances are large and negative both before and during the PSPP. Beyond households, this reduction is primarily absorbed by banks and the foreign sector. To understand the supply-side dynamics of the corporate bond market in the euro area, we use data from the ECB's Statistical Data Warehouse. In Figure 2, we plot the total amounts outstanding for corporate bonds issued by non-financial firms, financial firms excluding banks, and banks. Although these data also include bonds issued in foreign currency, which is a broader definition than what we use, the broad trends are comparable.

Following the government debt crisis in the euro area in 2012, banks have reduced the amount of debt outstanding dramatically. The timing suggests that this deleveraging of the banking sector is unrelated to the PSPP (although the programme may have helped). The debt dynamics for banks is strikingly different than for other financial firms, for which the total debt outstanding has been stable since the financial crisis, and for non-financial firms, for which the total debt outstanding gradually increased over time.

Figure 2: Corporate Debt Dynamics.

The figure displays the total face value of debt outstanding from January 1990 until December 2017 for non-financial firms (dashed line), financial firms excluding banks (dotted line), and banks (solid line).



Third, the ECB also purchases €184 billion of covered bonds. Like for corporate bonds, net issuances are negative as well and the flows come primarily from banks (in vulnerable and non-vulnerable countries) and the foreign sector. Again, these flows are similar to the flows before the PSPP and may be due to banks deleveraging instead of being caused by the PSPP.

Lastly, equity and foreign asset flows are relatively small compared to the flows in fixed income markets, other than for mutual funds. Hence, most of the rebalancing, in euro terms, happens within fixed income markets.[23]

[23]See also Di Maggio, Kermani, and Palmer (2019) for evidence of limited rebalancing in U.S. mortgage markets in response to the QE programmes in the U.S.

4.2. Which Sectors Sell to the ECB? Evidence from Micro Data

The results in the previous section rely on time-series information only and may therefore be impacted by broader trends in flows to various investors during our sample period. In this section, we extend these results by using cross-sectional information, in addition to time-series information, by estimating which investors sell the securities purchased by the ECB.

To fix ideas, we start from the market clearing condition in changes for security n at time t

$$\sum_i T_{int} + T_{Foreign,nt} + T_{ECB,nt} = I_{nt}, \tag{2}$$

where $T_{Foreign,nt}$ and $T_{ECB,nt}$ denotes the rebalancing of the foreign sector and the ECB, which are defined analogously to T_{int} in (1). I_{nt} corresponds to net issuances, which are defined as

$$I_{nt} = (S_{nt} - S_{n,t-1})P_{nt}, \tag{3}$$

where S_{nt} denotes the total supply of security n at time t.

To measure portfolio rebalancing, we compute a variance decomposition of (2) by regressing each of the terms on $T_{ECB,nt}$ across securities and time. To avoid lots of zeroes in these regressions, we aggregate the securities by issuer country and maturity brackets, where the residual maturity is in $[2, 5]$, $[5, 7.5]$, $[7.5, 10]$, $[10, 15]$ or $[15, 30]$. We estimate the coefficient separately by investor sector and investor country.

Alternatively, we can compute how much an investor's rebalancing deviates from simply scaling their position in proportion to the ECB's purchases. To motivate our alternative measure of rebalancing, consider two countries that differ in size, say, Germany and Malta, and that are perfectly home biased (German investors hold all German debt and Maltese investors hold all Maltese debt). The ECB follows the capital key to buy debt across countries, which implies that the ECB buys, in terms of euros, more German debt than Maltese debt. If German and Maltese investors sell the same share of their portfolios to accommodate the ECB's purchases, then the regression of T_{German} on T_{ECB} results in a slope coefficient larger than one, while a regression of T_{Malta} on T_{ECB} leads to a coefficient that is negative. After all, Maltese investors sell no German debt, of which the ECB buys a lot, and do sell Maltese debt, of which the ECB buys very little. Appendix A formalizes this intuition in a 2-country model.

Given the differences in initial portfolios that we have documented, we therefore compute

whether investors deviate from selling the same fraction of their initial portfolios, which we will label "abnormal rebalancing." We first compute the aggregate holdings across all investor sectors, excluding the ECB, $S^{\star}_{nt}$,

$$S^{\star}_{n,t-1} = \sum_i Q_{in,t-1} + Q_{Foreign,n,t-1}. \tag{4}$$

If investors sell in proportion to their initial portfolios, then the sales per sector would be $\frac{Q_{in,t-1}}{S^{\star}_{n,t-1}} T_{ECB,nt}$ and similarly for the foreign sector. Abnormal rebalancing is then defined as

$$T^{\star}_{int} = T_{int} + \frac{Q_{in,t-1}}{S^{\star}_{n,t-1}} T_{ECB,nt}, \tag{5}$$

where we note that T_{int} is negative for most sector as they sell in response to the programme. The market clearing condition in changes now can be written as

$$\sum_i T^{\star}_{int} + T^{\star}_{Foreign,nt} = I_{nt}. \tag{6}$$

We regress each of the terms on $T_{ECB,nt}$ across issuer countries, maturity brackets, and quarters.[24] Due to the accounting identity in (6), it also holds for these regression coefficients

$$\sum_i \beta^{\star}_i + \beta^{\star}_{Foreign} = \beta_I. \tag{7}$$

If all investors rebalance in proportion to their initial holdings and if supply does not respond to the asset purchase programme, then we have $\beta^{\star}_i = \beta_I = 0, \forall i$. Economically, if investor sector i sells more than proportionally in response to the programme, then $\beta^{\star}_i < 0$, and vice versa. We rewrite (5) to

$$T_{int} = T^{\star}_{int} - \frac{Q_{in,t-1}}{S^{\star}_{n,t-1}} T_{ECB,nt} = \left(\beta^{\star}_i - \frac{Q_{in,t-1}}{S^{\star}_{n,t-1}} \right) T_{ECB,nt} + \epsilon_{int}, \tag{8}$$

where ϵ_{int} is the regression error from regressing $T^{\star}_{int}$ on $T_{ECB,nt}$ and $\mathbb{E}(\epsilon_{int} T_{ECB,nt}) = 0$.

We aggregate the right-hand side for a given investor and divide by total ECB purchases to assess which investors sell in response to a €1 of assets purchases. We compute the average response across the seven quarters for which we have purchases, 2015Q2 until 2017Q4.

[24] This regression assumes that the rate of rebalancing is constant across issuer countries and maturities,

$$T^{\star}_{int} = \alpha^{\star}_i + \beta^{\star}_i T_{ECB,nt} + \epsilon_{int}.$$

Figure 3: Portfolio Rebalancing in Response to ECB Purchases.

The figure reports the rebalancing by different investor sectors in response to ECB purchases. The first bar for each sector corresponds to abnormal rebalancing ($\beta_i^\star$). It measures how investors rebalance beyond simply scaling back their initial holdings in proportion to ECB purchases. The sum of these bars equals zero. The second bar for each sector measures total rebalancing, which subtracts the rebalancing due to initial holdings. The sum of these bars equals one. The coefficients are estimated from 2015Q2 until 2017Q4.

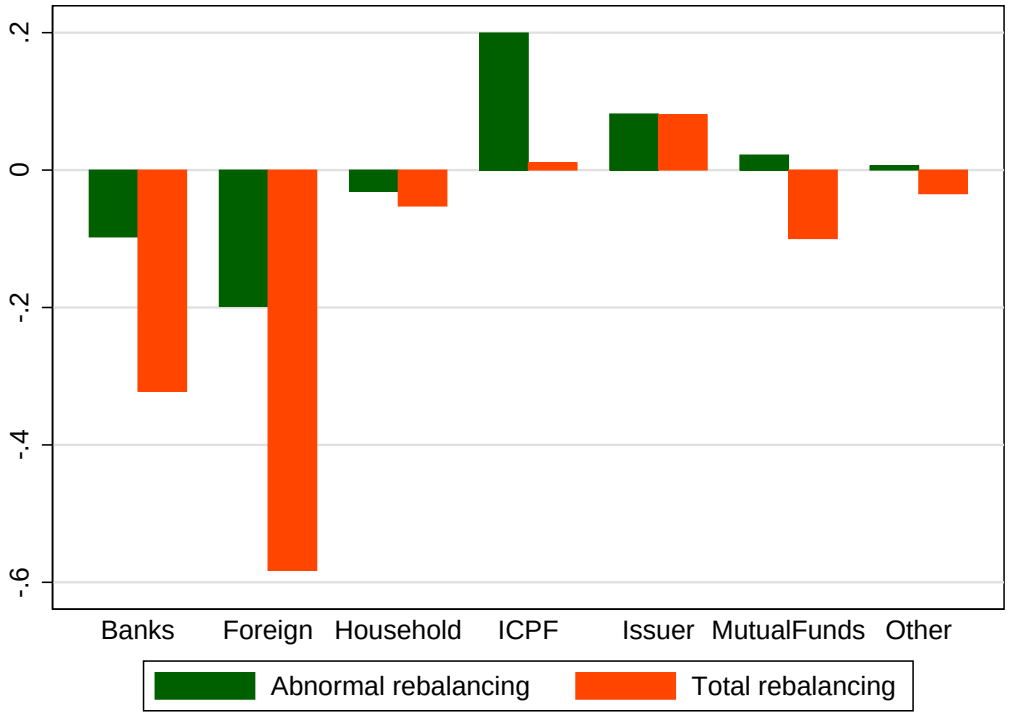


Figure 3 reports the results. The first bar for each sector corresponds to abnormal rebalancing, $\beta_i^\star$. The sum of these bars equals zero. The second bar for each sector measures total rebalancing, see (8). The sum of these bars equals minus one.

The first set of bars shows that the foreign sector sells to the ECB, while insurance companies and pension funds tend to buy bonds with similar maturities and geographies as the ECB. Long-term investors therefore amplify the asset purchase programme.

The second set of bars allows us to answer the question how a €1 purchase of assets is accommodated by different investors. We find that the foreign sector sells close to €0.60, banks sell around €0.30, and mutual funds sell €0.10. Insurance companies and pension funds buy a small fraction.

In summary, based on the time-series analysis in the previous section and using panel data in this section, we conclude that most of the purchases are accommodated by the foreign sector. Within the euro area, banks sell the largest amount, while long-term investors instead purchase government bonds.

4.3. The Dynamics of Risk Exposures

The theories discussed in the introduction typically have implications for risk exposures in addition to portfolio flows. In Table IX, we report the evolution of the distribution of risk exposures. We normalize the total to 100 in 2014Q4. This implies that totals above 100 correspond to an increase in, for instance, euro duration risk. Panel A reports duration risk, Panel B government credit risk, and Panel C corporate credit risk. In terms of total risk, we find that duration risk increases as a result of the decline in yields. Government credit risk is hump-shaped. This is driven in part by the decline in yields, but also due to changes in credit ratings of some countries, for instance, the upgrade of Greece in late 2013 and early 2014 and the downgrade of France in 2015.[25] Corporate credit risk declines rapidly, as discussed before, which is due to the decline in bank debt.

The increase in duration risk is more than offset by ECB purchases. The total increases to 119% in 2017Q4, but the ECB owns 26%. Most other sectors remain stable or slightly increase in case of insurance companies and pension funds in vulnerable countries. This increase in duration risk by long-term investors may help to reduce the duration mismatch with their liabilities.

The increase in government credit risk in 2016 is held by the ECB (from 3% in 2014Q4 to 12% in 2016Q2) and by institutions in vulnerable countries (from 47% in 2014Q4 to 63% in 2016Q2). The total amount of government credit risk declines to 116% by the end of the sample. The share of the ECB by then increased to 19% and the share held by the foreign sector declined from 26% in 2014Q4 to 22% in 2017Q4. As a result, the overall exposure to government credit risk of euro-area investors did not change much over our sample. The only trend worth noting is that long-term investors in vulnerable countries increased their share from 10% in 2014Q4 to 15% in 2017Q4.

The reduction in corporate credit risk to 74% in 2017Q4 is moving of the balance sheets of banks (-13%) and the foreign sector (-9%). The ECB's share increases to 7% implying that the amount of credit risk on the balance sheet of investors increased even more. Perhaps surprisingly, we find the largest reduction in exposure to corporate credit risk for banks in vulnerable countries. The results suggest that banks reduce their holdings of debt issued by other financial institutions and the supply of their own bonds. This points to cross-holdings of corporate debt in the banking sector. To make this point more precise, we report the home bias in the holdings of financial firms in Figure 4. Consistent with the dynamics of risk exposures, we find that banks in vulnerable countries have a strong home bias in their holdings of corporate bonds issued by banks. These cross holdings further complicate the

[25]The total amount of government risk is more volatile, as a result of changes in ratings. As we use security-level ratings, there is more volatility compared to the aggregate country-level ratings.

Table IX: The Distribution and Dynamics of Risk Exposures.

The table reports the distribution and dynamics of duration exposures (Panel A), government (Panel B), and corporate credit (Panel C) risk exposures. The distribution of risk exposures is normalized to 100 in 2014Q4. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016).

Panel A: Duration risk

	Sector	2013	2014				2015				2016				2017			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Banks	12	12	12	12	12	12	11	11	11	12	12	12	11	11	10	11	11
	Mut.Funds	9	10	11	11	12	13	12	12	12	13	13	13	12	12	12	13	12
NV	ICPF	18	18	19	20	21	23	21	21	20	23	24	24	22	22	23	23	23
	Household	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Other	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Banks	6	7	7	7	7	7	7	7	6	7	8	8	8	8	8	7	7
	Mut.Funds	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2
V	ICPF	4	5	5	5	5	6	5	5	6	7	8	8	8	8	8	8	8
	Household	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2
	Other	1	1	1	1	2	2	1	1	1	2	2	2	1	1	1	1	1
	Foreign	26	28	30	30	32	34	30	30	29	30	30	28	25	23	24	24	24
	ECB	1	1	1	1	1	2	3	5	7	9	12	15	17	20	23	24	26
	Total	85	90	94	95	100	108	98	100	100	111	117	117	111	112	116	118	119

Panel B: Government credit risk

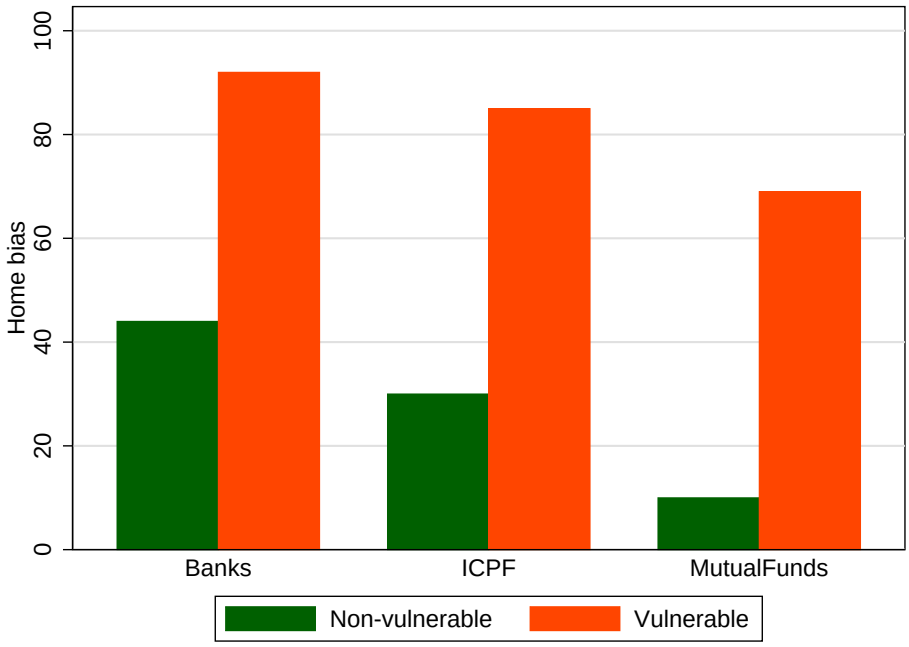
	Sector	2013	2014				2015				2016				2017			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Banks	7	7	7	8	7	8	8	8	8	8	8	8	7	7	7	6	6
	Mut.Funds	6	7	8	8	8	9	9	9	9	10	10	10	8	8	9	9	8
NV	ICPF	6	6	6	7	7	8	7	8	8	8	9	9	7	7	8	8	8
	Household	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Banks	25	26	22	22	22	22	21	22	21	25	29	24	21	22	20	20	19
	Mut.Funds	6	6	6	6	6	7	6	6	6	6	6	6	6	6	5	6	6
V	ICPF	9	9	9	10	10	11	10	11	12	13	15	15	14	15	15	15	15
	Household	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4
	Other	4	4	4	4	4	4	4	4	4	7	9	8	7	7	7	6	8
	Foreign	28	31	28	28	26	33	29	34	32	29	30	28	23	23	23	23	22
	ECB	3	3	3	3	3	4	5	7	8	10	12	14	14	16	18	19	19
	Total	100	105	99	102	100	112	104	114	113	121	133	127	112	116	117	117	116

Panel C: Corporate credit risk

	Sector	2013	2014				2015				2016				2017			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Banks	15	14	15	15	14	13	13	13	12	13	12	12	11	11	11	10	10
	Mut.Funds	14	14	15	15	15	14	13	13	12	13	13	13	13	13	13	13	13
NV	ICPF	14	14	14	14	14	14	13	13	12	14	14	14	14	13	13	13	13
	Household	5	5	5	5	5	4	4	4	4	4	3	3	3	3	3	3	2
	Other	2	2	2	2	2	2	2	2	1	2	1	1	1	1	1	1	1
	Banks	30	25	23	22	18	16	14	14	13	14	24	16	14	12	11	10	9
	Mut.Funds	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
V	ICPF	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
	Household	8	8	7	6	6	6	6	6	4	4	4	4	4	3	3	3	2
	Other	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
	Foreign	20	20	18	18	18	17	15	14	11	12	12	10	9	10	9	9	9
	ECB	0	0	0	0	0	1	1	1	1	1	2	3	3	4	5	6	7
	Total	116	110	107	105	100	95	89	88	78	85	93	85	81	79	77	76	74

feedback loop between banks and governments.

Figure 4: Home Bias in Bonds of Financial Firms across Institutions.



5. Connecting Portfolio Rebalancing and Asset Prices

In this section, we connect investors' portfolio rebalancing to asset prices using an asset demand system as in Koijen and Yogo (2019). We specify the model in Section 5.1. As asset prices are endogenous to demand shocks, we propose an instrument to identify exogenous variation in prices using some of the unique features of the PSPP in Section 5.2. In addition to estimating the slope of demand curves, it also provides a low-frequency estimate of the impact of the PSPP on government bond yields. In Section 5.3, we estimate the asset demand system and compute the implied elasticities to connect portfolio rebalancing and its impact on asset prices.

5.1. Specification of the Asset Demand System

We denote investor's country by h, the issuer's country by n, and quarter by t. We group investors by institutional type across investor countries. The euro investment in government bonds issued by country n of a sector located in holder country h is denoted by $B_{ht}(n)$. The investment in all other securities in the euro area is denoted by $O_{ht}(n)$. We use as the outside asset all non-government debt fixed income securities in the euro area (that is, asset categories 3 to 5).

The portfolio weight is defined by

$$w_{ht}(n) = \frac{B_{ht}(n)}{O_{ht}(n) + \sum_n B_{ht}(n)}, \tag{9}$$

and $w_{ht}(0) = 1 - \sum_n w_{ht}(n)$ for the outside asset.

We model the demand for government debt as a function of prices, expressed in terms of yields, and characteristics

$$w_{ht}(n) = \frac{\delta_{ht}(n)}{1 + \sum_n \delta_{ht}(n)}, \tag{10}$$

where

$$\ln \delta_{ht}(n) = \beta_{0h} y_t(n) + \beta_{1h}' x_t(n) + \beta_{2h} b_{ht}(n) + \phi_{ht} + \epsilon_{ht}(n). \tag{11}$$

Koijen and Yogo (2019) provide a micro foundation for this empirically-tractable model of asset demand curves. In particular, they show that this specification is consistent with a model in which investors have mean-variance preferences. In addition, investors assume that returns follow a factor model and both expected returns and factor loadings are affine

functions of a set of characteristics. Hence, $x_t(n)$ includes characteristics that capture the risk-return tradeoff faced by investors.

For government debt, expected returns and risk are largely driven by maturity (capturing the exposure to the so-called "level factor") and government credit risk. The vector of issuer country characteristics, $x_t(n)$, therefore includes the probability of default (which is a function of a country's rating), the logarithm of the total face value outstanding to capture size, the logarithm of GDP per capita, and the average maturity.

In addition, we include a characteristic, $b_{ht}(n)$, which equals one if n equals h and zero otherwise, which captures home bias. We also include holder country - quarter fixed effects. In this way, we identify the demand elasticity with respect to price and other characteristics based on cross-sectional variation across inside assets. We refer to the variation in demand that cannot be accounted for by prices and characteristics, $\epsilon_{ht}(n)$, as latent demand. In structural models, latent demand captures investors' private information and views about risk and expected returns as well as investors' constraints.

5.2. Estimating the Asset Demand System and The Impact of QE on Government Yields

To estimate the demand curve in (10) and (11), we assume that characteristics are exogenous to latent demand, that is, $\mathbb{E}[\epsilon_{ht}(n) \mid x_t(n), z_{ht}(n)] = 0$. However, we cannot assume that yields are exogenous with respect to demand shocks as, in equilibrium, positive latent demand will result in higher prices and lower yields.

We therefore estimate the demand system using instrumental variables. To construct an instrument for government bond yields, we use a unique feature of the PSPP. We use the announced purchases of the ECB, scaled by the size of a country's government bond market, as an instrument for yield changes.

Formally, denote the sum of past and announced purchases of the PSPP in quarter t as A_t, where announced purchases are the product of the announced monthly purchases and the length of the programme. The time-series variation that we use are summarized in Table X.

Table X: PSPP announcement and subsequent adjustments.

Announcement	PSPP	Extension	Extension	Extension	Extension
Date	1/22/2015	12/03/2015	03/10/2016	1/19/2017	10/26/2017
Start	Mar-15	Sep-16	Apr-16	Apr-17	Dec-17
End	Sep-16	Mar-17	Mar-17	Dec-17	Sep-18
Number of months	19	6	12	9	9
Purchases (bn/month)	60	60	80	60	30

The time-series variation in A_t is naturally correlated with economic conditions and

cannot be used as a source of exogenous variation. However, purchases across countries are allocated according to the capital key. The weight of a country n in the capital key is given by

$$K_n = \frac{1}{2}\left[\frac{GDP_n}{\sum_m GDP_m} + \frac{Pop_n}{\sum_m Pop_m}\right],$$

where GDP_n denotes a country's GDP and Pop_n a country's population. The capital key is revised infrequently and we use the capital key in 2014Q4.

Our instrumental variable is $z_t(n) = \min\{A_t K_n / M_t(n), 0.33\}$, where $M_t(n)$ is the size of the bond market in 2014Q2. We pick it well before the start of the programme so that supply-side responses to the programme do not impact our instrument. For a few countries with small debt markets, our measure sometimes exceeds the 33% purchase ceiling and we cap it at 33% in those cases. Figure 5 plots the instrument for Germany.

The first-stage regression of our instrumental variables estimator is then

$$y_t(n) = \gamma_0 + \gamma_1 z_t(n) + \gamma_2' x_t(n) + \phi_t + \eta_t(n). \tag{12}$$

As our specification includes time fixed effects, γ_1 is not identified using time-series variation. Instead, γ_1 is identified using changes in the amounts purchased across countries in consecutive quarters. In particular, γ_1 measures how much more yields decline in country A relative to country B if the ECB purchases a larger fraction of the residual supply. Hence, the key assumption is that the capital key, which depends on population size and the level of GDP, is exogenous with respect to the PSPP.

Figure 5: Evolution of the instrument for Germany.

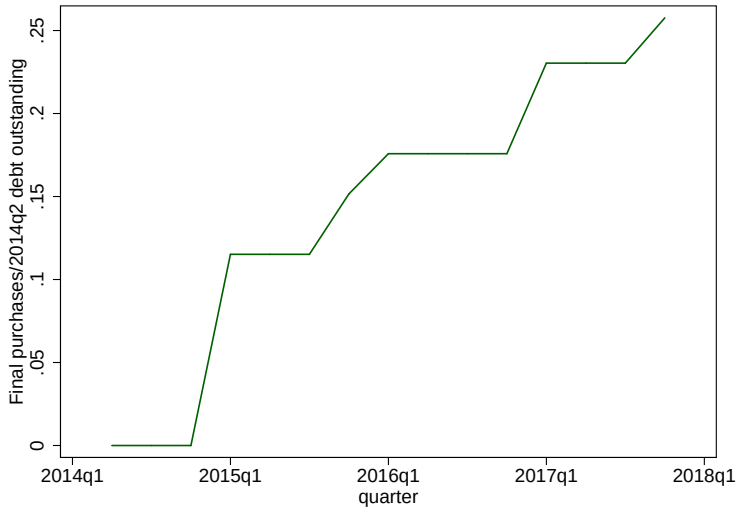


Table XI: Estimation Asset Demand System.

We estimate the demand system $\ln(w_{ht}(n)/w_{ht}(0)) = \beta_{0h} y_t(n) + \beta'_{1h} x_t(n) + \beta_{2h} b_{ht}(n) + \phi_{ht} + \epsilon_{ht}(n)$ in (10) and (11) using instrumental variables. Column (1) reports the first stage and columns (2) to (7) the second-stage demand curves for insurance companies and pension funds (ICPF), banks, mutual funds, Other, the household sector, and foreign investors. The sample is from 2014q2 to 2017q4. The explanatory variable is the (face value) weighted average yield of government debt from country n in percentage points. GDP is the GDP of country n in 2014 in EUR trillion. PD is the probability of default of country n as of 2014q4. Maturity is the face value weighted average maturity of debt from country n in quarter t. We include all euro-area countries except Cyprus, Estonia, Greece, Luxembourg, and Malta.

	(1) First	(2) ICPF	(3) Bank	(4) MutFunds	(5) Other	(6) HH	(7) Foreign
Yield (p.p.)		.236	.100	.057	1.480 ***		.532 *
		(.316)	(.404)	(.342)	(.493)		(.311)
$Z_t(n)$	-1.724 ***						
	(.424)						
Probability of default	50.803 ***	-54.440 ***	-9.785	12.593	-98.641 ***	29.349 ***	-59.496 ***
	(3.035)	(16.311)	(20.575)	(17.648)	(24.327)	(4.427)	(16.068)
Log GDP per capita	-.068	-.215 **	-.109	-.179 *	-.021	.853 ***	.486 ***
	(.071)	(.091)	(.115)	(.096)	(.139)	(.112)	(.090)
Log face value outstanding	-.005	.588 ***	.830 ***	.844 ***	.662 ***	.442 ***	.991 ***
	(.016)	(.020)	(.024)	(.021)	(.029)	(.019)	(.020)
Maturity	.051 **	.125 ***	-.010	-.007	-.017	-.256 ***	-.162 ***
	(.019)	(.034)	(.043)	(.036)	(.052)	(.028)	(.033)
Home bias		3.789 ***	4.915 ***	2.932 ***	5.049 ***	5.439 ***	
		(.099)	(.111)	(.096)	(.122)	(.106)	
Constant	.473	-18.747 ***	-25.355 ***	-24.447 ***	-24.440 ***	-22.196 ***	-29.277 ***
	(.559)	(.551)	(.652)	(.565)	(.780)	(.645)	(.591)
Quarter	Yes	No	No	No	No	No	Yes
Holder country - Quarter	No	Yes	Yes	Yes	Yes	Yes	No
R^2	0.78	0.61	0.71	0.65	0.65	0.68	0.97
Observations	210	3,791	3,243	3,198	2,571	2,931	210

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

As we use a Bartik estimator, we cannot identify the programme's impact on yields that is identical across countries and that does not vary with the capital key, as follows immediately from (12).

The estimation results are reported in the first column of Table XI. The estimate of γ_1 is -1.72 with a standard error of 0.42, suggesting that the instrument is not weak. The coefficient of -1.72 implies that when the ECB purchases 10% of the overall supply, yields decline by -17.2bp.

Table XII: Yield impact implied by the first stage.

We report the value of the instrument in the second column as of 2017Q4. We estimate the impact of government bond yields, as implied by the first stage, of the PSPP. We include all euro-area countries except Cyprus, Estonia, Greece, Luxembourg, and Malta.

Issuer country	Instrument	Yield impact (in %)
Austria	0.20	-0.34
Belgium	0.16	-0.28
Germany	0.26	-0.45
Estonia	0.23	-0.40
Finland	0.33	-0.57
France	0.20	-0.34
Ireland	0.33	-0.57
Italy	0.18	-0.31
Lithuania	0.33	-0.57
Latvia	0.33	-0.57
The Netherlands	0.22	-0.38
Portugal	0.33	-0.57
Slovenia	0.33	-0.57
Slovakia	0.33	-0.57
Mean	0.27	-0.47

To estimate the overall impact of the PSPP, we multiply this estimate by the value of the instrument as of 2017Q4, the end of our sample, in Table Table XII. There is significant heterogeneity in the impact on yields, ranging from -28bp in Belgium to -57bp in countries that reach the 33% purchase limit (Finland, Ireland, Lithuania, Latvia, Portugal, Slovenia, and Slovakia). We estimate the average impact to be 47bp. This estimate is close to the event study estimate reported in Andrade, Breckenfelder, De Fiore, Karadi, and Tristani (2016), who estimate the impact on 10-year yields to be 45bp.

5.3. Estimating the Asset Demand System

We report the estimation results of the demand curves for different investor sectors in Table XI in columns (2) to (7). To ensure that the demand system has a unique equilibrium, we impose the constraint derived in Koijen and Yogo (2019) that the demand curve of each investor is downward sloping. In our specification, this implies that we impose that $\beta_{0h} \geq 0$.

This constraint binds only for the household sector, pointing to inelastic demand for this group of investors.

The way characteristics impact demand is intuitive in most cases: conditional on price, institutions tend to prefer bonds issued by larger and safer countries and the estimates point to a significant home bias for all sectors. In addition, insurance companies and pension funds prefer to hold long-maturity bonds, while the opposite is true for the foreign sector.

We use the demand system to connect the price effects in column (1) to the elasticity of demand with respect to price for various investors. The demand elasticity is a function of β_{0h}, see Koijen and Yogo (2019),

$$-\frac{\partial q_{ht}(n)}{\partial p_{ht}(n)} = 1 + 100\frac{\beta_{0h}}{\tau_{nt}}(1 - w_{ht}(n)). \tag{13}$$

where lowercase indicates log of variables, $Q_{ht}(n)$ the quantity of bonds held, and τ_{nt} the average maturity.

We report the average, standard deviation, the minimum, and maximum over time in Table XIII. A coefficient of zero implies that demand is inelastic and larger values imply that demand is more sensitive with respect to price. Hence, aside from the residual category "Other," the foreign sector is most elastic. The demand elasticities are in all cases substantially higher than the estimates for stock markets. For instance, Chang, Hong, and Liskovich (2015), report an elasticity close to one. The higher elasticity for government bond markets may reflect the fact that government bonds issued by different countries in the euro area are closer substitutes than equities issued by different companies.

For the other institutions, we find that the point estimates of insurance companies and pension funds imply somewhat more elastic demand compared to mutual funds and banks, but the estimates are quite imprecise. To relate this finding to our earlier rebalancing figures, in which we show that insurance companies and pension funds actually bought long-term bonds, it is important to recall that our demand estimates include investor - quarter fixed effects. As a result, aggregate trends for a given sector do not impact our estimates and long-term investors have slightly more elastic demand in allocating their capital to government bonds across different countries in the euro area.

To illustrate how the demand estimates relate to our evidence on price effects, we consider a simple back-of-the-envelope calculation. The ECB purchased, and announced to purchase, 27% of outstanding government debt, see Table XII. The size-weighted average demand elasticity equals 6,[26] which results in a price effect of $27\%/6 = 4.5\%$. This implies for bonds

[26]What matters for the aggregate elasticity is a size-weighted average of the estimates of the different sectors.

with an average maturity around 10 years that the yields decline by -45bp, which is close to our estimates in Table XII.

Table XIII: Summary statistics for price elasticity.

For each holder country h, quarter t and issuer country n we compute the price elasticity as in (13). We report the average, standard deviation, the minimum, and maximum over time. The weight of each sector is based on holdings of government debt in 2014Q2, and total elasticity is the weighted average elasticity.

Sector	Obs.	Mean	St.dev.	Min.	Max.	Weight
Banks	3243	2.45	0.34	1.16	3.73	23
Mut. Funds	3198	1.84	0.19	1.06	2.58	12
ICPF	3791	4.42	0.76	2.01	7.46	17
Other	2574	22.06	5.59	2.34	41.44	4
Foreign	210	8.65	1.65	6.19	15.51	42
Household	2931	1.00		1.00	1.00	3
Total		5.98				100

5.4. The Gains and Losses by Institutional Type and Geography

We conclude by computing which investors gain and lose from the PSPP. To this end, we compute the total euro-area duration risk, in euros, by institutional type and geography in Table XIV in 2015Q1. Assuming a parallel shift in the yield curve, we multiply the euro duration by the estimate of the yield impact of -47bp, see Table XII, and report the total gains in the final column of the table.

The total valuation effect equals €377 billion, of which €179 billion went to investors in non-vulnerable countries, €67 billion to investors in vulnerable countries, and the remaining €131 billion to investors outside of the euro area.

For banks, mutual funds, and insurance companies and pension funds in non-vulnerable countries, the duration of their portfolios exceeds the duration of the same institutions in vulnerable countries. These institutions in non-vulnerable countries, therefore, experience larger valuation effects as a result of the PSPP-induced decline in yields. Among all institutions in each region, insurance companies and pension funds experience the largest benefit due to the long-duration assets that they hold. However, their liabilities also have long durations, so the overall impact of the PSPP on the funding position of long-term investors cannot be assessed without additional information on their liabilities.

Lastly, in evaluating the benefit of the PSPP to different sectors, it is important to distinguish the short- and long-run benefits. In the short run, the valuation benefit (as so far as the benefits are not more than offset by a commensurate increase in the value of the liabilities) is positive and may relax financial constraints. Foreign investors, by liquidating

Table XIV: Who gained from QE?

The table reports the size of the euro area fixed income portfolio (categories 1 to 5, 2015Q1) the quantity of duration risk and the duration of the bond portfolio held by each sector by country group. We compute the impact of a shock of 47bps on the portfolio (EUR billion).

Riskiness	Sector	Holding	Amount of duration risk	Duration	Impact (in bn)
Non-vulnerable	Banks	2,515	9,258	3.7	44
	Mutual funds	1,593	9,791	6.1	46
	ICPF	2,041	16,436	8.1	77
	Households	258	758	2.9	4
	Other	320	1,669	5.2	8
	Total	6,727	37,912		179
Vulnerable	Banks	1,766	5,144	2.9	24
	Mutual funds	454	2,088	4.6	10
	ICPF	639	3,884	6.1	18
	Households	522	2,049	3.9	10
	Other	197	1,132	5.7	5
	Total	3,578	14,297		67
	Foreign	5,013	27,972	5.6	131

part of their positions in response to the declining yields, realize their capital gains. However, if institutions hold the bonds until maturity and then roll them over to newly-issued bonds, the yield on the new bonds will be lower and the long-run investment opportunities deteriorate as a result.

6. Conclusions

We use new data on security-level portfolio holdings of institutional investors and households in the euro area to evaluate the impact of the ongoing asset purchase programme of the ECB on the dynamics of risk exposures and asset prices. We measure how investors adjust their portfolios by studying portfolio flows as well as changes in risk exposures to euro-area duration, government and corporate credit, and equity risk exposures as the programme evolves. To connect the changes in portfolio holdings to price effects, we estimate an asset demand system using an instrumental-variables estimator. To evaluate the impact of the programme, we calculate how much different institutional types, both in non-vulnerable and vulnerable countries, as well as the foreign sector gain as a result of the programme.

We find that the foreign sector accommodates most of the purchases by the ECB thus far. Consistent with this finding, we estimate their demand to be the most elastic and their presence consequently dampens the impact of the PSPP on yields. Despite the large

flows, we do not find significant rebalancing to other asset class or evidence that risks get concentrated in the portfolios of a small set of institutions.

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A. Home Bias, Country Size, and Measuring Rebalancing

Consider two countries that are symmetric in terms of portfolios, other than that one country is larger than the other country. Countries are indexed by $c = 1, 2$. Each country has a single institution. The assets are denoted by A_c. We assume $A_1 = xA_2 = xA$, where $x > 1$. The portfolio weights of country 1 are given by $w_1 = (\xi, 1-\xi)$. The portfolio weight of country 2 by $(1-\xi, \xi)$, where $\xi \in (0.5, 1)$. Hence, each country is home biased.

Market clearing implies that supply satisfies

$$S_1 = \xi A_1 + (1-\xi)A_2 = (x\xi + 1 - \xi)A, \tag{14}$$

$$S_2 = (1-\xi)A_1 + \xi A_2 = (x(1-\xi) + \xi)A, \tag{15}$$

implying that $S_1 > S_2$. We normalize $A = 1$.

Suppose the ECB buys a fraction $\theta \in (0, 1-\xi)$ of each country's supply. Hence, T_{ECB} can be computed as

$$T_{ECB} = \begin{pmatrix} \theta(x\xi + 1 - \xi) \\ \theta(x(1-\xi) + \xi) \end{pmatrix}. \tag{16}$$

Assume that both investors sell a fraction θ of their portfolios. The rebalancing in response to the ECB purchases are equal to

$$T_1 = \begin{pmatrix} -\theta x\xi \\ -\theta x(1-\xi) \end{pmatrix} \tag{17}$$

and

$$T_2 = \begin{pmatrix} -\theta(1-\xi) \\ -\theta\xi \end{pmatrix}. \tag{18}$$

Assuming supply remains constant, the market clearing condition in changes holds. The slope for the institution in country 1 is

$$\beta_1 = \frac{-x\xi + x(1-\xi)}{(x\xi + 1 - \xi) - (x(1-\xi) + \xi)} = \frac{x(1-2\xi)}{(1-x)(1-2\xi)} = \frac{x}{1-x} < -1, \tag{19}$$

and for country 2

$$\beta_2 = 1 - \beta_1 = \frac{1-2x}{1-x} > 0. \tag{20}$$

With this measure of rebalancing, we get the counterintuitive result that $\beta_2 > 0$, while both investors accommodate QE by scaling their portfolios in proportion. Intuitively, the ECB buys a lot Country 1 and less of Country 2. The investor in Country 2 sells a lot of Country 2 and little of Country 1, which suggests it amplifies the effect of the QE programme.

Next, we consider an alternative way to measure rebalancing. We start from the market clearing condition in changes

$$\Delta Q_{ECB} P = -\Delta Q_1 P - \Delta Q_2 P, \tag{21}$$

where the products of vectors are to be interpreted as element-by-element multiplication. The idea is that the ECB purchases may need to be "attributed" to different investors in proportion to their initial portfolios. That is,

$$\Delta Q_{ECB} = \frac{Q_1}{S}\Delta Q_{ECB} + \frac{Q_2}{S}\Delta Q_{ECB}. \tag{22}$$

We can then rewrite the market-clearing condition as

$$0 = \left(\Delta Q_1 + \frac{Q_1}{S}\Delta Q_{ECB}\right) P + \left(\Delta Q_2 + \frac{Q_2}{S}\Delta Q_{ECB}\right) P. \tag{23}$$

This is similar as before, other than that we add a "fixed effect" to each country's rebalancing based on their initial portfolios. Define

$$T_i^\star \;=\; \left(\Delta Q_i + \frac{Q_i}{S}\Delta Q_{ECB}\right) P, \tag{24}$$

and T_{ECB} is the same as before. We now consider the regressions

$$T_i = \alpha_i^\star + \beta_i^\star T_{ECB} + \epsilon_i, \tag{25}$$

where the market clearing condition implies

$$\beta_1^\star + \beta_2^\star = 0. \tag{26}$$

Importantly, in step 2, we now measure the rebalancing induced by the ECB as

$$-\frac{Q_i}{S}\Delta Q_{ECB} + \beta_i \Delta Q_{ECB}. \tag{27}$$

If we apply this alternative framework to the example above, then

$$T_1^\star = \begin{pmatrix} -\theta x \xi \\ -\theta x(1-\xi) \end{pmatrix} + \begin{pmatrix} \frac{\xi x}{\xi x + 1 - \xi} \theta(\xi x + 1 - \xi) \\ \frac{(1-\xi)x}{x(1-\xi)+\xi} \theta(x(1-\xi) + \xi) \end{pmatrix} = 0_{2\times 1}. \tag{28}$$

Hence, $\beta_1^\star = \beta_2^\star = 0$, and the rebalancing is in proportion to the ECB purchases.

B. Additional tables and figures

Table B.1: Rebalancing Before the PSPP

The table reports average portfolio rebalancing from 2013Q4 until 2014Q4. The asset categories are defined as: Elig. Govt. - PSPP eligible government bonds, Inelig. Govt. - PSPP ineligible government bonds, IG-Corp. - Investment grade corporate bonds, SG-Corp. - Speculative grade corporate bonds, ABS&CB - ABS and covered bonds, Equity - Euro area equity, and Foreign - Non-euro area assets. The top panel reports the rebalancing for investor sectors in non-vulnerable countries and the second panel for investors in vulnerable countries. The third panel reports the rebalancing of the foreign sector and the ECB. The bottom panel reports net issuances. The flows are reported in billions of euros.

		Asset category						
Riskiness	Sector	Elig. Govt.	Inelig. Govt.	IG Corp.	SG Corp.	ABS &CB	Equity	Foreign
Non-vulnerable	ICPF	1	7	-2	4	-2	2	11
	Banks	8	5	-18	3	-12	5	-25
	Mutual Funds	8	3	-3	9	-4	22	97
	Household	-2	0	-5	-3	-1	4	3
	Other	4	-3	0	0	-1	-2	0
Vulnerable	ICPF	7	4	-1	0	-1	1	1
	Banks	15	-9	-20	-22	-20	-4	4
	Mutual Funds	9	1	2	3	0	14	31
	Household	-5	-1	-13	-10	0	2	-13
	Other	-2	0	0	-1	0	1	-4
	ECB	-6	6	0	0	8	0	0
	Foreign	22	-42	2	-26	-12	–	–
	Issuer	61	-30	-60	-44	-45	–	–