Inspecting the Mechanism of Quantitative Easing in the Euro Area

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Abstract

Using new security-level portfolio holdings data in the euro area by country and investor type, we study how investors rebalance in response to 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, sovereign, and corporate credit risk exposures across investors and geographies. We find that 70% of ECB purchases are sold by the foreign sector and that risk mismatch, if anything, reduces. We use an instrumental variables estimator to show that the average impact on yields was -13bp. We connect the portfolio rebalancing and price effects by estimating a sector-level asset demand system for government debt.

Keywords: Quantitative Easing, Portfolio Rebalancing, Risk Concentration.

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 stated objective is to increase inflation to a level close to, but below, 2%. Initially, the size of the programme was announced to be €60 billion per month until September 2016, starting in March 2015. The programme has subsequently been expanded and is intended to continue until September 2018.

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. To analyze and test the importance of various channels on asset prices, inflation, and economic growth more broadly, the literature has mostly focused on the response of asset prices around key policy announcements.[1]

We contribute to this literature by looking at asset prices and portfolio holdings jointly. We use new security-level portfolio holdings data 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, we observe the holdings of government bonds, corporate bonds, asset-backed securities (including covered bonds), and equities, both in and outside of the euro area, at a quarterly frequency. We link these data to detailed information on prices and security characteristics and security-level purchase data of the ECB, both from the ongoing asset purchase programme as well as the legacy holdings from earlier programmes. Although our data are at the level of the holder country and investor sector, we report our results at the level of vulnerable countries (Italy, Spain, Portugal, Greece, Cyprus, and Ireland) and non-vulnerable countries (all other countries) to not disclose any confidential information.

Our sample is from 2013Q4 until 2016Q4, covering the first 22 months of purchases that amount to €1.4 trillion. For all securities in an investor's portfolio, we measure the euro-area duration, sovereign and corporate credit, and equity risk exposure. Starting from market clearing, we quantify the risk exposures of investors to these main risk factors.[2]

Our paper is motivated by three questions that test the mechanisms underlying broad groups of theories. First, we ask which investors rebalance their portfolios as the programme unfolds. We provide a simple regression framework, starting from the market clearing condition in changes, to measure which investors sell in response to the purchase programme.

[1] See for instance Gagnon, Raskin, Remache, and Sack (2011) and Krishnamurthy and Vissing-Jørgensen (2011) for the United States and Krisnamurthy, Nagel, and Vissing-Jorgensen (2014) for Europe.

[2] 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 sovereign and equity risk and we can measure exposures for other institutions than banks, such as mutual funds, insurance companies, and pension funds.

As a point of reference, Wallace (1981) and Eggertsson and Woodford (2003) provide irrelevance results analogous to those of 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.[3] In the presence of heterogeneous investors, the same economic mechanism implies that only investors exposed to the trading profits and losses of the central bank (e.g., through taxation) should adjust their portfolios.

Empirically, we document a heterogenous response across investors with the foreign investors selling the largest amount, around €0.70 per euro purchased by the ECB, followed by banks and mutual funds. Long-term investors, such as insurance companies and pension funds, if anything, buy the same bonds as the ECB.

We also test whether asset prices are affected by the programme. The typical challenge in estimating the impact of asset purchase programmes on yields is that the announcement of a programme depends on aggregate economic conditions, which also affect bond yields directly. The solution in the literature is to measure the price response on days featuring important announcements. We will refer to this as a high-frequency, single-difference estimator. One potential drawback of this empirical strategy is that investors may anticipate (parts of) the purchase programme and that expectations adjust gradually in response to the flow of macro-economic and financial news. Moreover, prices may be slow to adjust if investors require time to process policy announcements or to reallocate capital, which raises questions about the long-run impact (Greenlaw, Hamilton, Harris, and West, 2018).

We propose an alternative estimator using some of the unique features of the purchase programme to identify the impact on yields. The ECB[4] buys bonds across countries according to the "capital key." The weight of a country in the capital key is an average of a country's GDP and population share, and we argue that population size is exogenous (at least, in the medium run). Second, within a country, the ECB intends to act "market neutral," which we interpret as purchasing bonds according to the maturity distribution of outstanding bonds. Using the maturity distribution before the programme was announced gives us variation across bonds within a given country. By interacting the exogenous component of the capital key with the maturity distribution, we obtain exogenous variation in purchases across countries and maturities. We relate this to changes in bond yields from 2014Q2 until 2015Q1. We refer to this as a low-frequency, difference-in-difference estimate that complements the high-frequency, single-difference estimates.

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

[4]In practice, bonds are purchased by national central banks as we explain below. For simplicity, we often refer to the ECB implementing the programme.

We estimate that bond yields decline (on average) by 13bp, although there is significant heterogeneity across countries and maturity groups. The decline in yields can, for instance, be due to the fact that the programme signals a lower future path of short rates (Eggertsson and Woodford, 2003) or the programme may lower risk premia (Vayanos and Vila, 2009).[5] Our facts on portfolio rebalancing and yields both challenge the traditional irrelevance theorems.

Our second question is motivated by concerns that, if the programme is successful, the yields of safe assets and the funding cost of intermediaries decrease, which may motivate investors to take on (excessive) levels of leverage, leading to financial fragility (Woodford, 2011, Coimbra and Rey, 2016). 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 the QE programme. However, the primary concern is that risks get concentrated in certain sectors. Although these risk shifting incentives are perhaps best addressed through capital and risk regulation of banks and insurance companies, regulation is typically slow to adjust.

Empirically, we use our risk accounting framework to track the dynamics of risk exposures and risk concentration over time. If we map holdings to duration, sovereign credit, and corporate credit risk exposures, we find that the largest transfer of duration and sovereign credit risk is from the foreign sector to the ECB and, to a smaller extent, to insurance companies and pension funds in vulnerable countries. However, we do not find evidence of large-scale rebalancing across asset classes within the euro area.

Another class of non-neutrality theories, see for instance Brunnermeier and Sannikov (2016), points out that in the presence of financial frictions, an increase in the prices of assets held by compromised institutions relaxes their financial constraints and increases lending activity, which in turn affects inflation and economic growth. We find that banks in vulnerable countries hold €533 billion in eligible government debt. Coupled with the decline in yields of 13bp, we find that banks holding 5-year bonds experience a capital gain around €3.5 billion.

Our third question is prompted by the relatively small decline in yields in response to the large amount of purchases. To connect both findings, while accounting for the heterogeneous response across investors, we estimate a sector-level asset demand for government debt (Krishnamurthy and Vissing-Jørgensen, 2007, Koijen and Yogo, 2017). By mapping portfolio rebalancing and yield movements to demand elasticities using our demand system, we find that the price elasticity of demand for government bonds is substantially higher than recent estimates from equity markets. We also use the model to recover investors' expectations

[5] See also Greenwood and Vayanos (2014) and Greenwood, Hanson, and Vayanos (2015).

about future ECB purchases and we show that changes in expectations closely track key policy announcements.

In addition to inspecting the mechanism of purchase programmes, our findings have broader implications for asset pricing models. Traditional models do not explicitly feature institutional investors. In recent years, in part in response to the financial crisis, a new generation of asset pricing models explores the role of institutional frictions and some of these models are useful to think about the impact of asset purchase programmes.[6] Most models feature one class of intermediaries, which are perhaps best interpreted as banks. Our results highlight the importance of heterogeneity across institutions in absorbing demand shocks.[7]

1. Institutional Background

We briefly summarize the asset purchase programmes implemented by the ECB 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 primarily used to buy sovereign bonds 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 the third covered bond purchase programme (CBPP3).

In January 2015, the ECB announced the extended asset purchase programme (APP), which is the main focus of our paper. The APP contains three components: it extends the ABSPP and CBPP3 and adds the public sector purchase programme (PSPP). The PSPP will purchase bonds of euro-area governments, agencies, and European institutions.

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 programmes would lead to Eurosystem purchases of €1.14 trillion, which is about 15% of the total GDP in the euro area. 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

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

[7] See Coimbra and Rey (2016), Koijen and Yogo (2017), and Greenwood, Hanson, and Liao (2016) for models with richer heterogeneity across institutions.

inflation at a level close to, but below, 2%.

Before the start of the PSPP, the purchases as part of the ABSPP and CBPP3 amount to €10 billion a month. In addition, the ECB announced that the PSPP was split into purchasing debt of supranational institutions[8] 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 debt and €44 billion of government debt (Claeys, Leandro, and Mandra, 2015). The €44 billion of purchases are allocated to bonds issued by euro-area governments according to each country's share of the ECB's capital, the so-called capital key. The capital key reflects the GDP and population share of each member state. These two determinants have equal weighting so that countries with a large population and high GDP, such as for instance Germany, have a relatively high share (25%) relative to smaller countries (we provide further details in Section 5).[9] The purchases are held both by national central banks and the ECB. For 20% of the asset purchases as part of the PSPP, there is loss sharing via the ECB. Profits and losses on ECB holdings are shared among national central banks according to the capital key. Throughout the paper, we refer to ECB purchases as the sum of purchases by national 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 BBB or better), 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.[10] 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.

Debt of certain national agencies is also eligible, such as for instance the debt of the Landeskreditbank Baden-Württemberg Foerderbank. Across maturities, the ECB intends to act as "market neutral" as possible, which we interpret as buying (approximately) in proportion to the outstanding maturity distribution between 2 and 30 years.

The PSPP has been modified several times. First, in December 2015, the end date of the programme was extended from September 2016 until March 2017 and the deposit facility rate was lowered to -30bp. Second, in March 2016, the size of the programme was scaled up

[8]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.

[9]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.

[10]These limits are imposed to avoid that the ECB has a blocking minority in a debt restructuring involving collective action clauses.

from €60 billion to €80 billion per month and the deposit facility rate was lowered further to -40bp. In addition, investment-grade corporate bonds are now considered to be eligible as well. Third, the ECB announced in December 2016 to lower purchases from €80 billion to €60 billion per month starting in April 2017, while extending the programme to December 2017. The minimum residual maturity was reduced to one year and restrictions on yields in relation to the deposit facility rate were removed. Lastly, the ECB announced in October 2017 to further reduce purchases at a monthly pace of €30 billion until the end of September 2018.

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).[11] 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. Our sample ends in 2016Q4.

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.[12] 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.[13] The holdings reported in the SHS correspond to approximately €27 trillion for each quarter. The assets covered include both government and corporate debt, 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.

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

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

[13] 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.

To protect the confidentiality of our data, we compute the duration risk held by the ECB using publicly-available data on holdings of the ECB. If the weighted average maturity is available, we select a sample of government bonds with maturity in a one-year window around that of the ECB and compute the weighted-average duration of these bonds, which we assign as the duration of the ECB. For covered bonds and ABS, we take the average market duration.

We link the holdings data to asset characteristics. The main source for data on characteristics is the Centralised Securities Database (CSDB). The CSDB contains information on more than six million outstanding debt securities, equities, and mutual fund shares issued by both companies residing in the euro area and outside. The data are from both public and commercial sources and is managed by the ESCB (ECB, 2010). A key variable used in CSDB is price, where market prices are used when available. For debt securities for which the price is 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.[14] 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 therefore exclude indirect holdings, for instance via holdings of mutual fund shares, to avoid double-counting. 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

[14]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."

market value). However, we always have accurate data on holdings of euro-area investors for securities issued inside and outside of the euro area.

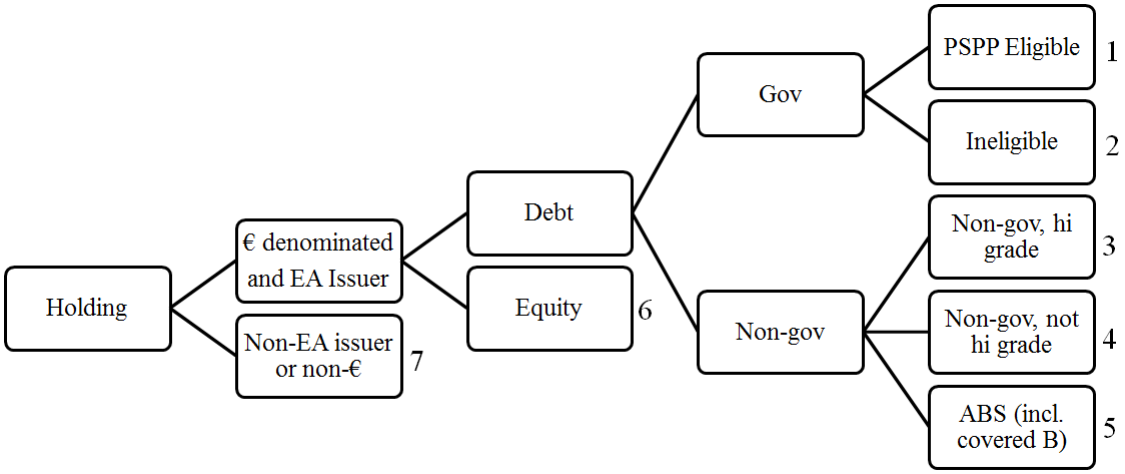


Figure 1: Summary of security types.

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 is purchased as part of the PSPP.

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 use information on debt type from the CSDB.[15] 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 B.1 summarizes the definitions of the asset categories.

[15]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.

2.3. Investor Types

We do not have direct data on the portfolio holdings of, what we call, the "foreign sector," which are investors located outside of the euro area. We compute their holdings 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 B.1.

Investor types differ along, at least, 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 short-term liabilities that may be subject to runs, while insurance companies have long-term liabilities that cannot be withdrawn easily in most countries.[16] The combination of long-term liabilities and risk regulation leads insurance companies and pension funds to hold long-term bonds, in particular when interest rates are low (Domanski, Shin, and Sushko (2015)).

For some of the calculations, we separate countries into two groups based on the extent to which countries were affected by the euro crisis (following Altavilla, Pagano, and Simonelli (2016)). The first group includes the more vulnerable countries, namely Italy, Spain, Portugal, Greece, Cyprus, and Ireland. The second group consists of relatively non-vulnerable countries, namely 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 common in measuring cross-border holdings, we cannot measure securities positions of euro-area institutions that are held through offshore institutions, and institutions located outside the euro area (see Milesi-Ferretti, Strobbe, and Tamirisa (2010) and Zucman (2013) for further discussions). However, we do know holdings in mutual funds that are domiciled in Luxembourg and Ireland, which are the largest mutual fund centers for the euro.

Second, we have accurate data on the 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.

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

3. Initial Conditions: Holdings and Risk Exposures before the Programme

We summarize the heterogeneity in portfolio characteristics of institutional portfolios before the announcement and implementation of the PSPP programme.

3.1. Securities Holdings

In Table I, we report the holdings by sector and country group for each asset category. We compute the average market value of portfolio holdings from 2013Q4 to 2014Q4, which is before the PSPP programme was announced. These holdings therefore summarize the initial heterogeneity in institutional portfolios across sectors and geographies.

Table I: Holdings by investor type, holder country group, and asset category.

The table reports the average market value of holdings, computed before the announcement of the PSPP programme, 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 holdings for investor sectors in non-vulnerable countries and the bottom panel for vulnerable countries. The classification of vulnerable and non-vulnerable countries follows Altavilla et al. (2016). All figures are in billions of euros.

		Asset category							
Riskiness	Sector	Elig. Govt.	Inelig. Govt.	IG Corp.	SG Corp.	ABS &CB	Equity	Foreign	Total
Non-vulnerable	Banks	838	453	673	194	615	127	648	3,548
	Mutual Funds	585	214	299	252	179	904	2410	4,843
	ICPF	948	167	383	208	186	137	479	2,508
	Household	20	15	98	149	12	463	145	902
	Other	126	82	41	53	26	767	86	1,181
	Total	2,517	931	1,494	856	1,018	2,398	3,768	12,982
Vulnerable	Banks	533	472	153	187	563	63	261	2,232
	Mutual Funds	160	133	43	44	24	161	811	1,376
	ICPF	362	101	71	43	37	26	64	704
	Household	176	109	109	211	5	198	64	872
	Other	123	66	12	23	2	262	38	526
	Total	1,354	881	388	508	631	710	1,238	5,710
	Foreign	2,273	1,213	287	389	306	2,629	-	7,097
	ECB	114	45	0	0	21	0	0	180

The top panel summarizes the holdings by sector for non-vulnerable countries and the middle panel for vulnerable countries. The bottom panel presents the holdings of the ECB and the foreign sector. Each of the columns corresponds to an asset category. In terms of assets under management, institutions in non-vulnerable countries are significantly larger.

Insurance companies and pension funds invest a large fraction of their portfolio 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. This allocation is consistent with the long-maturity liabilities of these institutions.

Banks also invest a large share of their portfolios in eligible government debt and are also 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 in particular foreign securities. This suggests 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 one-third of the 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, in Germany).

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

The holdings of eligible government debt across institutions play a central role in theories that point out that asset purchase programmes can relax financial constraints of compromised institutions by increasing the value of their assets (Brunnermeier and Sannikov, 2016). Moreover, the holdings of sovereign debt by banks in the same country has been highlighted as an important concern for financial stability in the euro area (Altavilla et al., 2016). We extend this literature by studying the home bias in sovereign debt portfolios across institutions that differ, for instance, in terms of their risk regulation.

We report the holdings of PSPP-eligible debt by holder country group and investor sector in Table II. Each panel contains three columns. The first column reports the market value of holdings in 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. The third column therefore measures the home bias in the allocation to eligible debt.

Table II: 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 sector's portfolio invested in PSPP-eligible government debt (in %). The third column reports the share of a sector's portfolio invested in PSPP-eligible debt of 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. €)	Eligible debt (%)	Home bias (%)
Non-vulnerable	Banks	838	25	55
	Mutual Funds	585	12	19
	ICPF	948	38	51
	Household	20	2	65
	Other	126	11	71
	Total	2,517	20	46
Vulnerable	Banks	533	24	84
	Mutual Funds	160	12	64
	ICPF	362	52	86
	Household	176	20	95
	Other	123	24	95
	Total	1,354	24	85
	Foreign	2,273	–	–
	ECB	114	64	–

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 II is, however, that all institutions in vulnerable countries have a stronger home bias, compared to non-vulnerable countries. Banks invest 84% of their sovereign debt portfolio in their own country, insurance companies and pension funds 86%, and even mutual funds 64%.

Acharya and Steffen (2015) discuss various reasons why banks in peripheral countries invest heavily in sovereign debt. One explanation is based on the fact that banks can borrow cheaply from the ECB and invest in high-yielding sovereign bonds, thereby earning the "carry." As sovereign bonds have zero risk weights under Basel II regulations, this trade is riskless from the perspective of regulators. However, as any sovereign bond has a zero risk weight, this explanation does not necessarily imply a home bias. More importantly, mutual funds are not subject to the same risk weights, yet their portfolios have a similar home bias as the portfolios of regulated institutions such as banks, insurance companies, and pension funds.

Alternatively, financial institutions may internalize the fact that in case of a sovereign

default, the banking sector will default or experience runs as well. With limited liability, it may be optimal for financial institutions to invest in sovereign bonds of their own country as in states in which these bonds pay off, the institutions are likely to survive as well (Diamond and Rajan, 2011).

Financial repression provides a third possible explanation of the home bias in peripheral countries, where financial institutions are encouraged or forced to buy bonds of their own government to lower sovereign borrowing costs, see Becker and Ivashina (2014) and Ongena, Popov, and Horen (2016) in the context of banks in the euro area. Although one may be inclined to conclude that this theory cannot explain the home bias of mutual funds, it is important to keep in mind that most mutual funds in the euro area are offered through banks. The pressure on banks may therefore incentivize mutual funds to tilt their portfolios towards sovereign debt of their own country.

These findings are also important from a financial stability perspective. Policy discussions tend to focus on the bank-sovereign feedback loop. However, given the role that insurance companies, pension funds, and mutual funds play to safeguard retirement savings, a sovereign default would not only affect the banking system but also households' long-term savings.

3.2. Risk Exposures of Investment Portfolios: Measurement

In addition to summarizing portfolio holdings and flows in response to the asset purchase programme, we are interested in measuring the distribution and dynamics of risk exposures to euro-area financial market risks across investors. To this end, we distinguish five dimensions of risk: (i) euro-area duration risk, (ii) euro-area sovereign 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 measure exposures. For euro-area interest rate risk, we use duration risk. We measure the duration of government bonds, both eligible and ineligible, corporate bonds, ABS, and covered bonds.[17] To compute duration, we need to know the yield-to-maturity, the coupon rate, and the payment frequency of the coupons. For sovereign credit risk, we measure the risk exposure using the credit rating of all eligible and ineligible government bonds. For each country, we use the credit rating on long-term debt denominated in the home currency from the four main credit rating agencies. 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 a measure of the riskiness of a country's government bonds.

We follow a similar procedure to measure corporate credit risk exposure. In this case, we aggregate holdings across all corporate bonds, ABS, and covered bonds. We map the ratings

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

to default frequencies using estimates for 5-year cumulative corporate default probabilities reported in Moody's (2015). 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.

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. Analogously, for foreign risks, we 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 III. In the first column, we report the duration of the overall portfolio, which also accounts for fixed-income securities issued outside of the euro area or denominated in currencies other than euros. The second column reports the euro-area duration risk. By comparing both columns, we find that these numbers generally coincide other than for mutual funds in vulnerable countries and for the foreign sector. 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.

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

The corporate credit risk exposure is also higher for institutions in vulnerable countries, although the difference is less extreme than for sovereign risk. The ECB's corporate bond portfolio, which only includes covered bonds before the start of the PSPP, is safest across all institutions, followed by banks in non-vulnerable countries.

Table III: 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 sovereign credit risk exposure is measured by the 5-year cumulative probability of default for either sovereigns or firms as reported in Moody's (2015) and the rating is the average rating of the four main credit rating agencies. For 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.	Sovereign	Corporate	Equity	Foreign
Non-vulnerable	Banks	3.1	3.1	0.5	0.5	4	18
	Mutual Funds	5.2	5.1	0.8	1.2	19	50
	ICPF	6.8	7.1	0.6	1.0	5	19
	Household	2.5	2.4	0.6	1.7	51	16
	Other	4.1	4.2	0.3	1.2	65	7
Vulnerable	Banks	2.1	2.1	2.1	1.4	3	12
	Mutual Funds	5.7	3.8	1.6	1.8	12	59
	ICPF	5.6	5.7	1.6	1.6	4	9
	Household	3.7	3.6	1.6	2.1	23	7
	Other	4.7	4.8	2.1	2.1	50	7
	Foreign	6.2	4.9	0.8	1.1	–	–
	ECB	3.5	3.5	2.0	0.6	0	0

3.4. The Distribution of Risk Exposures

To measure the distribution of risk exposures across investors, and hence changes in risk concentration as the programme unfolds, we propose a risk accounting framework. We focus on the same risk factors as in the previous section.[18] Ideally, we would observe the entire balance sheet of institutions and measure risk mismatch between assets and liabilities. Unfortunately, these data are not available for most institutions and we therefore focus on the distribution of risk exposures of cash securities and how the distribution of risk exposures

[18] Although we focus on univariate risk measures, it may be interesting to explore the risk of the overall portfolio, which depends on the covariance of various risk factors. This is potentially important as the correlation between, for instance, equity and government bond returns in Germany tends to be negative, while it is significantly higher in Italy. Combined with home bias, this implies that holding a portfolio of stocks and bonds is riskier for Italian institutions than for German institutions.

changes in response to the asset purchase programme.

The results are presented in Table IV for all five risk factors that we consider. The final column reports the size of a given sector per country group. By definition, each of the columns (excluding the subtotals) aggregates to 100.

Insurance companies and pension funds bear 27% of all euro-area duration risk, the foreign sector 31%, and banks 19%. The exposure of banks is perhaps surprising given the relatively short duration of their liabilities although this may be optimal if banks have market power in deposit markets (Drechsler, Savov, and Schnabl, 2017).

Vulnerable countries are most exposed to sovereign risk, which reflects the home bias of these institutions. Banks in vulnerable countries alone bear 23% of all the risk, while they only bear 6% of the duration risk. Compared to banks in non-vulnerable countries, which are more than 50% larger than banks in vulnerable countries, banks in vulnerable countries bear almost four times the sovereign risk. We estimate that the ECB is exposed to 1% of euro-area duration risk and 4% of all sovereign 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 is exposed to 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, both sovereign and corporate credit risks are concentrated in the banking sector in vulnerable countries.

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 42%, where mutual funds account for the largest share (16% of 42%). 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 foreign securities. 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. Inspecting the Mechanism: Rebalancing and Risk Concentration

In this section, we study portfolio flows and the dynamics of risk exposures during the PSPP programme from 2015Q2 until 2016Q4.

Table IV: 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.	Sovereign	Corporate	Equity	Foreign	Size
	Banks	13	7	14	2	13	3,548
	Mutual Funds	12	7	13	16	48	4,842
Non-vulnerable	ICPF	21	7	13	2	10	2,509
	Household	1	0	5	8	3	903
	Other	2	1	2	13	2	1,182
	Total	49	22	47	42	75	12,984
	Banks	6	23	22	1	5	2,232
	Mutual Funds	2	5	3	3	16	1,376
Vulnerable	ICPF	6	9	4	0	1	705
	Household	3	5	7	3	1	871
	Other	2	4	1	5	1	526
	Total	19	46	37	12	25	5,711
	Foreign	31	29	18	46	0	7096
	ECB	1	4	0	0	0	179

Table V: Portfolio Rebalancing During the PSPP.

The table shows the cumulative rebalancing from 2015Q2 to 2016Q4 by asset category (EUR billion). The holdings are measured in terms of market value as of 2015Q2. The share sold is the rebalancing in eligible 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). All figures are in billions of euros.

Riskiness	Sector	Govt.	Corp.	ABS&CB	Equity	Foreign	Holdings	Share sold
Non-vulnerable	Banks	-153	-88	-105	-1	-8	1,266	-12
	Mutual Funds	-70	18	-34	17	239	834	-8
	ICPF	20	20	-20	6	78	1,174	2
	Household	-12	-41	-3	9	3	28	-43
	Other	13	-5	-7	58	9	208	6
Vulnerable	Banks	-114	-10	-52	4	12	1,000	-11
	Mutual Funds	-33	13	-8	5	188	298	-11
	ICPF	148	46	-4	12	92	486	30
	Household	-66	-97	-2	10	4	238	-28
	Other	-26	-5	-1	-15	15	162	-16
	Foreign	-687	-111	-108	134	0	3,594	-19
	ECB	1,198	50	138	0	0	333	360
	Total	218	-210	-206	239	632		

4.1. Portfolio Rebalancing Across Asset Categories

We start by reporting the average portfolio rebalancing across sectors and holder country groups 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 ensures that portfolio rebalancing is not driven by price effects. We then aggregate the rebalancing for each asset category in a given quarter. In Table V, we report the average rebalancing per quarter in billions of euros. As a point of reference, Table B.2 summarizes the average rebalancing during the quarters before the PSPP from 2013Q4 until 2014Q4.

We first focus on government debt. During the first seven quarters, the ECB purchases €1,198 billion. The majority was sold by the foreign sector with €687 billion during the same period. 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 suggest that sectors that are affected by changes in the risk exposures of

the central bank's portfolio (through taxation or adjustments in subsidies) should rebalance their portfolios. However, it is consistent with estimates of the impact of asset purchase programmes in Japan based on aggregate statistics from the Flow of Funds (Saito and Hogen (2014)). One possible interpretation is that markets are somewhat segmented and that foreign investors are more global than euro-area investors. In response to lower yields in the euro area due the asset purchase programme, as we show below, foreign investors rebalance their portfolio towards more attractive investment opportunities outside of the euro area.

The banking sector sells another €267 billion and mutual funds €103 billion. Insurance companies and pension funds in fact buy €168 billion, which is concentrated 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 of their liabilities (Domanski et al., 2015). By market clearing, the sum of the flows across investor sectors equals net issuances. Total issuances during this period amount to €218 billion.

Second, we see large negative net issuances for corporate bonds, both before and during the PSPP. The reduction is absorbed by the foreign sector and in particular banks. 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. These data also include bonds issued in foreign currencies, which is a broader definition than we use, but the broader trends are comparable. Following the crisis in the euro area in 2012, banks have reduced the amount of debt outstanding dramatically. Given the timing, this is unrelated to the PSPP programme, although lower yields may help banks to reduce leverage. The debt dynamics for banks is strikingly different than for other financial firms, for which the debt outstanding is stable since the financial crisis, and non-financial firms, for which debt has been increasing gradually over time.

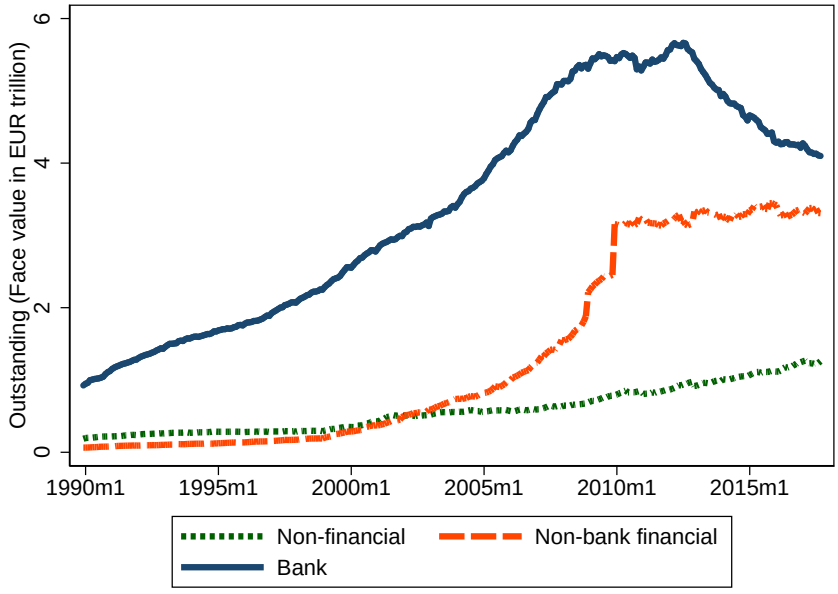
Third, the ECB also purchases €138 billion of covered bonds. Since net issuances are negative as well, there are large negative flows from banks, in both vulnerable and non-vulnerable countries, as well as the foreign sector. Again, these flows are similar to the flows before the PSPP and may be due 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.[19]

[19]See also Di Maggio, Kermani, and Palmer (2016) for evidence of limited rebalancing in U.S. mortgage markets in response to the QE programmes in the U.S.

Figure 2: Corporate Debt Dynamics.

The figure displays the total face value of debt outstanding from 1990 to 2016 for non-financial firms (dashed line), financial firms excluding banks (dotted line), and banks (solid line).



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

In the previous section, we report the average rebalancing across different asset categories. However, the portfolio rebalancing that we observe may be due to other factors than the ECB's asset purchases. We now use our micro data to quantify the portfolio-rebalance channel more directly.

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, respectively, 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 within a country into maturity brackets where the residual maturity is, expressed in years, in $[2, 5]$, $[5, 7.5]$, $[7.5, 10]$, $[10, 15]$ or $[15, 30]$. We estimate the coefficient separately by investor sector and holder country.

However, differences in country size combined with the home bias in investors' portfolios (see Table II), may lead to counter-intuitive estimates. To see this, consider two countries that differ in size, for instance, Germany and Malta. If investors in both countries 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 a lot of German debt and much less 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 provides a simple two-country example formalizing this intuition.

Given the differences in initial portfolios, we are interested in studying whether investors sell the *same fraction* of their initial portfolios to accommodate ECB purchases. We first compute the aggregate holdings across all investor sectors, excluding the holdings of the ECB, $\widehat{S}_{int}$,

$$\widehat{S}_{int} = \sum_i Q_{int} + Q_{Foreign,nt}. \tag{4}$$

We then compute portfolio rebalancing if each investor sells in proportion to their holdings,

$$T_{ECB,nt} = \sum_{h,s} \frac{Q_{in,t-1}}{\widehat{S}_{in,t-1}} T_{ECB,nt} + \frac{Q_{Foreign,n,t-1}}{\widehat{S}_{in,t-1}} T_{ECB,nt}.$$

Using this as our null model for portfolio rebalancing, we define "abnormal rebalancing," $\widehat{T}_{int}$, as

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

and analogously for the foreign sector. $\widehat{T}_{int} = 0$ if all investors sell in proportion to their initial holdings. The market clearing condition (in changes) can then be written as

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

We regress each of the terms on $T_{ECB,nt}$ across issuer countries, maturity brackets, and quarters and denote the slope coefficients by $\widehat{\beta}$. Equation (6) implies

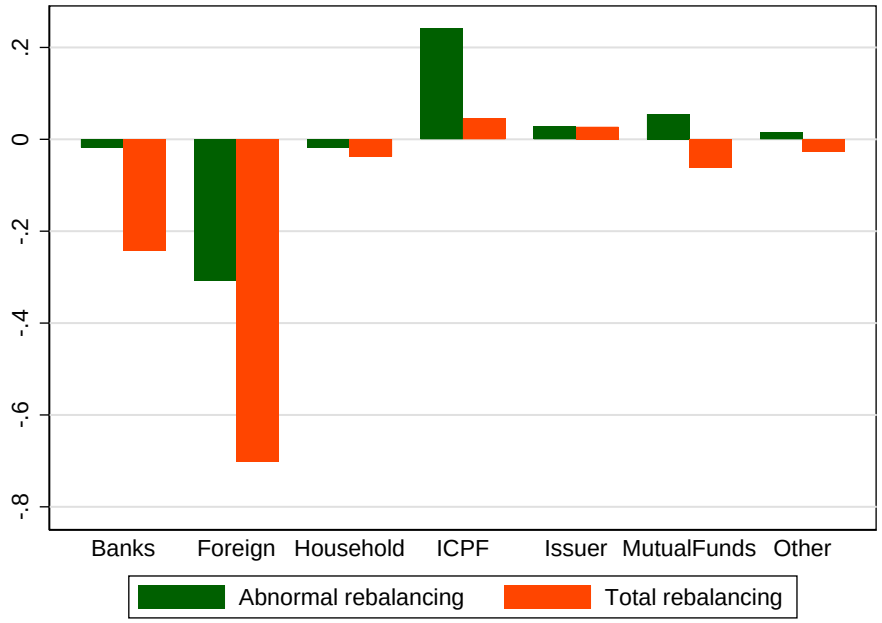
$$\sum_i \widehat{\beta}_i + \widehat{\beta}_{Foreign} = \beta_I. \tag{7}$$

If all investors rebalance in proportion to their initial holdings and if supply does not respond to the asset purchase programme, then we have $\widehat{\beta}_i = \beta_I = 0, \forall i$. Economically, when $\widehat{\beta}_i < 0$, investor sector i sells more than proportionally in response to purchases by the ECB. When $\widehat{\beta}_i > 0$, the investor sector is less elastic.

We report the average response across the seven quarters of purchases by investor sector in Figure 3. The first bar for each sector corresponds to abnormal rebalancing, $\widehat{\beta}_i$. The sum of these bars equals zero. The second bar for each sector measures total rebalancing. The sum of these bars equals one.

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 ($\widehat{\beta}_i$). It measures how investors rebalance beyond 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 2016Q4.



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 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 €0.7, banks sell a little over €0.2, and mutual funds close to €0.1. Insurance companies and pension funds do not sell and in fact buy in the same way as the ECB. Changes on the supply side, as measured by the issuer sector, are virtually unrelated to ECB purchases.

4.3. The Dynamics of Risk Exposures

In Table VI, 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 a risk factor. Panel A reports duration risk, Panel B sovereign credit risk, and Panel C corporate credit risk. In terms of total risk, we find that duration risk increases due to declining yields. Sovereign credit risk is U-shaped. This is driven in part by the decline in yields, but also due to changes in credit ratings of some countries and, in particular, the upgrades of Greece in late 2013 and early 2014 and the downgrade of France in 2015. Corporate credit risk is declining rapidly, as discussed before, which is primarily due to the decline in bank debt.

While overall duration risk increases to 110% by 2016Q4, the ECB owns 17% of it. The foreign sector reduces its share from 33% in 2015Q1 to 25% in 2016Q4. Most other sectors remain stable or slightly increase (e.g., insurance companies and pension funds in vulnerable countries).

Sovereign credit risk increases to 120% in 2016Q4, following a jump in 2015Q1 to 114%. The foreign sector owns 36% of the 114% in 2015Q1, but this declines to 27% of 120% in 2016Q4. The ECB absorbs a large fraction of this sovereign credit risk as it owns only 4% in 2015Q1 and 13% in 2016Q4. Insurance companies and pension funds in vulnerable countries also increase their share from 10% in 2015Q1 to 13% in 2016Q4, consistent with this sector buying alongside the ECB.

Taken together, our results imply a transfer of duration and sovereign credit risk from the foreign sector to the ECB and to insurance companies and pension funds in vulnerable countries.

Corporate credit risk declines to 70% in 2016Q4 from 94% in 2015Q1. The sectors most affected are banks (a reduction of 10% since 2015Q1) and the foreign sector (-8%). The ECB's share hardly increases from 1% in 2015Q1 to 3% 2016Q4. Perhaps surprisingly, we find the largest reduction exposure to corporate credit risk for banks in vulnerable countries. The low-frequency decline is from 30% in 2013Q4 to 10% in 2016Q4 compared to 15% and 9% for banks in non-vulnerable countries.

Table VI: The Distribution and Dynamics of Risk Exposures.

The table reports the distribution and dynamics of duration exposures (Panel A), sovereign (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

Riskiness	Sector	2013	2014				2015				2016			
		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	10
	Mut. funds	9	10	11	12	12	13	12	12	12	13	14	14	13
Non-vulnerable	ICPF	18	19	20	20	22	23	21	21	21	23	24	24	23
	Household	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
	Banks	5	6	6	6	6	7	6	6	6	7	7	7	6
	Mut. funds	2	2	2	2	2	3	2	2	2	2	2	2	2
Vulnerable	ICPF	4	5	5	5	6	6	6	6	7	8	8	9	8
	Household	3	3	3	3	3	3	3	3	3	3	2	2	2
	Other	1	2	2	2	2	2	2	2	1	2	2	2	1
	Foreign	26	28	30	30	31	33	30	30	29	29	30	29	25
	ECB	1	1	1	1	1	2	3	5	7	9	12	15	17
	Total	84	91	95	96	100	107	99	101	102	111	116	119	110

Panel B: Sovereign credit risk

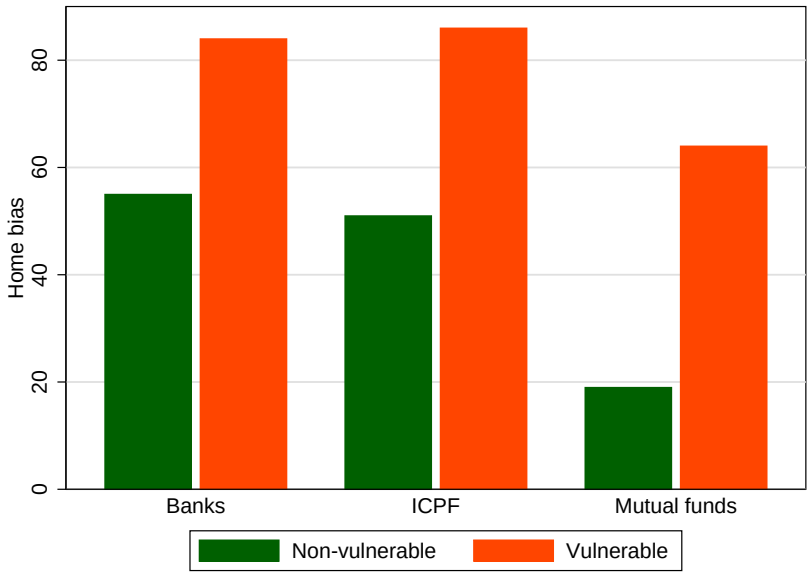
Riskiness	Sector	2013	2014				2015				2016			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Banks	7	7	7	7	7	7	7	7	7	7	7	7	7
	Mutual Funds	7	7	7	8	8	9	8	9	9	9	9	9	9
Non-vulnerable	ICPF	7	7	7	7	8	9	8	9	9	9	9	10	9
	Household	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other	1	1	1	1	1	1	1	1	1	1	1	1	1
	Banks	26	25	22	22	21	24	25	25	25	24	25	24	23
	Mutual Funds	6	5	5	6	5	6	5	5	5	5	5	5	5
Vulnerable	ICPF	9	9	8	9	9	10	9	9	11	12	13	13	13
	Household	5	5	5	5	5	5	5	5	5	4	4	4	4
	Other	5	5	4	4	4	4	4	4	4	8	8	8	9
	Foreign	30	29	29	29	28	36	36	40	39	30	30	30	27
	ECB	4	4	4	3	3	4	5	6	7	8	10	12	13
	Total	107	104	101	100	100	114	113	120	121	120	122	122	120

Panel C: Corporate credit risk

Riskiness	Sector	2013	2014				2015				2016			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Banks	15	15	15	15	14	13	13	13	10	10	10	9	9
	Mutual Funds	14	14	14	14	14	14	13	13	12	12	12	12	12
Non-vulnerable	ICPF	13	14	14	14	14	14	13	13	12	13	13	13	12
	Household	5	5	5	5	4	4	4	4	3	3	3	3	3
	Other	2	2	2	2	2	2	2	2	1	1	1	1	1
	Banks	30	25	23	21	18	16	14	14	18	18	10	9	10
	Mutual Funds	3	3	3	3	3	3	3	3	3	3	3	3	3
Vulnerable	ICPF	5	5	5	5	5	4	4	4	4	5	5	5	5
	Household	8	8	7	7	6	6	6	6	2	2	2	2	3
	Other	1	1	1	1	1	1	1	1	0	0	0	0	1
	Foreign	20	20	19	19	19	17	15	14	11	10	9	10	9
	ECB	0	0	0	0	0	1	1	1	1	1	2	2	3
	Total	116	111	107	105	100	94	88	87	77	77	69	69	70

The reduction in holdings of corporate debt coincides with the reduction of supply of corporate bonds by the banking sector. This points to cross-holdings of corporate debt in the banking sector, and in particular in vulnerable countries. To make this point more explicitly, 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 may amplify the sovereign-bank feedback loop and calls for a system-wide evaluation instead of a bank-by-bank analysis.

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



5. Inspecting the Mechanism: Evidence from Asset Prices

In this section, we estimate the impact of the PSPP on the yield curve. In general, the challenge in identifying the impact on prices is that the announcement of an asset purchase programme is endogenous to broader economic conditions that also affect yields. To address this concern, the standard approach in the literature is to identify the key event days and to measure the yield curve response on those days, see Andrade, De Fiore, Karadi, Tristani (2016) for a review. This high-frequency single-difference estimator relies on identifying the correct event days and ideally that the announcement is largely unexpected, which may be problematic when expectations about the programme evolve gradually over time, for instance, in response to the flow of macro-economic news.

Instead, we propose a low-frequency difference-in-difference estimator to estimate the

impact of the PSPP programme on government bond yields. We focus on the period from 2014Q2-2015Q1, which includes the period when the programme is announced. It also includes three weeks of PSPP purchases as the actual purchases started on March 9th. We use features of the purchase programme that generate exogenous variation across countries and maturity brackets to try and estimate the causal impact on yields.[20]

As discussed before, the ECB purchases bonds across countries according to the capital key. The weight of a country c in the capital key is given by

$$K_c = \frac{1}{2}\left[\frac{GDP_c}{\sum_c GDP_c} + \frac{Pop_c}{\sum_c Pop_c}\right],$$

where GDP_c denotes a country's GDP and Pop_c a country's population. The capital is revised infrequently and we use the capital key in 2014Q4. Within a country, the rules are less strict, and the ECB intends to act in a "market-neutral" way, which we interpret as buying according to the maturity distribution of bonds outstanding. We denote the fraction of bonds (measured in terms of face value) in a given maturity range τ by $\mu_{c,\tau}$, where we use the distribution in 2014Q4. This is the maturity distribution before the programme was announced.

As the programme was announced to last for 19 months during which the ECB buys €44 billion per month, the predicted purchases for country c in maturity bracket τ equals

$$\Pi_{c,\tau} = 19 \times 44 \times \mu_{c,\tau} \times K_c.$$

In theory, the price effects depend on the reduction in residual supply. We therefore scale the purchases by the size of the market in a given country (measured in face value). We denote the scaled purchases by $\pi_{c,\tau}$.

To estimate the impact on yields, we consider the following regression

$$\Delta y_{c,\tau} = a + b\pi_{c,\tau} + \gamma' X_{c,\tau} + \epsilon_{c,\tau}, \tag{8}$$

where $\Delta x = x(2015Q1) - x(2014Q2)$ and $X_{c,\tau}$ are other factors that may drive the yield changes in a country, such as maturity, sovereign risk, and economic conditions. We use the probability of default as before to capture differences in exposure to aggregate shocks that may have caused a decline in yields during this period. We measure economic conditions by the logarithm of GDP per capita, but consider various alternative economic indicators as well. We include dummy variables for the maturity brackets as $[2, 5]$, $[5, 7.5]$, $[7.5, 10]$,

[20] One can potentially use other features of the purchase programme, such as the rule that bonds with a yield-to-maturity below the deposit facility rate cannot be purchased.

[10, 15], and [15, 30].

One possible concern is that the capital key depends on GDP, which reflects a country's economic conditions. To alleviate this concern, we also consider an IV estimator. We use the population share multiplied by the maturity distribution in a given country, scaled by the country's bond market, as an instrument for PSPP purchases. As an alternative approach to alleviating this concern, we consider specifications in which we directly control for GDP and GDP scaled by the size of the bond market.

Figure 5: Instrument Versus Expected Purchases.

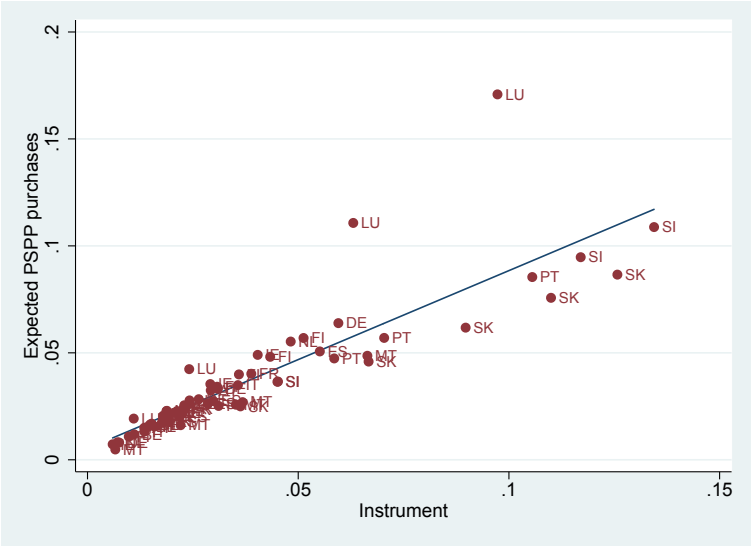


Figure 5 displays a scatter plot of expected PSPP purchases and our instrument. Although we find some deviations as GDP per capita is relatively high in, for instance, Germany and Luxembourg and relatively low in Slovenia and Portugal, the instrument and expected purchases are highly positively correlated.

The estimation results of (8) are reported in Table VII. The first column reports the first stage regression of the IV estimation, the second column the second stage regression, and in the final column we report the results when we estimate the model using OLS. As is obvious from the first stage regression, consistent with Figure 5, the instrument is strongly related to expected purchases and we have a near perfect fit with an R-squared of 92%. Consequently, the IV estimate and the OLS estimate are virtually identical at -3.3 and -3.5, respectively. In terms of the controls, we find that the yields fall more for longer-maturity bonds. For instance, bonds with residual maturities between 15 and 30 years fall by 1.3 percentage points compared to only 0.4 percentage points for bonds with residual maturities between 5 and 7.5 years. Moreover, yields fall more for countries with lower GDP per capita and higher sovereign risk, implying that yields fall more in vulnerable countries.

Table VII: Expected Purchases and Yield Changes.

The first column reports the first-stage regression of expected purchases on the instrument that depends on population size and the size of the government bond market in a given country. The controls are dummy variables for (residual) maturity brackets, the probability of default, and log GDP per capita. The second column reports the second-stage of regression of changes in yields on expected purchases. The final column reports the estimates of an OLS regression of yield changes on expected PSPP purchases. We measure the yield changes from 2014Q2 until 2015Q1. We report the standard errors in parentheses.

	(1) Expected purchases	(2) 2014Q2-2015Q1	(3) 2014Q2-2015Q1
Instrument	0.999***		
	(0.0440)		
Maturity [5,7.5]	0.00428	-0.372***	-0.373***
	(0.00344)	(0.0554)	(0.0591)
[7.5,10]	0.00361	-0.804***	-0.808***
	(0.00355)	(0.0588)	(0.0625)
[10,15]	0.000436	-1.123***	-1.128***
	(0.00372)	(0.0603)	(0.0640)
[15,30]	0.000148	-1.304***	-1.310***
	(0.00376)	(0.0629)	(0.0666)
Country risk (PD)	0.190*	-12.31***	-12.28***
	(0.0991)	(1.664)	(1.776)
Log GDP per capita	0.0298***	0.158***	0.159***
	(0.00314)	(0.0516)	(0.0551)
Expected purchases		-3.346***	-3.504***
		(0.722)	(0.732)
R^2	0.917	0.917	0.917
Observations	67	65	65

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

To interpret the coefficient of -3.5, we multiply the coefficient with expected purchases and average across all countries and maturity groups. The average decline in yields equals -13bp. However there is significant heterogeneity and the predicted change in yields ranges from -2bp to -60bp.

In Table B.3, we explore various alternative specifications in which we control for GDP per capita (in levels and logs), growth in GDP per capita, the GDP share of a country, and the GDP share normalized by the size of the bond market in a given country. The coefficient on PSPP purchases is always statistically significant at the 5% level and the point estimates vary between -2.5 and -4.0. In Table B.4, we consider a placebo test by studying the yield changes from 2013Q4-2014Q2, which is before the PSPP programme was announced and discussed. We find that the coefficient is statistically insignificant ($t = 1.25$) and has the

wrong sign (2.8). We also estimate the same regressions for each maturity group maturity group, implying that we only use cross-country information to identify the coefficients. The point estimates range from -1.7 to -4.5.

6. Connecting Quantities and Prices: An Asset-demand System

In this section, we estimate a sector-level asset demand system for government debt to connect the evidence on portfolio rebalancing and bond yields.

6.1. Model Specification and Estimation

We denote the holder country by h, the issuer country by n, and quarter by t. We estimate the model separately by institutional type. We assume that preferences are stable over time and across holder countries. The euro investment of a sector in holder country h in government bonds issued by country n is denoted by $B_{ht}(n)$. The investment in all other securities (both in- and outside of the euro area) is denoted by $O_{ht}(n)$. For the foreign sector, we use the total holdings in non-euro area bonds as the outside asset based on the Coordinated Portfolio Investment Survey (CPIS) from the IMF.

The portfolio weight is defined by

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

and for the outside asset

$$w_{ht}(0) = \frac{O_{ht}(n)}{O_{ht}(n) + \sum_n I_{ht}(n)}. \tag{10}$$

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

$$w_{ht}(n) = \frac{\exp(\delta_{ht}(n))}{1 + \exp(\delta_{ht}(n))}. \tag{11}$$

where

$$\delta_{ht}(n) = \beta_0 y_t(n) + \beta_1' x_t(n) + \beta_2 z_{ht}(n) + \phi_{ht} + \epsilon_{ht}(n). \tag{12}$$

The vector of issuer country characteristics, $x_t(n)$, includes the average maturity, the logarithm of GDP to capture size, and the probability of default (which is a transformation of a country's credit rating, as before). We include a dummy variable, $z_{ht}(n)$, which equals

one if n equals h and zero otherwise, to capture home bias. Koijen and Yogo (2017) show that this demand curve can be micro-founded by an investor with mean-variance preferences who views expected returns and risk, as measured by factor exposures, as functions of characteristics. For sovereign debt, expected returns and risk are largely driven by maturity (capturing the exposure to the level factor) and sovereign credit risk. We refer to $\epsilon_{ht}(n)$ as latent demand, which captures expectations about future purchases, economic growth, and inflation. We show below how to isolate the part of $\epsilon_{ht}(n)$ associated with expectations about future purchases.

In estimating (12), we also include holder sector - time fixed effects, which allows for flexible substitution patterns to the outside assets over time. This also implies that the estimates of $(\beta_0, \beta_1, \beta_2)$ are unaffected by the choice of the outside asset. We estimate the parameters using OLS by regressing $\log(w_{ht}(n)/w_{ht}(0)) = \delta_{ht}(n)$ on yields, characteristics, and the fixed effects.

We report the estimation results in Table VIII for all six sectors. The signs on the characteristics are intuitive in most cases: conditional on price, investors prefer bonds issued by larger and safer countries and we again uncover a strong home bias for each of the sectors.

To interpret the coefficient on yields, we compute the demand elasticity, which is given by, see Koijen and Yogo (2017),

$$-\frac{\partial q_{ht}(n)}{\partial p_{ht}(n)} = 1 + 100\frac{\beta_0}{\tau_{nt}}(1 - w_{ht}(n)). \tag{13}$$

where lowercase letters correspond to the 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 IX. A first observation is that demand is relatively elastic compared to estimates for equity markets. Chang, Hong, and Liskovich (2015), for instance, report an elasticity close to one, while we find elasticities ranging from 4.6 to 11.3. Moreover, consistent with the earlier rebalancing figures, the demand of the foreign sector is highly elastic with an elasticity of 8.6.

As a back-of-the-envelope calculation, we can compute the impact on yields from the QE programme. During our sample, the ECB purchased 15% of outstanding government debt. For a demand elasticity of 9, this would imply a price effect of 1.7%. With an average maturity of around 10 years, the yield effect is around -17bp, which is of the same order of magnitude as our earlier estimates.

Table VIII: Estimation Asset Demand System.

The dependent variable $log(r_d)$ is the log ratio of holdings of government bonds (categories 1 and 2) by investors to holdings of the outside asset. The outside asset is non-government securities for euro area investors (categories 3 to 7). For foreign investors we use holdings of non-euro denominated bonds as the outside asset (source: IMF). Specifications (1) to (6) are respectively for ICPF, banks, Mutual Funds, Other, the Household sector and Foreign investors. The sample if from 2014q2 to 2016q4. 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. Debt from Estonia, Greece and Cyprus are excluded.

	ICPF	Banks	Mutual funds	Other	Household	Foreign
Yield (%)	0.385***	0.246*	0.490***	0.555***	0.677***	0.528**
	(0.114)	(0.131)	(0.121)	(0.157)	(0.130)	(0.224)
log(GDP)	0.928***	1.069***	1.053***	1.008***	0.692***	1.368***
	(0.0206)	(0.0237)	(0.0225)	(0.0303)	(0.0255)	(0.0380)
PD	-16.50***	7.094	7.834*	-15.70***	-10.44**	-12.92*
	(3.972)	(4.431)	(4.137)	(5.279)	(4.336)	(7.785)
Home	4.061***	5.045***	3.208***	4.893***	5.606***	
	(0.126)	(0.132)	(0.125)	(0.150)	(0.133)	
Maturity	0.0485*	0.0791**	-0.0305	0.131***	-0.208***	0.205***
	(0.0276)	(0.0325)	(0.0302)	(0.0396)	(0.0338)	(0.0499)
Quarter	No	No	No	No	No	Yes
Holder-quarter	Yes	Yes	Yes	Yes	Yes	No
R^2	0.576	0.689	0.616	0.664	0.627	0.905
Observations	2983	2532	2485	1967	2272	176

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.2. Expectations, Portfolio Rebalancing, and Yields

In estimating the price effects in Section 5, we focused on the period from 2014Q2 to 2015Q1. So while yields declined, the ECB did not yet buy any bonds, and these yields reflect expectations about the programme. Our results on flows covers the period from 2015Q2 to 2016Q4, during which the programme was adjusted several times. In this section, we show how to connect expectations about future purchases, portfolio rebalancing, and yields using our demand system.

Assume that the ECB announces a purchase programme of $E_t(n)$ per country, to be implemented next period. We define "generalized latent demand" to include the time fixed effect, ϕ_{ht},

$$\eta_{ht}(n) \equiv \phi_{ht} + \epsilon_{ht}(n).$$

Table IX: 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.

Sector	Obs.	Mean	St.dev.	Min.	Max.
ICPF	2,983	6.66	1.22	2.65	10.73
Banks	2,532	4.62	0.82	1.39	7.21
Mutual funds	2,485	8.24	1.59	1.53	13.39
Other	1,967	9.05	2.06	1.50	15.04
Household	2,272	11.28	2.05	2.08	18.11
Foreign	176	8.63	1.60	6.20	14.32

Investors will price bonds as if the purchase programme is already in place,[21] implying that the market clearing condition changes from

$$P_t(n)S_t(n) = \sum_h w_{ht}(n, y_t(n), X_t(n), z_{ht}(n), \eta_{ht}(n))A_{ht}, \tag{14}$$

to

$$\widehat{P}_t(n)S_t(n) - E_t(n) = \sum_h w_{ht}(n, \widehat{y}_t(n), X_t(n), z_{ht}(n), \eta_{ht}(n))A_{ht}. \tag{15}$$

Yields decline to satisfy the additional demand, $\widehat{y}_t(n) < y_t(n)$. However, as investors initially did not sell any bonds to the ECB, we will have the following market clearing condition,

$$\widehat{P}_t(n)S_t(n) = \sum_h w_{ht}(n, \widehat{y}_t(n), X_t(n), \eta_{ht}(n) + \Delta_{ht}(n))A_{ht}. \tag{16}$$

As portfolio shares and characteristics initially do not change, we observe the same demand at higher prices, leading to increased latent demand, $\Delta_{ht}(n) > 0$. Empirically, the challenge is that (generalized) latent demand may move for other reasons than the QE programme, for instance due to expectations about future inflation or credit risk.

Hence, we cannot use latent demand directly as a measure of expectations about the programme, but we can identify programme expectations using the capital key. Combining the last two equations yields

$$\sum_h w_{ht}(n, \widehat{y}_t(n), X_t(n), \eta_{ht}(n) + \Delta_{ht}(n))A_{ht} - E_t(n) = \sum_h w_{ht}(n, \widehat{y}_t(n), X_t(n), \eta_{ht}(n))A_{ht}.$$

[21] There is a small adjustment associated with the time value of money, which we ignore here.

Consider a first-order approximation of $w(n, \widehat{\eta}_h)$ around $\Delta_h(n) = 0$

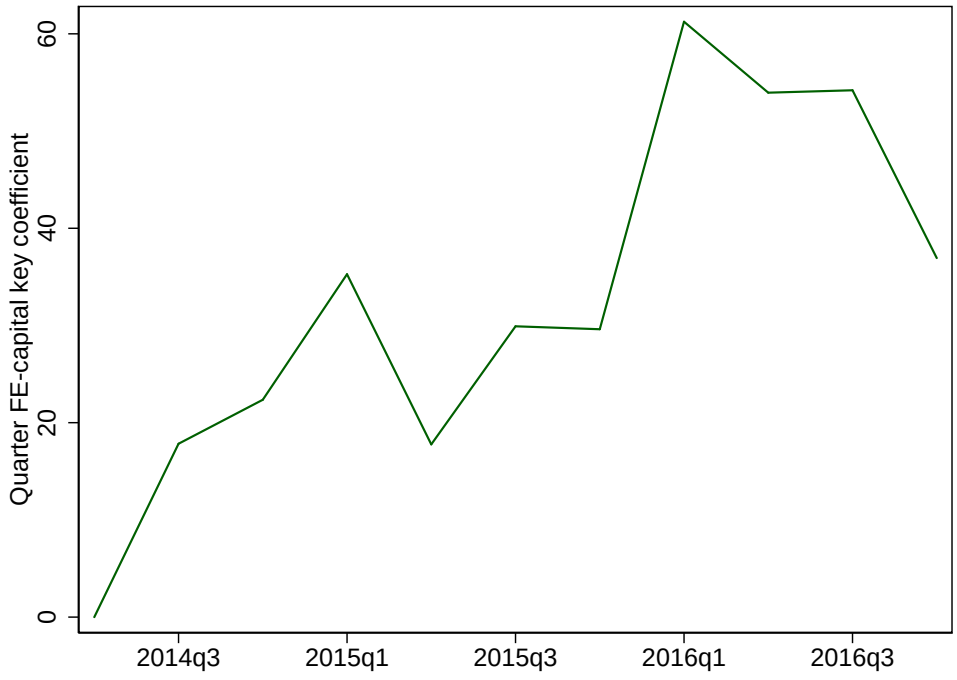
$$w(n, \eta_h(n) + \Delta_h(n)) \simeq w(n, \eta_h) + w(n, \eta_h)(1 - w(n, \eta_h))\Delta_h(n), \tag{17}$$

which implies

$$E_t(n) = \sum_h A_{ht} w_{ht}(n, \eta_{ht}(n))(1 - w_{ht}(n, \eta_{ht}(n)))\Delta_{ht}(n). \tag{18}$$

This equation shows that, with appropriate weighting, latent demand reflects expected purchases. Intuitively, jumps in expected purchases translate into jumps in latent demand in proportion to the capital key.

Figure 6: Expectations about Purchases.



Consider the panel regression from 2014Q2 to 2016Q4, which assumes, as before, that the programme was not anticipated before 2014Q2,

$$z_t(n) = \alpha_0 + \sum_{t=1}^{T} \alpha_t KC(n) + u_t(n), \tag{19}$$

where $KC(n)$ is the weight of country n in the capital key and

$$z_t(n) \equiv \sum_h A_{ht} w_{ht}(n)(1 - w_{ht}(n))\eta_{ht}(n). \tag{20}$$

In Figure 6, we plot the estimated coefficients, $\widehat{\alpha}_t$. Consistent with the actual announcements, latent demand increases in proportion to the capital key leading up to the initial announcement in the first quarter of 2015 and the large extensions in December 2015 and March 2016.

7. Conclusions

Using new security-level holdings data in the euro area, we test the mechanisms underlying broad groups of theories by focusing on three main questions. First, if QE is irrelevant, then standard theories suggest that (i) investors exposed to the gains and losses of the central bank (e.g., via taxation or the probability of bailouts) should rebalance their portfolios and (ii) asset prices are unaffected. We find that the foreign sector, which is unlikely to be most impacted by the eurosystem's losses, sells most to the ECB with around €0.70 per euro purchased by the ECB. In addition, we use a low-frequency difference-in-difference estimator and find that yields fall significantly with 13bp. Our low-frequency estimator shows that the effects found using event studies are not just due to temporary price pressure, but are more permanent instead.

Second, and moving beyond the neutrality theories, one class of models suggest that the purchase programme may lead to excessive risk taking and risk concentration. If we map holdings to duration, sovereign credit, and corporate credit risk exposures, we find that the largest transfer of duration and sovereign credit risk is from the foreign sector to the ECB and, to a smaller extent, to insurance companies and pension funds in vulnerable countries. However, we do not find evidence of large-scale rebalancing.

Another class of models implies that if the programme lowers yields, then it matters if these bonds are held by financially constrained institutions. By relaxing their constraints, the programme may spur lending activity and economic growth more broadly. Using data on holdings and the decline in yields, we estimate that the banking sector in vulnerable countries gains around €3.5 billion as a result of the programme.

Our third question is prompted by the relatively small decline in yields in response to the large amount of purchases. To connect both findings, while accounting for the heterogeneous response across investors, we estimate a sector-level asset demand for government debt. By mapping portfolio rebalancing and yield movements to demand elasticities using our demand

system, we find that the price elasticity of demand for government bonds is substantially higher than recent estimates from equity markets. We also use the model to recover investors' expectations about future ECB purchases and we find that changes in expectations closely track key policy announcements. Our approach can be used to recover expectations about other policies such as fiscal or regulatory reforms.

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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

$$S_1 = \xi A_1 + (1-\xi)A_2 = (x\xi + 1 - \xi)A, \tag{21}$$

$$S_2 = (1-\xi)A_1 + \xi A_2 = (x(1-\xi) + \xi)A, \tag{22}$$

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

$$T_{ECB} = \begin{pmatrix} \theta(x\xi + 1 - \xi) \\ \theta(x(1-\xi) + \xi) \end{pmatrix}. \tag{23}$$

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

$$T_1 = \begin{pmatrix} -\theta x\xi \\ -\theta x(1-\xi) \end{pmatrix} \tag{24}$$

and

$$T_2 = \begin{pmatrix} -\theta(1-\xi) \\ -\theta\xi \end{pmatrix}. \tag{25}$$

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

$$\beta_1 = \frac{-x\xi + x(1-\xi)}{(x\xi + 1 - \xi) - (x(1-\xi) + \xi)} = \frac{x(1-2\xi)}{(1-x)(1-2\xi)} = \frac{x}{1-x} < -1, \tag{26}$$

and for country 2

$$\beta_2 = 1 - \beta_1 = \frac{1-2x}{1-x} > 0. \tag{27}$$

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

$$\Delta Q_{ECB} P = -\Delta Q_1 P - \Delta Q_2 P, \tag{28}$$

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,

$$\Delta Q_{ECB} = \frac{Q_1}{S}\Delta Q_{ECB} + \frac{Q_2}{S}\Delta Q_{ECB}. \tag{29}$$

We can then rewrite the market-clearing condition as

$$0 = \left(\Delta Q_1 + \frac{Q_1}{S}\Delta Q_{ECB}\right) P + \left(\Delta Q_2 + \frac{Q_2}{S}\Delta Q_{ECB}\right) P. \tag{30}$$

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

$$T_i^\star = \left(\Delta Q_i + \frac{Q_i}{S}\Delta Q_{ECB}\right) P, \tag{31}$$

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

$$T_i = \alpha_i^\star + \beta_i^\star T_{ECB} + \epsilon_i, \tag{32}$$

where the market clearing condition implies

$$\beta_1^\star + \beta_2^\star = 0. \tag{33}$$

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

$$-\frac{Q_i}{S}\Delta Q_{ECB} + \beta_i \Delta Q_{ECB}. \tag{34}$$

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

$$T_1^\star = \begin{pmatrix} -\theta x \xi \\ -\theta x (1-\xi) \end{pmatrix} + \begin{pmatrix} \frac{\xi x}{\xi x + 1 - \xi} \theta (\xi x + 1 - \xi) \\ \frac{(1-\xi) x}{x(1-\xi) + \xi} \theta (x(1-\xi) + \xi) \end{pmatrix} = 0_{2 \times 1}. \tag{35}$$

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: 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.

Table B.2: 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	–	–

Table B.3: ECB expected purchases and yield changes (OLS).

	(1) 2014Q2-2015Q1	(2) 2014Q2-2015Q1	(3) 2014Q2-2015Q1	(4) 2014Q2-2015Q1	(5) 2014Q2-2015Q1	(6) 2014Q2-2015Q1
Expected purchases	-3.306***	-3.930***	-3.504***	-2.502***	-2.627***	-4.043***
	(0.773)	(0.791)	(0.732)	(0.566)	(0.742)	(1.028)
Maturity [5,7.5]	-0.362***	-0.378***	-0.373***	-0.354***	-0.353***	-0.374***
	(0.0626)	(0.0607)	(0.0591)	(0.0450)	(0.0578)	(0.0635)
[7.5,10]	-0.784***	-0.815***	-0.808***	-0.770***	-0.769***	-0.808***
	(0.0658)	(0.0647)	(0.0625)	(0.0473)	(0.0608)	(0.0691)
[10,15]	-1.116***	-1.143***	-1.128***	-1.089***	-1.093***	-1.143***
	(0.0677)	(0.0663)	(0.0640)	(0.0488)	(0.0629)	(0.0720)
[15,30]	-1.276***	-1.319***	-1.310***	-1.263***	-1.258***	-1.307***
	(0.0696)	(0.0695)	(0.0666)	(0.0501)	(0.0644)	(0.0750)
Country risk (PD)	-15.46***	-13.14***	-12.28***	-14.82***	-14.94***	-14.55***
	(1.478)	(1.735)	(1.776)	(1.067)	(1.373)	(1.695)
GDP per capita		3.462**				
		(1.477)				
Log GDP per capita			0.159***			
			(0.0551)			
Growth in GDP per capita				-0.0687***		
				(0.00924)		
GDP share					0.748***	
					(0.224)	
GDP share / Size of the bond market						0.296
						(0.273)
R^2	0.905	0.913	0.917	0.952	0.921	0.907
Observations	65	65	65	65	65	65

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

Table B.4: ECB expected purchases and yield changes (separate regressions for each maturity group) and placebo regression using yield change from 2013q4 to 2014q2

	(1)	(2)	(3)	(4)	(5)	(6)
	2014Q2-2015Q1	2014Q2-2015Q1	2014Q2-2015Q1	2014Q2-2015Q1	2014Q2-2015Q1	Placebo
Expected purchases	-4.482**	-3.639***	-1.742	-3.892	-4.004	2.757
	(1.616)	(0.837)	(2.565)	(3.059)	(3.730)	(2.199)
Country risk (PD)	-12.47***	-16.39***	-17.10***	-22.26**	-13.22***	26.85***
	(2.535)	(2.408)	(4.356)	(7.304)	(2.350)	(4.244)
Maturity [5,7.5]						0.332*
						(0.180)
[7.5,10]						0.340*
						(0.184)
[10,15]						0.299
						(0.194)
[15,30]						0.174
						(0.196)
R^2	0.814	0.845	0.608	0.517	0.796	0.432
Observations	13	14	13	13	12	67

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