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The (unintended?) consequences of the largest liquidity injection ever

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Abstract

We study the design of lender of last resort interventions and show that the provision of long-term liquidity incentivizes purchases of high-yield short-term securities by banks. Using a unique security-level data set, we find that the European Central Bank's three-year Long-Term Refinancing Operation incentivized Portuguese banks to purchase short-term domestic government bonds that could be pledged to obtain central bank liquidity. This "collateral trade" effect is large, as banks purchased short-term bonds equivalent to 8.4% of amount outstanding. The resumption of public debt issuance is consistent with a strategic reaction of the debt agency to the observed yield curve steepening.

JEL: E58, G21, G28, H63

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1 Introduction

The importance of financial intermediaries for the macroeconomy has become evident in the past decade. The collapse of the U.S. subprime mortgage market and the subsequent increase of peripheral European sovereign yields impaired these regions' financial sectors, which in turn transmitted the shocks to firms and households, contributing to long-lasting recessions.[1] As part of their policy response, central banks throughout the world provided extraordinary liquidity to the banking sector to counter ongoing credit contractions, effectively acting as lenders of last resort. While this type of intervention is based on a vast body of theoretical literature, existing empirical research provides little or no guidance on how central banks should design their liquidity provisions to restore bank intermediation.[2]

In this paper, we analyze the transmission of the largest lender of last resort (LOLR) intervention ever conducted, the European Central Bank (ECB) three-year Long Term Refinancing Operation (LTRO). With this operation, the ECB extended the maturity of its liquidity provision to banks from a few months to three years, with the stated goal to "support bank lending and liquidity in the euro area money market." Using a novel proprietary data set from the Portuguese national central bank, Banco de Portugal (BdP), we analyze the effect of this maturity extension on banks' holdings of securities.

We show that the maturity extension incentivized banks to buy high-yield domestic government bonds and pledge them as collateral for central bank loans in what we call a "collateral trade." Banks engaged in this trade mainly using bonds with shorter maturities

[1] Ivashina and Scharfstein (2010) and Chodorow-Reich (2014b) present evidence on the negative real effects of the 2008 financial crisis. Popov and van Horen (2016) and Acharya et al. (2016a) present evidence on the negative real effects of the European sovereign debt crisis.

[2] Mario Draghi, in a recent speech at the first ECB Annual Research Conference, said the central bank had to "conduct both policy and research in real time (...) operating in largely unchartered waters (...) based on the best insights that research could provide at the time" and that central banks internal analysis had "inevitably moved ahead of academia during the crisis".

to match the maturity of the assets with the maturity of the central bank loans. Our findings draw a causal link between the long maturity of ECB liquidity and the collateral trade, as we do not observe collateral trades during the LTRO period by non-banks (that have no access to ECB liquidity) and during the pre-LTRO period by banks (that have access). Finally, we provide evidence consistent with equilibrium effects on the sovereign yield curve (steepening caused by high demand for short-term bonds) and the public debt issuance activity of the sovereign debt agency (increased post-LTRO issuance of short-term bonds).

We formalize the intuition behind the collateral trade with a simple economic argument. In an environment with costly external financing, banks hold liquid reserves as insurance against shocks. If the central bank steps in and provides cheap loans against high-yield securities, banks can use their cash reserves to purchase such collateral securities and pledge them to obtain liquidity from the central bank and replenish their original reserves. This strategy allows banks to maintain a cash buffer throughout (as opposed to a traditional carry trade) and make a profit if the asset yields a return that exceeds the cost of the loan.[3]

Banks can minimize funding liquidity risk by matching the maturity of the bonds purchased with the maturity of central bank loans. In fact, compared with bonds maturing before the central bank loan, bonds maturing after the central bank loan expose banks to the risk that their prices may be lower by the time the central bank loan matures. With conventional liquidity provisions, however, the short-term maturity of the central bank loans leaves few available assets to limit the risk on this trade. Moreover, in equilibrium, as banks demand more public debt at shorter maturities, the sovereign yield curve steepens allow-

[3]This intuition is clearly illustrated in the Banco Carregosa's (a medium-sized bank in our sample) 2012 Annual Report : "The Bank [...] invested essentially in short-term deposits with other financial institutions and in the Portuguese public debt, in most cases, with maturities up to 2015. [...] transforming the short-term financing with the ECB into 3 years, the Bank not only maintained a very comfortable position regarding permanent liquidity but also guaranteed the same position for the coming 2 years."

ing the government debt agency to issue public debt, taking advantage of the lower yields, especially at short maturities.

In the context of the European sovereign debt crisis, domestic government bonds are the perfect high-yield security to engage in this collateral trade. First, euro denominated government bonds, compared with other asset classes, have a zero capital requirement, making them particularly attractive from a regulatory capital standpoint. Second, domestic government bonds are even more attractive in riskier countries as banks can use them to risk-shift and satisfy eventual government pressures to buy domestic public debt in bad times.

Our narrative, formalized in a simple model, generates four predictions: (i) Banks buy government bonds after the announcement of extended maturity loans, (ii) such purchases are caused by the policy and are more concentrated in shorter maturities, (iii) the sovereign yield curve steepens, and (iv) the sovereign debt agency issues more public debt after the announcement. The last two predictions highlight two possibly unintended equilibrium consequences of the policy as the LTRO might have helped governments refinance their debt at lower yields.[4]

We start our empirical analysis by testing the first and second predictions. First, we show that banks that buy more government bonds during the LTRO allotment borrow more at the central bank facility. In particular, consistent with buy-and-borrow behavior, banks match their purchases of eligible collateral one-to-one with their ECB borrowing. Second, we show that the LTRO causes government bond purchases by comparing, in a difference-in-differences setting, holdings of bonds before and after the central bank intervention. We also confirm that banks purchase relatively more bonds maturing before (short-term bonds) than after (long-term bonds) the loan, controlling for time-varying bank characteristics and

[4]French President Nicolas Sarkozy remarked at a press conference related to the LTRO announcement: "This means that each state can turn to its banks, which will have liquidity at their disposal."

bank-bond maturity heterogeneity using fixed effects.

Our results are economically significant: We find that the LTRO causes a €4.1 billion increase in holdings for short-term bonds, equivalent to 8.4% of the total amount outstanding at the time. Consistent with the preference for short-term securities, the effect on long-term bonds is more limited as the LTRO causes an increase of only €2.8 billion, equivalent to 3.1% of the amount outstanding. We employ three additional tests to confirm our causal claim. First, we show that the effect does not appear in other periods, with the exception of November 2011, where it coincides with another (smaller, but similar) ECB long-term liquidity injection. Second, we take advantage of a public data set on mutual fund asset holdings and confirm that our results do not extend to these financial intermediaries that have no access to ECB liquidity. Third, we show that our results hold in the intensive margin, namely that the more a bank borrows at the LTRO, the greater its preference for short-term bonds.

We then provide, in the absence of clean econometric tests, evidence consistent with the third and fourth predictions. First, we show that the Portuguese sovereign yield curve steepens during the LTRO allotment. In particular, when comparing prices before and after the intervention, yields at a maturity of more than three years are basically unchanged, while short-term yields collapse, with two-year and three-year maturity yields dropping by 500 basis points and 250 basis points, respectively. To link the shift in the yield curve with the collateral trade, we analyze the yield curve in other countries. Consistent with our narrative, we observe a steepening in other peripheral countries like Spain and Italy where risky domestic public debt was likely used for the collateral trade. On the other hand, we do not observe the sovereign yield curve steepening in core countries like Germany and France.

Finally, we show that the Portuguese sovereign debt agency, which had practically stopped issuing public debt during the six months before the LTRO, resumed public debt issuance right after the operation announcement. As the government rollover need was constant before and after the announcement and is thus unlikely to explain this abrupt change in issuance behavior, this evidence is consistent with a strategic reaction by the sovereign debt agency to a lower cost of funding.

Given the post-LTRO drop in yields, the collateral trade was, ex-post, very profitable and effectively constituted a stealth recapitalization of the financial sector. Using our granular data, we are able to compute the profits from banks' holdings of domestic government bonds and show that the appreciation of sovereign bonds in the months after LTRO led to capital gains of about €3.0 billion, equivalent to 7.2% of book equity. An additional gain of €0.8 billion resulted from the increase in holdings during the LTRO allotment.

Our contribution is twofold. First, our findings contribute to the LOLR literature by showing new results on the effect of loan maturity and collateral eligibility on the transmission of LOLR interventions. Second, we add to the growing literature on the linkages between sovereign and credit risk by showing that central bank policies can contribute to increased domestic sovereign bond holdings by banks. Our paper also informs the policy debate by offering a comparison between quantitative easing and liquidity injections. Although LTRO, through the collateral trade, looks like an "indirect quantitative easing (QE)," we show that it might have caused a steepening of the sovereign yield curve, an effect that is at odds with the curve flattening usually associated with QE.

The importance of our results extends outside the euro area as central bank liquidity injections have expanded around the world, with the implementation of similar policies in countries such as the United States, the United Kingdom, Russia, and China. Note that we do not analyze the effect of the LTRO on private credit supply nor claim that our results imply that the intervention was unsuccessful. Actually, we show that the collateral trade, while exacerbating the vicious sovereign-banking loop, might have helped peripheral countries to refinance their debt, raising the possibility that the effect on government bond holdings was not entirely unintended.

Related Literature Our paper is related to four strands of literature. First, we contribute to the growing body of research analyzing the linkages and feedback loops between the sovereign and the financial sectors.[5] The increase in holdings of government bonds by European banks has been documented by Acharya and Steffen (2015) in the context of the eurozone crisis. Several authors of recent studies claim that the observed pattern is consistent with moral suasion from governments or bank risk-shifting or both.[6] Our paper is closer to Drechsler et al. (forthcoming), who study the collateral pledged to the ECB in the pre-LTRO period and show that banks' tapping behavior at the lender of last resort is at odds with standard theories. Our study is the first to show that the long maturity of central bank liquidity incentivizes peripheral banks to buy high-yield domestic government bonds. Compared with previous studies, our comprehensive data set allows us to unveil, using security-level holdings, the transmission mechanism, or what we call the "collateral trade."[7]

Second, our findings on the effect of the LTRO on portfolio choice relate to the vast literature on the transmission of monetary policy through the financial sector.[8] The transmission

[5] Acharya et al. (2014) model a loop between sovereign and financial sector credit risk and find evidence of two-way feedback from credit default swap (CDS) prices. Bolton and Jeanne (2011) present a model where diversification of banks' holdings of sovereign bonds leads to contagion and Broner et al. (2010) show that public debt repatriation through secondary markets is a punishment for increased default probability.

[6] Drechsler et al. (forthcoming), Acharya et al. (2016a) suggest that this behavior is consistent with risk-shifting. Becker and Ivashina (2016), De Marco and Macchiavelli (2016), and Ongena et al. (2016) suggest that this behavior is consistent with moral suasion. Altavilla et al. (2016) show that both behaviors are in place. Uhlig (2013) and Crosignani (2015) show that these two hypotheses are intertwined, as governments and regulators have an incentive to allow banks to risk-shift.

[7] We observe the cross-section of the *universe* of Portuguese financial institutions, crucially including the smaller entities that are neither publicly traded. Until now the literature used either the stress test data (covering only very large banks) or Bankscope data (where bond nationality is undisclosed), as in Acharya and Steffen (2015) and Gennaioli et al. (2014). To our knowledge, the only studies that use security-level data sets compared to ours are Buch et al. (2016) and Hildebrand et al. (2012), both focused on Germany. Unlike these two papers, we focus on a *peripheral* country whose financial sector was severely hit by the crisis and, therefore, targeted by the ECB intervention.

[8] In their seminal paper, Kashyap and Stein (2000) focus on the bank lending channel of conventional

of lender of last resort policies to private lending through the financial sector is studied by, among others, Andrade et al. (2015) and Carpinelli and Crosignani (2015), who find a positive effect on lending by French and Italian banks, respectively. On a less positive note, van der Kwaak (2015) and Corbisiero (2016) build general equilibrium models and find that the effect on output is essentially zero. van Bekkum et al. (2016) show that the eligibility of risky collateral caused increased credit supply to riskier households in the Netherlands. Instead of studying private credit supply, we focus on holdings of risky securities that can then be pledged at the central bank, in particular domestic government bonds.

Third, our analysis of the banking sector demand for domestic sovereign debt relates to the equally large literature on sovereign debt management. Bai et al. (2015) and Broner et al. (2013) show that countries react to crises by issuing more short-term debt. Our paper proposes an alternative explanation. When central banks provide long-term liquidity to banks, sovereign debt agencies face high demand for short-term bonds, that might be used by banks to engage in collateral trades.

Fourth, our analysis relates to the emerging literature on the interaction and coordination of fiscal and monetary policies during the financial crisis. Greenwood et al. (2014) present evidence that the U.S. Treasury behaved strategically, issuing more short-term debt during the Federal Reserve QE program, consistent with the Greenwood et al. (2015) trade-off model predictions. Our findings suggest that, although QE tends to flatten the yield curve, the indirect purchases triggered by programs like LTRO might cause a steepening of the yield curve, with consequences for the strategic reaction of the fiscal authority, which might choose to tilt the maturity structure of its issuances towards the shorter end.

The rest of the paper proceeds as follows. In Section 2, we illustrate the collateral trade

monetary policy. Like Chodorow-Reich (2014a) on the U.S. case, we focus our attention on a specific measure of unconventional monetary policy, where the ECB fulfills its role as a lender of last resort.

and develop four empirical predictions. In Section 3, we present the empirical setting and describe the data. We present our empirical analysis in Section 4 and discuss some of the results of our analysis in greater detail in Section 5. Section 6 concludes.

2 The Design of the LOLR and the Collateral Trade

The intuition behind the theory of the lender of last resort (LOLR) is simple. Banks hold fewer liquid assets than liquid liabilities and are therefore subject to runs. During a run, the central bank should act as a lender of last resort providing unlimited liquidity to illiquid, but solvent, banks to counter a likely costly deleveraging.

According to Bagehot (1873), the LOLR liquidity should be granted "early and freely to solvent firms, against good collateral at high rates." High rates, that is penalty rates compared with the private market, make sure that banks relatively unaffected by the funding stress continue to obtain funding in the private market. The prescription regarding collateral eligibility is, however, more vague, as the LOLR should accept collateral securities "that are considered safe in normal times." Moreover, the existing literature does not specify the maturity at which the LOLR should lend to banks. In this paper, we argue that both collateral eligibility and maturity matter for the transmission of LOLR liquidity.

In particular, we show that a lender of last resort that provides *long-term* liquidity accepting high-yield securities as collateral encourages banks to engage in what we call a "collateral trade." In the next subsection, we illustrate the collateral trade and its equilibrium effects, focusing on the intuition of our economic argument. The reader is referred to Appendix A for a formal model.

2.1 The Collateral Trade

Consider an economy in which external financing is costly and banks hold some liquid reserves for insurance motives. Let us place in this environment a lender of last resort that provides long-term liquidity to banks, collateralized by government bonds that are, in normal times, considered safe, but have high-yields during sovereign crises. In this setting, during a sovereign crisis, banks can use their reserves to purchase high-yield government bonds that can be then pledged at the central bank to replenish their original reserves.

Banks can minimize the risk of this trade by purchasing government bonds that have a maturity equal to or less than the maturity of the LOLR loan. In fact, if a bank engages in the collateral trade using collateral with maturity exceeding that of the LOLR loan, it will be more exposed to funding liquidity risk: If those securities drop in price during the term of the LOLR loan, not only may the bank receive a margin call from the central bank, but the bond itself may be worth less by the time the loan expires. Either of these situations force the bank to raise additional funds to either meet the margin call or repay the loan, which might be very costly during crises and increase uncertainty regarding liquidity management.

If collateral securities have a term that is shorter than the loan, however, the risk associated with the margin call is lower, and the security matures (that is, becomes cash) before the loan is due.[9] Note that the combination of eligibility of high-yield securities and the long maturity of LOLR loans make this trade particularly attractive. If the LOLR only accepts low yield securities as collateral, the spread between the LOLR loan and the return on holding the security would be lower. If the LOLR loans are short-term, the majority of eligible collateral securities would mature after the LOLR loan exposing the bank to higher

[9] The collateral maturing before the LOLR loan still results in a margin call, which the bank can cover with the newly available funds, and so entails much less risk. In addition, the bank obtains an additional profit, as the bond yield exceeds the borrowing cost in the first place.

funding liquidity risk.

In equilibrium, the collateral trade also causes two interesting effects. First, the sovereign yield curve steepens as banks engaging in the collateral trade increase their demand for short-term government bonds. Second, the sovereign debt agency reacts to the price effect and optimally tilts its debt issuance to more short-term auctions so to take advantage of the cheaper short-term debt.

2.2 Four Predictions

Having illustrated the collateral trade, we now summarize four predictions of our economic argument in a context where the lender of last resort provides long-term funding against high-yield government bonds.

Prediction 1: Banks buy high-yield government bonds to borrow at the LOLR. Banks engaging in the collateral trade buy eligible collateral securities and borrow from the LOLR.

Prediction 2: The LOLR causes high-yield government bonds purchases. The LOLR induces banks to engage in a collateral trade, by buying high-yield government bonds. More specifically, according to our narrative, banks develop a preference for *short-term* bonds in order to match the maturity of central bank loans with the maturity of the asset pledged to secure them.

Prediction 3: The sovereign yield curve steepens. The increased demand for short-term government bonds by investors with access to the LOLR liquidity causes a steepening of the sovereign yield curve.

Prediction 4: The sovereign debt agency issues more (short-term) debt. As short-term sovereign yields drop, the sovereign debt agency reacts by increasing its public debt issuance using short-term bonds.

3 Data and Setting

The laboratory where we bring the four predictions to data is the Portuguese financial sector during the largest LOLR intervention ever conducted, namely the ECB three-year LTRO. In this section, we present the empirical setting and describe the data.

3.1 Empirical Setting

During the European sovereign crisis, the ECB effectively acted as a lender of last resort.[10] In particular, starting in 2008, banks in peripheral countries (Greece, Italy, Ireland, Portugal, and Spain) became increasingly reliant on central bank liquidity to compensate for the contraction of private sources of funding.

The ECB provides liquidity to the financial sector using collateralized loans. Any bank located in the eurozone can obtain a cash loan from the monetary authority, provided that it pledges sufficient collateral. Over this collateral requirement, there is no limit on the amount of funds that a bank can obtain from the central bank. Eligible collateral includes government bonds, asset-backed securities, covered bonds, and corporate bonds. Although every bank can borrow at the same interest rate from the ECB, the haircut depends on the characteristics of the pledged security (residual maturity, rating, coupon structure, and asset class). The maturity of the loan is typically either one week or three months.[11]

[10]The role of ECB as a lender of last resort during the crisis is analyzed by Acharya et al. (2015), Carpinelli and Crosignani (2015), Drechsler et al. (forthcoming), and Garcia-de-Andoain et al. (forthcoming).

[11]The absence of a limit on the amount of funds that banks can borrow from the ECB was introduced in October 2008 ("full allotment" policy). The ECB normally offers two types of loans: (i) MRO loans with a maturity of one week and (ii) LTRO loans with a maturity of three months. During the crisis, in 2010 and 2011, the ECB strengthened its supply of longer term funding with extraordinary 6-month and 12-month LTROs. Three 6-month LTROs were allotted in April 2010, May 2010, and August 2011 and one 12-month maturity LTRO was allotted in October 2011. We describe the ECB collateral framework in greater detail in the Online Appendix.

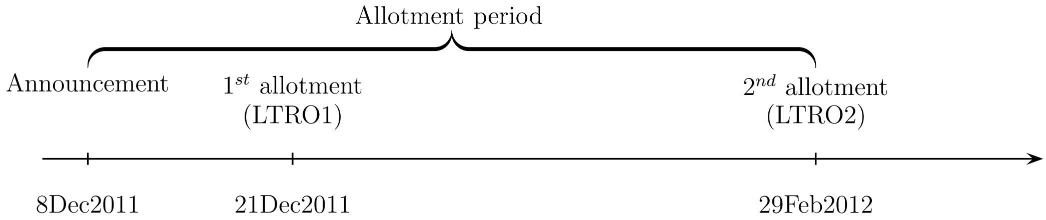

Figure 1: LTRO Timeline. This figure illustrates the timeline of the LTRO intervention. The announcement (December 8, 2011) is followed by the two allotments (December 21, 2011 and February 29, 2012).

The sovereign crisis worsened considerably in the second half of 2011, with sovereign CDS spreads of large countries such as Italy and Spain, reaching record highs in November. On December 8, 2011, the ECB announced the provision of two unprecedented three-year maturity loans, the three-year LTRO. The stated goal of the policy was to provide long-term funding to banks in order to "support bank lending and money market activity."[12] Long maturity and below-market haircuts for these loans made this liquidity operation very attractive.[13] In particular, more than 800 eurozone banks tapped the facility, to obtain liquidity of €1 trillion, making this the largest liquidity injection in the history of central banking.

Figure 1 shows the timeline of the operation. The December 8 announcement is closely followed by the allotment of the first loan (LTRO1) on December 21 and, two months later, by the second and final allotment (LTRO2) on February 29. We refer to the period between the announcement and LTRO2 as the "allotment period."

[12]The announcement of the three-year LTRO can be found at `www.ecb.europa.eu`.

[13]The terms of the ECB loans, namely the combination of haircuts and the interest rates, was more attractive compared to the private market, *especially* for banks located in peripheral countries. This implicit subsidy is discussed in Drechsler et al. (forthcoming). Perhaps not surprisingly, more than two thirds of the total LTRO loans was allotted to banks in peripheral countries, where such subsidy was particularly large.

3.2 Data

Our main data set is the merger of two proprietary data sets from BdP and a publicly available data set from the Portuguese Securities Market Commission (CMVM).[14] These data sets are monthly panels from January 2005 to May 2014.

The first data set contains monthly information on the composition of the balance sheets of all monetary and financial institutions regulated by BdP. This unbalanced panel contains information on 81 banks, 10 savings institutions, and 13 money market funds and allows us to observe key bank balance-sheet variables. As a complement, we obtain information on the collateral pool of Portuguese banks at the ECB by instrument: government debt, marketable assets, additional credit claims, and government-guaranteed bank bonds.

The second data set contains monthly *security-level* data of all holdings of Portuguese government debt by domestically regulated institutions. The universe of entities of this second data set is larger than that of the first, as it includes all non monetary financial institutions such as mutual funds, hedge funds, brokerages, and pension funds, among others. For each institution, we have data on book, face, and market value of all holdings of Portuguese government debt at the security (ISIN) level. We match this data set with bond-level information such as yield, residual maturity, and amount issued, obtained from Bloomberg.[15] Note that we do not have standard balance sheet characteristics (for example, total assets) for the institutions appearing in only the second data set.

The third data set addresses this gap. It contains publicly available data on mutual fund portfolio composition from the website of the CMVM, the Portuguese Securities Market Commission. We gather data on the total assets of mutual funds holding domestic govern-

[14]In the Online Appendix, we provide a more detailed description of the data set.

[15]We are able to match more than 98% of the value of holdings in the data set with Bloomberg.

ment bonds included in the security-level data set and other mutual funds. The security-level data set has 709 entities. Of these, 52 are banks or money market funds included in the first data set.[16]

4 Empirical Analysis

In this section, we test the first two predictions (effect on demand for government bonds) and provide evidence consistent with the last two predictions (equilibrium effects on prices and bond issuance). In our narrative of Section 2.1, banks use high-yield collateral, in the form of government bonds, to engage in the collateral trade.

We argue that during the European sovereign debt crisis, government bonds, particularly domestic ones, were the best type of high-yield security to engage in this trade for several reasons. First, any euro-denominated government bond has a zero risk weight in determining bank capital requirements. Purchasing a bond issued by a eurozone country is therefore a very cheap way, from a regulatory standpoint, to gain access to ECB liquidity. Second, in addition to this preferential treatment, *domestic* government bonds are even more attractive in risky countries during a sovereign crisis. In a setting characterized by extensive implicit and explicit government guarantees over the banking system and a substantial degree of sovereign bank linkages, banks and sovereigns tend to default in the same set of states of the world. Due to risk-shifting, government debt thus offers a better return to domestic

[16]Some other 286 are matched with the CMVM data set. The remaining 371 are unmatched, so we do not have balance sheet information for them. The CMVM data set has 479 entities. Of these, 12 are money market funds in the first data set; 286 are in the second data set and 181 are unmatched that is, are mutual funds which did not hold domestic government bonds in the period of our sample. In practice, since we require balance-sheet size information for most of our empirical tests, we will mainly use the information on banks and mutual funds.

banks than to foreign ones, and public debt tends to be repatriated.[17] The only states of the world that may lead banks not to deem domestic sovereign debt safe investments are those in which the price of the purchased bonds may change (in the absence of both sovereign and bank default), thereby affecting the bank's capacity to repay the ECB loan or resulting in the ECB issuing a margin call to the bank.[18]

Figure 2 compares aggregate government bond holdings at face value of banks (which could access the LTRO) and non-banks (which were excluded from the LTRO) from June 2011 to June 2012. The vertical lines correspond to the announcement and the second and final allotment. The figure shows that Portuguese banks (solid line) were large holders of domestic government bonds before the LTRO, and that they increased their holdings significantly *after* the announcement and *before* the second allotment (LTRO2). The behavior of non banks (dashed line), that did not have access to the ECB lending facilities, hardly changed during the LTRO period.[19]

4.1 Banks' Buy-and-Borrow Behavior

We now check whether eligible collateral securities purchased in the allotment period, in particular domestic government bonds, correlate with LTRO borrowing (Prediction 1). Driven

[17]When sovereigns and banks default in the same states of the world, banks do not internalize any losses when choosing their portfolios. If there are other agents in the market who price this risk, government debt will thus appear to be underpriced from the bank's perspective (see Crosignani (2015)). Banks might also prefer to buy domestic government bonds hoping that the government will then have less incentives to be a tougher regulator. Finally, the government might also directly pressure banks to buy domestic public debt (Becker and Ivashina (2016), De Marco and Macchiavelli (2016), and Ongena et al. (2016)).

[18]Should the collateral value drop, without the option of early repayment (which only occurs after one year), banks are required to pledge additional collateral or place cash in margin call deposits at the ECB.

[19]Bond issuance cannot explain this fact. As a percentage of amount outstanding, banks increased their holdings of government bonds from 17.7% in November 2011 to 21.3% in February 2012, while non banks slightly decreased theirs from 7.7% to 7.0%. We cannot normalize quantities in Figure 2 by total assets as we do not observe assets of non banks.

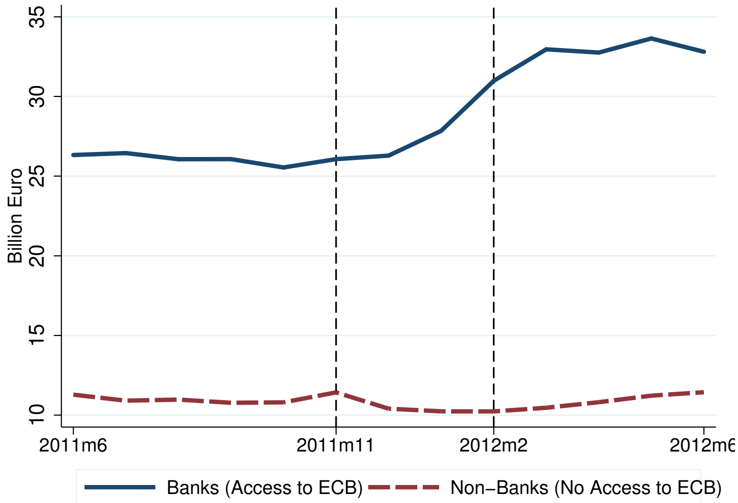

Figure 2: Holdings of Domestic Government Debt. This figure plots the evolution of the quantity of domestic government bonds held by banks (solid line) and non-banks (dashed line) from June 2011 to June 2012. Quantity is measured as the total face value in billion euro. The two vertical dashed lines delimit the allotment period.

by the observation that government bond holdings increase between December 2011 and February 2012, we focus on the second allotment (LTRO2).[20]

Our strategy is to analyze the correlation in the cross-section of banks between change in holdings of eligible collateral in the allotment period and LTRO2 borrowing. More formally, we run the following simple cross-sectional regression in the subsample of financial institutions (banks and savings institutions) that have access to ECB liquidity:

$$\text{LTRO2}_i = \alpha + \beta \Delta \text{EligColl}_{i,\text{Feb12-Nov11}} + \gamma \text{TotalEligColl}_{i,\text{Nov11}} + \epsilon_i \tag{1}$$

[20]There are several reasons that might inhibit banks from using LTRO1 and not LTRO2 for their collateral trade: (i) uncertainty (resolved before LTRO2 as suggested by Andrade et al. (2015)) that tapping LTRO might send a bad signal to the market, (ii) little time (two weeks compared to three months for LTRO2) to buy government bonds in the secondary market, and (iii) window-dressing so as not to show increased government bond holdings on the 2011 annual report (based on bank balance sheet as of December 31). In Section 5.4, we analyze bank behavior at LTRO1 and further motivate our focus on LTRO2.

	LTRO2 Uptake	
ΔGovt (Face Value)	0.933***	
	(0.091)	
ΔGovt (Market Value)		1.034***
		(0.098)
ΔACC	0.837***	0.838***
	(0.031)	(0.030)
ΔGGBB	1.196**	1.229**
	(0.583)	(0.553)
ΔOther Marketable	0.802***	0.801***
	(0.036)	(0.035)
Total Collateral$_{Nov11}$	0.218*	0.221*
	(0.131)	(0.125)
Observations	68	68
R-squared	0.960	0.962

Table 1: Banks' Buy-and-Borrow Behavior. This table presents the estimation results for specification (1). The dependent variable is total uptake at LTRO2 normalized by total assets in November 2011. Independent variables include changes in holdings of central bank eligible collateral between November 2011 and February 2012 and the stock of eligible collateral in November 2011. Eligible collateral includes domestic government bonds, additional credit claims (ACC), government guaranteed bank bonds (GGBBs), and other marketable securities. All variables are normalized by bank assets in November 2011. All independent variable are haircut-adjusted. In the first (second) column, we measure changes in government bond holdings using face (market) values. In the Online Appendix, we provide a detailed description of the ECB collateral framework. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

in which the dependent variable is the total uptake at LTRO2, $\Delta\text{EligColl}_{i,\text{Feb12-Nov11}}$ is a vector of changes (one change per asset class) in holdings of eligible collateral during the allotment period, and $\text{TotalEligColl}_{\text{i,Nov11}}$ is the stock of total eligible collateral in November 2011, as banks might be using their pre-existing holdings of collateral to access LTRO loans. Changes are measured between November 2011 (the last observation before the announcement) and February 2012 (LTRO2 date).[21] Independent variables are haircut-adjusted and

[21] LTRO2 was allotted on the last day of February but settled on March 1, 2012. Hence, our February observations are the last snapshot before the LTRO2 borrowing that is seen only in March data.

all variables are normalized by bank assets in November 2011, as large banks are more likely to buy more securities and borrow more at the central bank in absolute amounts.

We observe four types of ECB-eligible collateral: domestic government bonds, additional credit claims, government-guaranteed bank bonds, and other marketable assets (for example, foreign government bonds, asset-backed securities, and covered bank bonds).[22] If banks are engaging in the collateral trade by buying eligible collateral and borrowing at LTRO2, the β coefficients should be close to 1. We show the estimation results in Table 1, in which we measure changes in domestic government bond holdings using face values (column (1)) and market values (column (2)). We include both measures, as bank borrowing capacity at the ECB depends on the market value of collateral assets, but changes measured in market value might simply reflect price movements, not changes in actual bank holdings of a security. Consistent with buy-and-borrow behavior, the coefficient of interest is close to 1, suggesting that banks did borrow approximately €1 for each euro of increased domestic government bond holdings during the allotment period.

Interestingly, the estimated coefficient is also close to 1 for the other three types of eligible collateral, suggesting that the collateral trade might not be limited to domestic government bonds. In Figure 3, we take advantage of an additional data set on collateral pledged, aggregated at the country level, and plot the time-series evolution of various types of collateral pledged by Portuguese banks at the ECB.[23] In the allotment period, while haircut-discounted pledged domestic government bonds increase from €17.3 billion to €21.0 billion, other marketable assets decrease from €39.9 billion to €35.9 billion, consistent with our narrative and suggesting that banks preferred to buy domestic government bonds compared

[22]We provide a detailed description of ECB collateral framework in the Online Appendix.

[23]The "shared risk" category refers to non-marketable assets accepted under the general framework of the Eurosystem, namely credit claims, and whose risk is shared with the system.

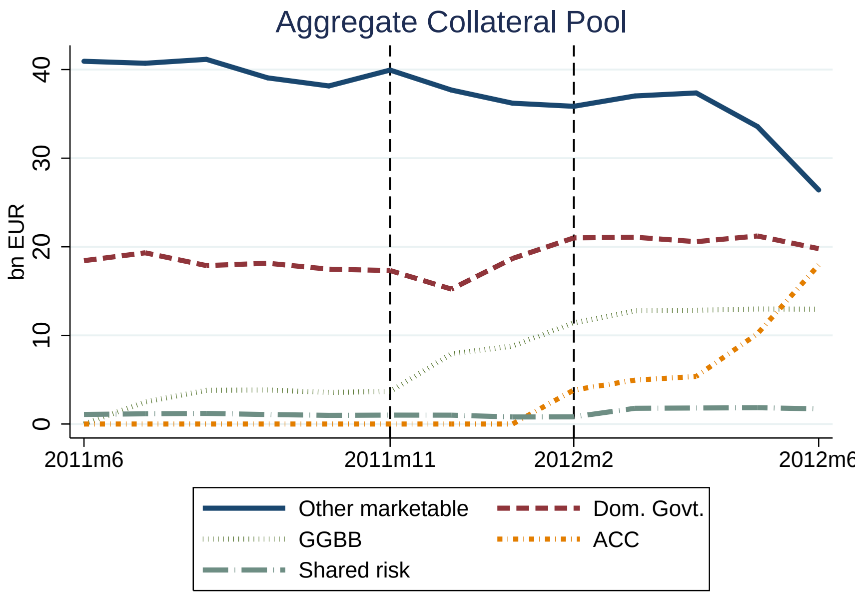

Figure 3: Pledged Collateral by Type of Eligible Asset. This figure plots aggregates amounts of assets pledged as collateral with the Eurosystem by Portuguese banks, discounted by haircuts. The categories included are exhaustive. They include domestic government bonds, government guaranteed bank bonds (GGBB) and other marketable assets for marketable assets and additional credit claims (ACC) and shared risk framework for non-marketable assets.

with other marketable assets. Pledged government-guaranteed bank bonds and additional credit claims increase in the allotment period. These two asset classes are the result of additional ECB and government measures aimed at helping banks to further increase the list of eligible assets through relaxation of eligibility criteria and government guarantees. However, despite their non-negligible value, these two types of collateral were used by a very small number of banks.[24]

[24]Six banks use government guaranteed bank bonds as collateral in November 2011 and increase their usage during the allotment period. Additional credit claims are accepted under national frameworks, which in the case of Portugal started on February 9, 2012. Unlike the previously-mentioned credit claims, the risk of these assets remains with national central banks. Six banks too were using additional credit claims by more than €1 million on their collateral pool by the end of that month. These claims would later become a substantial part of the collateral pools of Portuguese banks.

4.2 LTRO Causes Purchases of Domestic Government Bonds

We now test whether the LTRO caused an increase in government bond holdings (Prediction 2). Our narrative, developed in Section 3, suggests that institutions with access to this liquidity facility have an incentive to rebalance their government bond portfolio toward securities maturing before the second LTRO loan in February 2015. Hereafter, we refer to these securities as "short-term" bonds.

The first step in our empirical test is to properly measure bank-level changes in government bond holdings of different maturities. Such a variable requires particular care as one needs to simultaneously take into account that large banks will likely buy more bonds (that is, normalize by bank size) and that the amounts of short- and long-term bonds outstanding might be different and change over time (that is, normalize by amounts outstanding). The second normalization is particularly important in our context, as (i) new bonds might be issued and existing bonds mature each month, and (ii) the distribution of maturities of Portuguese government bonds is skewed with more long-term than short-term government bonds outstanding.[25]

Consider the following example. Bank A and Bank B both buy €50 in short-term government bonds and €50 in long-term government bonds. If Bank A is larger than Bank B, and if we are interested in analyzing the relative preference for government bonds, we should then divide bank holdings by bank total assets to take into account that Bank B has a stronger preference relative to its size. Assume also that there are €200 short-term government bonds outstanding and €400 long-term government bonds outstanding in that period. By simply looking at bank holdings, even after normalizing by bank size, it would seem that both banks did not favor a specific maturity. However, they are concentrating on

[25] In February 2012, short-term government bonds were 35% of the total amount outstanding.

shorter maturities relative to other investors as they purchase a greater share of the total short-term public debt compared with the long-term outstanding.

We tackle these two concerns by defining the following variable

$$\widetilde{\text{Holdings}}_{i,m,t} = \frac{\frac{\text{Govt. Holdings}_{i,m,t}}{\text{Amount Outstanding}_{m,t}}}{\frac{\text{Assets}_{i,t}}{\text{Total Assets}_t}}$$

This variable measures the share of public debt outstanding of maturity m ("short" or "long") held by institution i in month t, divided by the size of institution i relative to the size of the financial sector in month t. The numerator captures the share of short- or long-term government bonds outstanding held by one institution. The denominator scales the numerator so that holdings of large institutions do not have a disproportionate effect on the coefficients. While this measure makes it less obvious how to directly interpret the regression coefficients, we use the results to provide estimates of the aggregate effects.

To test Prediction 2, we first run the following two specifications on the subsample of institutions that have access to ECB liquidity (banks and savings institutions) in the period running from June 2011 to June 2012:

$$\widetilde{\text{Holdings}}_{i,Short,t} = \alpha + \beta \text{Post}_t + \eta_i + \epsilon_{i,t} \tag{2a}$$

$$\widetilde{\text{Holdings}}_{i,Long,t} = \alpha + \beta \text{Post}_t + \eta_i + \epsilon_{i,t} \tag{2b}$$

where the dependent variable is the share of short-term (long-term) public debt outstanding held by bank i in month t divided by the size of bank i relative to the size of financial sector in month t, Post_t is a time dummy equal to 1 after, and including, December 2011, and η_i is an institution fixed effect.[26] We classify a bond as having short maturity if it matures

[26]We decided to end our sample period in June 2012 in order not to overlap with Draghi's July 26, 2012

before or on February 2015, the LTRO maturity. With these two simple regressions, we ask whether banks purchased more short-term (long-term) government bonds after the LTRO announcement relative to the pre-announcement period.

We then run the following standard difference-in-differences specification for the same sample period and banks:

$$\widetilde{\text{Holdings}}_{i,m,t} = \alpha + \beta \text{Post}_t \times \text{Short}_m + \eta_{i,t} + \xi_{i,m} + \epsilon_{i,m,t} \tag{3}$$

where Short_m is a dummy variable equal to 1 for the portion of the sovereign bond portfolio maturing on or before February 2015, $\eta_{i,t}$ are institution-time fixed effects, and $\xi_{i,m}$ are institution-maturity fixed effects.[27]

Table 2 shows the estimation results for specifications (2a), (2b), and (3). The first two columns show that banks increase their holdings of both short- and long-term government bonds after the LTRO announcement. Consistent with our narrative, the effect is more pronounced for bonds with shorter maturities. This finding is confirmed by the difference-in-differences estimation result in the third column. The coefficient of the interaction term is positive and significant, showing that banks bought more short-term relative to long-term government bonds after the LTRO announcement, after controlling for institution-bond maturity and institution-time varying heterogeneity using fixed effects.

Aggregate Effect To get a sense of the quantitative importance of our results, we calculate the aggregate effect of the LTRO announcement on the demand for government bonds. We use the results in the first two columns of Table 2. For each bank-maturity observation in

OMT announcement, also known as"whatever it takes" speech.

[27] In the Online Appendix, we show that our results are robust to an alternative definition of *Short*, that is a bond is "Short" at time t if it is at most three years away from maturing.

	$\widetilde{\text{Holdings}}_{i,Short,t}$	$\widetilde{\text{Holdings}}_{i,Long,t}$	$\widetilde{\text{Holdings}}_{i,m,t}$
Post	0.086***	0.031***	
	(0.023)	(0.006)	
Post × Short			0.054***
			(0.021)
Institution FE	✓	✓	
Institution-Maturity FE			✓
Institution-Time FE			✓
Specification	(2a)	(2b)	(3)
Observations	893	893	1,786
R-squared	0.762	0.847	0.908

Table 2: LTRO and Government Bond Purchases. This table presents the results of specifications (2a), (2b) and (3). The dependent variable in column (1) (column (2)) is the share of total short (long) term public debt outstanding held by financial entity i divided by the size of entity i relative to total asset of the financial sector. The dependent variable in column (3) is the share of public debt of maturity m outstanding held by entity i divided by the size of entity i relative to total asset of the financial sector. This regression includes only institutions with access to the LTRO (banks and savings institutions). Independent variables include a Post_t dummy equal to one on and after December 2011 and a Short_m dummy equal to one if the government bond portfolio matures on or before February 2015 (LTRO maturity). The sample is monthly from June 2011 to June 2012. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

February 2012, we perform the following calculation:

$$\text{Demand Boost}_{i,m} = \beta_m \frac{\text{Assets}_{i,\text{Feb12}}}{\text{Total Assets}_{\text{Feb12}}} \text{Amount Outstanding}_{m,\text{Feb12}}$$

in which β_{short} and β_{long} are the coefficients in specifications (2a) and (2b). The result is the effect, measured in euros, on the demand for a given maturity of a given bank during the post-LTRO period. We then aggregate these amounts across the banking sector. We find that the LTRO announcement boosted demand for short-term bonds by €4.1 billion, around 8.4% of the amount outstanding. Regarding long-term bonds, demand was boosted by €2.8 billion, around 3.1% of the amount outstanding, leading to a total boost of 5.0% across maturities. Relative to the size of the banking sector, these were increases of 0.7% and 0.5% in terms of the total assets of the banking sector, respectively. These results suggest that the LTRO had an economically significant effect on the demand for government debt, especially at short maturities.

Placebo A potential concern in our difference-in-differences setting is that the described effect might also be present in periods other than the treatment period. Such cases would hinder our causal claim suggesting that our results are not driven by the long-term maturity of central bank liquidity provision and, more generally, that our specifications might suffer from an omitted variables bias, as holdings of short-term government bonds might be driven by unobservables.

To this end, we run placebo regressions, simulating the application of the treatment in every month in the sample. Interestingly, on four dates, a weaker treatment is actually in place as the ECB adopted other longer-than-usual liquidity provisions: three 6-month LTROs were allotted in April 2010, May 2010, and August 2011, and one 12-month LTRO was allotted in October 2011. The one in October is particularly relevant, as its maturity is already long enough to allow banks to match the maturity buying government bonds.[28]

We run the following specification for every month between June 2010 and May 2013:

$$\widetilde{\text{Holdings}}_{i,m,t} = \alpha + \beta \mathbb{I}_t \times \text{Short}_m + \eta_{i,t} + \xi_{i,m} + \epsilon_{i,m,t} \tag{4}$$

in which $\mathbb{I}_t$ is an indicator variable equal to 1 in period t and 0 otherwise, $\eta_{i,t}$ are institution-time fixed effects, and $\xi_{i,m}$ are institution-maturity fixed effects. For the purpose of these placebo regressions, and due to the larger sample period, we now classify all bonds expiring within 36 months of the treatment date as "short". This new definition coincides exactly

[28] In Section 5.5, we discuss what is different about these longer-term LTROs with one- and three-year maturities relative to the standard three-month LTROs.

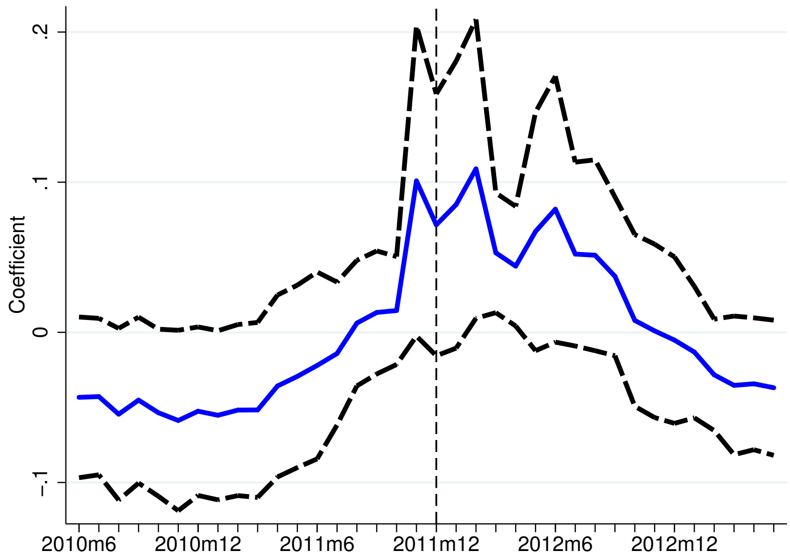

Figure 4: Placebo Test. This figure plots interaction coefficients from specification (4). The solid black lines plot coefficients and the dashed blue lines delimit the 90% confidence interval. The vertical dashed line indicates the LTRO announcement date (December 2011).

with our previous one for February 2012. Our variable of interest is the coefficient β of the indicator variable at different points in our sample.

In Figure 4, we plot the coefficients on the interaction term for each separate regression. The solid line plots the coefficient of interest on the indicator variable in a given period and the dashed lines delimit the 90% confidence interval. Outside of the period of the LTROs, the coefficient is close to 0 or even negative. In the three-year window we are studying, the coefficient only becomes positive and significant around the LTRO period. The coefficient is close to 0 until October 2011, but in November 2011, it spikes upward, likely capturing the effects of the one-year LTRO settled at the end of October that was eventually replaced by the three-year LTRO.[29]

[29]Banks were allowed to roll over the October one-year allotment into LTRO1.

Mutual Funds as a Control Group Our identification strategy relies on the assumption that in absence of the LTRO, banks would not buy more (short-term) government bonds after the announcement compared with the pre-announcement period. If such an identification assumption is not satisfied, our results might suffer from an omitted variable bias. So far, our analysis has used the subsample of financial institutions that have access to ECB liquidity, namely banks and savings institutions. We now check the plausibility of the identification assumption by analyzing the behavior of mutual funds, the only type of institution that we observe in our data that has no access to ECB liquidity.[30] We conduct two tests. First, we re-run the regressions in Table 2 for the subsample of mutual funds. Second, we run the following triple-difference specification:

$$\widetilde{\text{Holdings}}_{i,m,t} = \alpha + \beta \text{Post}_t \times \text{Short}_m \times \text{Access}_i + \eta_{i,t} + \xi_{i,m} + \mu_{m,t} + \epsilon_{i,m,t} \qquad (5)$$

in which the only new variable is Access_i, a dummy equal to 1 if the financial institution has access to the LTRO. We run specification (5) in the full sample of banks, saving institutions, and mutual funds and estimate the coefficient of the triple interaction saturating the regression with institution-time, institution-maturity, and time-maturity fixed effects.

We show the estimation results in Table 3. In the first three columns, we illustrate the results of the specifications in Table 2 for the subsample of mutual funds. The fourth column shows the results of the triple difference specifications in equation (5). The first three

[30] Following the description in Section 2.2, we use mutual funds as a control group; in particular, mutual funds which held domestic government bonds at any point in our larger sample between 2005 and 2014. In the Online Appendix, we present results using a broader sample that includes the *universe* of mutual funds as a control group. This includes mutual funds that never hold domestic government bonds at any point in our sample period. Our results are robust to this alternative sample selection. We did not adopt this larger sample as our preferred specification because of the high degree of portfolio specialization of these institutions.

	$\widetilde{\text{Holdings}}_{i,Short,t}$	$\widetilde{\text{Holdings}}_{i,Long,t}$	$\widetilde{\text{Holdings}}_{i,m,t}$	$\widetilde{\text{Holdings}}_{i,m,t}$
Post	-0.014	0.034***		
	(0.018)	(0.004)		
Post × Short			-0.048**	
			(0.019)	
Post × Short × Access				0.102***
				(0.028)
Institution FE	✓	✓		
Institution-Maturity FE			✓	✓
Institution-Time FE			✓	✓
Time-Maturity FE				✓
Sample Institutions	Mutual Funds	Mutual Funds	Mutual Funds	Full
Specification	(2a)	(2b)	(3)	(5)
Observations	3,233	3,233	6,466	8,252
R-squared	0.868	0.954	0.939	0.938

Table 3: Access to ECB Liquidity and Government Bond Purchases. Columns (1)-(3) of this table replicates the estimation reported in Table 2 for the subsample of mutual funds that hold domestic government bonds at any point during our sample period. Column (4) presents the results of specification (5). The dependent variable in column (1) (column (2)) is the share of total short (long) term public debt outstanding held by financial entity i divided by the size of entity i relative to total asset of the financial sector. The dependent variable in columns (3) and (4) is the share of public debt of maturity m outstanding held by entity i divided by the size of entity i relative to total asset of the financial sector. Independent variables include a Post_t dummy equal to one after, and including, December 2011, a Short_m dummy equal to one if the government bond portfolio matures on or before February 2015 (LTRO maturity), and a Access_i dummy equal to one for institutions that have access to ECB liquidity. The sample is monthly from June 2011 to June 2012. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

columns show that mutual funds are not more likely to purchase short-term bonds after the LTRO announcement; if anything, they are more likely to be purchasing longer maturities. This result holds when we do not split the sample and impose more restrictive fixed effects. The triple difference specifications confirm that, even with very restrictive fixed effects to control for other sources of heterogeneity, banks were more likely to increase their holdings of short-term bonds after the announcement of the LTRO.

Intensive Margin Our theoretical framework also suggests that the larger the LTRO borrowing, the stronger the demand for shorter-term collateral. A natural way to test this hypothesis is to extend our baseline specification to include an interaction term with a continuous variable that reflects the intensity of LTRO borrowing. We define intensity for bank i as follows:

$$\text{Intensity}_i = \frac{\text{LTRO}_i}{\text{Assets}_i}$$

in which LTRO_i is total long-term borrowing from the ECB at the end of March 2012 by entity i (the first observation that includes the second allotment), and Assets_i is the value of assets of entity i in the same period. This variable simply measures the fraction of assets that are funded by long-term ECB borrowing after the second allotment. We then adapt our specifications (2a), (2b) and (3) to:

$$\widetilde{\text{Holdings}}_{i,Short,t} = \alpha + \beta \text{Post}_t \times \text{Intensity}_i + \eta_i + \xi_t + \epsilon_{i,t} \tag{6a}$$

$$\widetilde{\text{Holdings}}_{i,Long,t} = \alpha + \beta \text{Post}_t \times \text{Intensity}_i + \eta_i + \xi_t + \epsilon_{i,t} \tag{6b}$$

$$\widetilde{\text{Holdings}}_{i,m,t} = \alpha + \beta \text{Post}_t \times \text{Short}_m \times \text{Intensity}_i + \eta_{i,t} + \xi_{i,m} + \nu_{t,m} + \epsilon_{i,m,t} \tag{6c}$$

The inclusion of the intensity variable allows us to introduce more restrictive fixed effects for time in (6a) and (6b) and for the interaction between time and maturity in (6c). A potential concern with these adapted specifications is that we measure intensity as total ECB borrowing by the end of the second allotment, three months after the policy has been announced. Naturally, this poses an endogeneity challenge, as increased holdings of government debt affect the pool of collateral owned by the bank and, therefore, how much the bank is able to borrow.

To address this issue, we take advantage of the fact that a considerable part of LTRO borrowing was a rollover of past ECB borrowing. For this reason, we instrument Intensity_i with total ECB borrowing as a percentage of assets in September 2011. Exogeneity of the instrument arises from our timing identification assumption: The LTRO was an unexpected policy, and, hence, any ECB borrowing in late September 2011, a week before the announce-

	$\widetilde{\text{Holdings}}_{i,Short,t}$	$\widetilde{\text{Holdings}}_{i,Long,t}$	$\widetilde{\text{Holdings}}_{i,m,t}$	$\widetilde{\text{Holdings}}_{i,Short,t}$	$\widetilde{\text{Holdings}}_{i,Long,t}$	$\widetilde{\text{Holdings}}_{i,m,t}$
Post × Intensity	0.038***	0.009***		0.022***	0.008***	
	(0.011)	(0.002)		(0.007)	(0.002)	
Post × Short × Intensity			0.029***			0.014**
			(0.010)			(0.006)
Instrument				✓	✓	✓
Entity FE	✓	✓		✓	✓	
Time FE	✓	✓		✓	✓	
Entity-Maturity FE			✓			✓
Entity-Time FE			✓			✓
Time-Maturity FE			✓			✓
Specification	(6a)	(6b)	(6c)	(6a)	(6b)	(6c)
Observations	893	893	1,786	893	893	1,786
R-squared	0.814	0.876	0.921	0.805	0.876	0.918
First Stage F-stat				490.4	490.4	489.8

Table 4: LTRO and Government Bond Purchases: Intensive Margin. This table presents the results of specifications (6a), (6b) and (6c). The dependent variable in columns (1) and (4) (columns (2) and (5)) is the share of total short (long) term public debt outstanding held by financial entity i divided by the size of entity i relative to total asset of the financial sector. The dependent variable in columns (3) and (6) is the share of public debt of maturity m outstanding held by entity i divided by the size of entity i relative to total asset of the financial sector. This regression includes only entities with access to LTRO, i.e. banks and savings institutions. Independent variables include a Post_t dummy equal to one on and after December 2011, a Short_m dummy equal to one if the government bond portfolio matures on or before February 2015 (LTRO maturity), and an Intensity_i continuous variable equal to LTRO borrowing divided by assets in March 2012. In columns (4)-(6), total borrowing from the ECB in September 2011 is used as an instrument for *Intensity*. The sample is monthly from June 2011 to June 2012. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

ment of a one-year LTRO and two months before the announcement of the three-year LTRO, is independent from any change in the behavior of government bond purchases occurring after the announcement. The results are presented in Table 4; again, we find a positive effect on both short- and long-term bond purchases, with a stronger effect on the former. This difference is also statistically significant, as confirmed by the difference-in-differences specification in column (6). These results confirm the existence of our finding on the intensive margin.

4.3 Effect on Government Bond Yields

We now ask whether the increased demand for short-term government bonds results in a steepening of the yield curve (Prediction 3). In the absence of a clean setting that allows us to formally test this equilibrium outcome, we simply provide evidence consistent with the prediction and discuss potential alternative explanations.

The top left panel of Figure 5 plots the Portuguese sovereign yield curve at three points in time: November 2011, February 2012, and May 2012. In the allotment period, between November and February, we observe that short-term yields fall, driving the steepening of the yield curve that carries on to May 2012. The top right panel plots the time series of the *slope* for the yield curve, defined as the 10-year minus the 1-year yield, from 2009 to 2013. Both figures are consistent with the LTRO inducing higher demand for short-term bonds and affecting prices accordingly.

Admittedly, from a theoretical point of view, the effect on prices should be entirely visible on the announcement day. However, as sovereign bond markets were very illiquid during this time period and the only active participants were the banks we are studying, which were likely to be constrained, we should instead expect prices to reflect binding constraints, liquidity premia, and many other factors other than the pure expected present discounted values of these securities' cash flows.

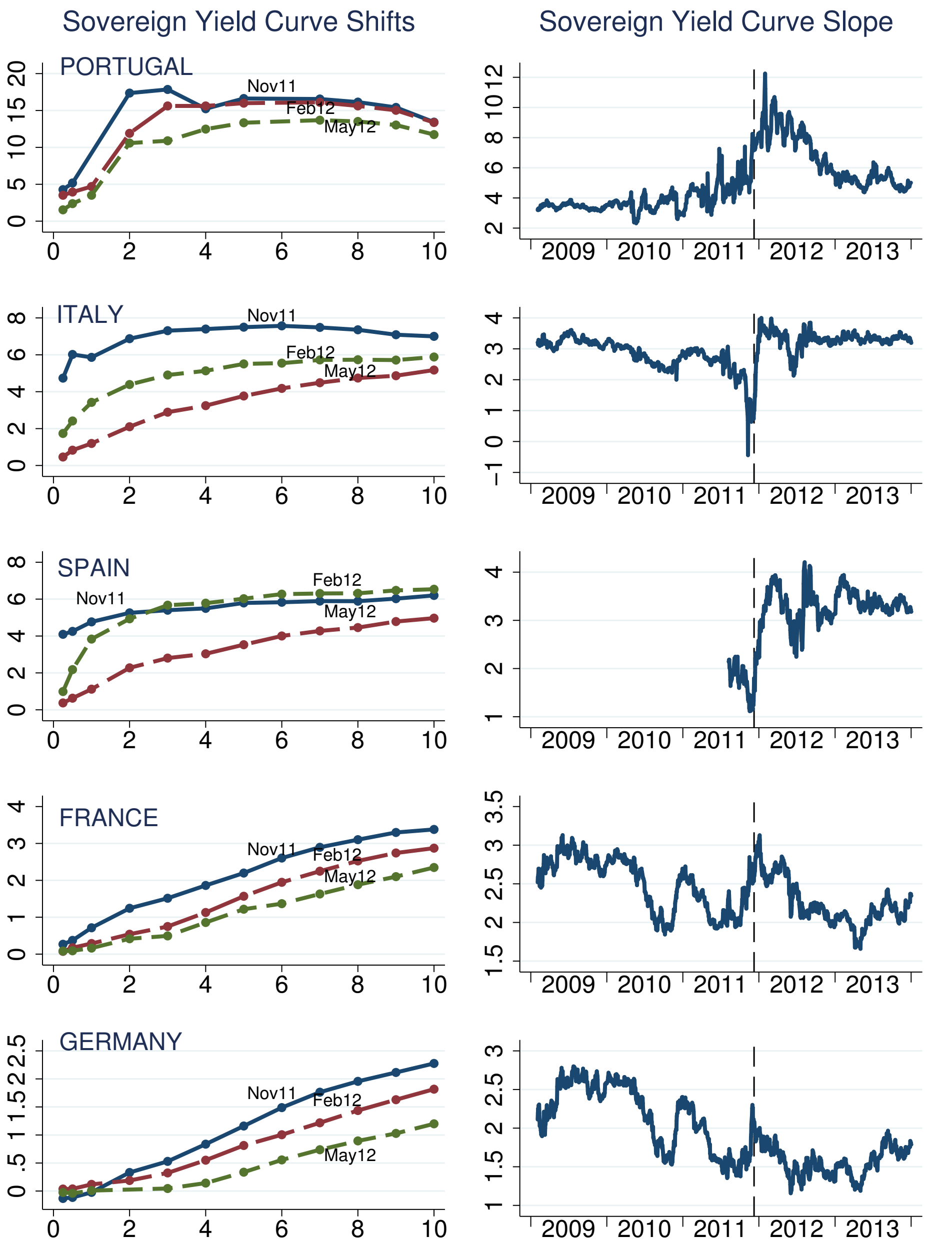

Figure 5: Evolution of the Sovereign Yield Curve. This figure shows the time series evolution of sovereign yields in Portugal, Italy, Spain, France, and Germany. The left column plots snapshots for these countries' yield curves at three different points in time (end of the month dates): November 2011, February 2012, and May 2012. The horizontal axis measures maturity in years and the vertical axis measures the percentage yield to maturity. The right column plots the time series (daily frequency) of the slope for the yield curve, measured as the ten-year yield minus the one-year yield, from 2009 to 2013. Portuguese spreads are obtained using the six-month yield as one-year yields are not available on Bloomberg during parts of the sample. The vertical dashed line corresponds to the LTRO announcement on December 8, 2011.

To investigate the link between the LTRO and the steepening of the sovereign yield curve, we analyze sovereign yield curves in other eurozone countries. According to our narrative, the collateral trade is more profitable if banks buy *high-yield* sovereign bonds. Hence, we should observe a steepening of the yield curve in risky peripheral countries and not in safe core countries. In the remaining panels of Figure 5, we analyze four large eurozone countries, two peripheral (Italy and Spain) and two core (France and Germany). Consistent with our narrative, we observe sovereign yield curve steepening only in the two risky peripheral countries.

One concern is that the changes in the yield curve may be unrelated to the LTRO and instead connected with the ECB Securities Markets Programme (SMP) launched in May 2010. As the SMP consisted of purchases of sovereign bonds in the secondary market (a textbook QE operation), observed changes in prices might be caused by purchases of short term securities by the central bank. However, Krishamurthy et al. (2015) show that the average remaining maturity of Portuguese bonds in the SMP portfolio was approximately five years during 2011, suggesting that most purchases were made at longer maturities. If anything, the contemporaneous SMP effect would work against our results, as purchases of bonds at longer maturities should flatten, not steepen, the yield curve.[31]

4.4 Public Debt Management

We now ask whether the increased demand for short-term government bonds and the equilibrium effects on the sovereign yield curve lead to increased public debt issuance, as the

[31] It is also unlikely that the SMP program influenced agents' behavior during the allotment period, given the shroud of secrecy around the details of the central bank purchases. In fact, the details of the SMP, such as amounts traded and securities purchased, were never disclosed: the only way through which the total volume of operations was known was through auxiliary open market operations that aimed at sterilizing the effect of the bond purchases.

sovereign debt management agency takes advantage of lower yields to auction new bonds (Prediction 4).[32] As in the previous subsection, in the absence of a clean empirical setting, we provide evidence consistent with this last prediction.[33]

In Figure 6, we plot monthly issuance volumes of public debt from June 2010 to April 2013. The dashed vertical line corresponds to the LTRO announcement. The figure documents that the debt agency increases debt issuance after the LTRO announcement, an observation that cannot be explained by rollover needs as before and after the LTRO, the amount of public debt maturing each semester is roughly constant, approximately €20 billion from 2011 to mid-2012.[34]

Interestingly, during the allotment period, there are four short-term zero coupon bonds maturing for a total of €13.5 billion and the government issues €7.9 billion using four zero-coupon bonds with maturities of one year (two bonds) and six-months (two bonds). This behavior is consistent with the fourth prediction, which states that the debt management agency has an incentive to tilt its issuances towards the short-end of the curve in response to market prices.

[32]Government debt is managed by the *Agência de Gestão da Tesouraria e da Dívida Pública - IGCP*, an autonomous public agency in charge of managing consolidated public debt.

[33]This exercise relates to a growing body of literature that studies the optimal composition of government debt issuances. Broner et al. (2013) show that emerging economies tend to borrow at shorter maturities due to lower costs. Arellano and Ramanarayanan (2012) motivate the same finding by observing that the incentives to repay, which are particularly important during downturns, are more effectively given by short-term debt. In a recent contribution, Bai et al. (2015) show that during crises governments issue shorter-maturity bonds with back-loaded payments. This latter feature allows the government to smooth consumption by aligning payments with future output.

[34]In Figure B.1 in the Appendix, we show public debt monthly maturing volumes.

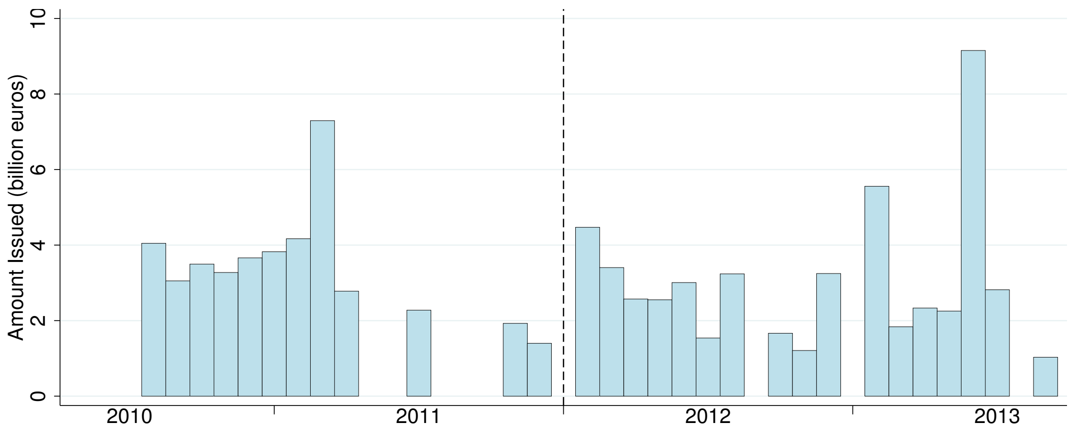

Figure 6: Public Debt Issuance Volume. This figure shows monthly issuance volumes of Portuguese public debt (billion euros) from June 2010 to April 2013. Issuance dates and volumes are taken from Bloomberg. In Figure B.1 in the Appendix, we show monthly maturing volumes.

5 Discussion

Having presented evidence for the collateral trade mechanism, we now proceed to discuss five questions that arise naturally from our analysis. First, which banks engaged in the collateral trade the most? Second, how did banks fund the collateral trade? Third, how much did they profit from it? Fourth, why did banks rely mostly on the second LTRO allotment for the collateral trade? And, finally, what is the role of the long LTRO maturity in attracting banks to borrow at the central bank?

5.1 Bank Heterogeneity

So far, according to our narrative, there is no reason why a bank should not engage in the collateral trade. In fact, the LTRO gives every bank the opportunity to invest in high-yield government bonds that can be then pledged as collateral to the central bank, regardless of its balance-sheet characteristics. It is nevertheless important to understand which banks engage in this behavior the most to inform policy about the transmission of this (possibly) unintended consequence and shed light on what drives bank-portfolio choice during long-term liquidity provisions.

Variable (BS)	Unit	No Trade	Trade>0	$\rho((BS, Trade)\|Trade > 0)$
Number of Banks		54	15	
Total Assets	bn euro	2.4	29.4	-53.2%
Leverage	A/E	6.0	11.0	-25.2%
Cash Reserves	% Assets	0.1	0.3	-22.0%
Securities	% Assets	10.6	25.4	41.8%
Total Govt. Bonds	% Assets	2.3	6.3	51.6%
Domestic Govt. Bonds	% Assets	1.9	5.7	57.3%
IIGS Govt. Bonds	% Assets	0.3	0.5	-3.4%
Equities	% Assets	1.8	3.2	-7.8%
Lending to Firms	% Assets	27.7	17.2	-35.1%
Lending to Households	% Assets	21.9	15.5	-19.9%
Securities Issued	% Assets	1.7	9.8	-27.7%
ECB Borrowing	% Assets	1.7	9.4	30.8%
Net Borr. from Banks	% Assets	18.0	-1.9	-14.6%
Deposits	% Assets	29.8	30.7	-14.3%
Short-term Funding	% Assets	57.7	59.8	26.4%

Table 5: Bank Characteristics and Government Bond Purchases. This table shows which banks engaged the most in the collateral trade. The third (fourth) column shows summary statistics in November 2011 (cross-sectional mean) for the group of banks with zero (strictly positive) collateral trade activity. The fifth column shows correlation between each balance sheet variables and the collateral trade activity in the subsample of institutions that have a positive collateral trade activity. Collateral trade activity is defined as government bond purchases between November 2011 and February 2012, divided by assets in November 2011. Securities are holding of securities, except equities. IIGS government bonds are government bonds issued by Italy, Ireland, Greece, and Spain. Securities liabilities are securities issued for funding purposes (e.g., bonds, commercial paper). Short-term funding are securities issued with a maturity less than one year, short-term deposits, and repurchase agreements. For the purpose of the last column, total assets is the natural logarithm of total assets.

In the third and fourth columns of Table 5, we divide banks in two subsamples: banks that engaged and banks that did not engage in collateral trade activity. We find that only 15 banks took advantage of the ECB liquidity provision to buy government bonds. These are large and highly levered institutions, responsible for 83% of total LTRO borrowing. In the last column, for those 15 institutions, we compute correlations between each balance sheet variable measured in November 2011 and bank-level collateral trade activity. Within the group of institutions that engage in the trade, banks that buy more government bonds tend to be smaller, have lower leverage, and hold relatively larger government bond portfolios.

How do we rationalize these findings? Banks with high leverage and banks heavily reliant on short-term funding are hit the hardest during the sovereign crisis. Hence, our evidence suggests that relatively healthier banks engage in the collateral trade the most. As we discuss in the next subsection, banks need to purchase government bonds in the allotment period *before* obtaining new liquidity from the central bank at LTRO2 and therefore need some initial balance sheet capacity to purchase new government bonds. It is likely that relatively more solid institutions have easier access to funding compared to more fragile institutions. These findings are consistent with Carpinelli and Crosignani (2015), who find that Italian banks with less runnable liabilities purchased more government bonds in this period and with Abbassi et al. (2016), who find that better-capitalized German banks increase their investments in securities, especially in those that had a larger price drop, compared with worse-capitalized banks during the crisis.[35]

5.2 Funding the Collateral Trade

Banks that wanted to engage in the collateral trade needed to buy the securities *before* pledging them at the central bank. The timing of this strategy is the key difference with respect to a standard carry trade in which banks buy high-yield securities *after* obtaining (cheaper) funding. How then did Portuguese banks finance the collateral trade?

To answer this question, Table 6 aggregates the balance-sheet of our sample banks before and at the time of the second LTRO allotment (November 2011 and February 2012, respectively) and presents levels and changes for several balance sheet items. We observe that *new* borrowing from the central bank amounted to €1.9 billion in the first allotment

[35] Our story is therefore consistent with classical models of arbitrage whereby less specialized or traditional investors enter a particular market if returns are sufficiently high.

	Nov11	Feb12	Change	%
Total Assets	571 235	582 656	11 421	2.0
Cash	1 603	1 477	-126	0.0
Securities	139 879	151 540	11 661	2.0
Government Bonds	23 768	27 793	4 026	0.7
Equities	24 930	26 864	1 935	0.3
Total Private Credit	292 830	288 814	-4 016	-0.7
Lending to Firms	121 363	117 561	-3 802	-0.7
Lending to Households	143 149	142 422	-728	-0.1
Lending to Banks	69 778	72 227	2 449	0.4
Other Assets	42 216	41 734	-482	-0.1
Total Liabilities	571 235	582 656	11 421	2.0
Equity	42 045	42 587	542	0.1
Securities Issued	90 809	98 103	7 294	1.3
ECB Total	45 724	47 611	1 888	0.3
Up to 1 year	38 274	26 298	-11 976	-2.1
1 to 2 years	7 450	1 100	-6 350	-1.1
More than 2 years	0	20 213	20 213	3.5
Borrowing from Banks	164 448	165 349	902	0.2
Deposits	195 481	197 223	1 742	0.3
Repo	7 760	6 403	-1 357	-0.2
Other Liabilities	24 968	25 379	411	0.1

Table 6: Banking Sector Aggregate Balance Sheet Nov11-Feb12. This table shows the aggregate banking sector balance sheet at November 2011 and February 2012. Categories are measured in million euros. The last column displays the change as a % of assets in November 2011. The additional levels of disaggregation of balance sheet categories (indented) are not exhaustive. February 2012 does not include the second LTRO allotment, which was settled only in March.

and the period up to the second allotment, so that a significant part of the total LTRO1 €20.2 billion uptake was used to roll over existing short- and medium-term ECB borrowing. Balance sheets increased from €571.2 billion to €582.7 billion, while equity was mostly stable, leading to a small increase in leverage.

There was a marginal decrease in cash reserves and the bulk of the adjustment on the assets side seems to come from private credit, which fell around €4 billion euros during this period. The fall in credit is particularly pronounced for non-financial firms. The fact that private credit fell during this period as balance sheets expanded suggests that the collateral trade might have had a crowding-out effect.

5.3 Collateral Trade Profits

We now compute profits from the collateral trade and measure the extent of the "stealth recapitalization" caused by the increase in bond prices after the LTRO.[36] For each bank, we compute three measures and present the aggregate results. The first is a narrower measure of "LTRO profits," equal to the increase in value of the November 2011 government bond portfolio between November 2011 and February 2012.[37] The second measure extends the first by having a larger time window. While the LTRO managed to halt the collapse of government bond prices, yields started trending back towards their pre-crisis levels mainly after the Outright Monetary Transactions (OMT) program announcement in July.[38] The third measure assesses the collateral trade, computing gains following the OMT announcement on the increase in holdings in the allotment period. More formally, we define the three measures as:

$$SR_i(\text{LTRO}) = \sum_{j \in \mathcal{J}} \Delta p_{j,\text{Nov11-Feb12}} \times Q_{i,j,\text{Nov11}} \tag{7a}$$

$$SR_i(\text{LTRO} + \text{OMT}) = \sum_{j \in \mathcal{J}} \Delta p_{j,\text{Nov11-Aug12}} \times Q_{i,j,\text{Nov11}} \tag{7b}$$

$$SR_i(\text{Collateral Trade} + \text{OMT}) = \sum_{j \in \mathcal{J}} \Delta p_{j,\text{Feb12-Aug12}} \times \Delta Q_{i,j,\text{Nov11-Feb12}} \tag{7c}$$

[36] We employ the term "stealth recapitalization" in the same sense as Brunnermeier and Sannikov (2013), who present a model where the central bank can recapitalize banks through open market operations and capital gains.

[37] Note that these profits are not necessarily caused by LTRO as prices are likely to also be affected by other factors. Moreover, we choose to use market values for the entire government bonds portfolio. Banks hold government bonds in their banking book and in their trading book. While only the latter is marked to market, we decide to use market values so as to better capture their true value should the bank decide to sell them in the secondary market or pledge them in repo operations.

[38] This was associated with the famous "whatever it takes" speech by ECB President Mario Draghi. In Figure B.2 in the Appendix, we show Portuguese sovereign yields during our sample period.

in which j is a security, $\mathcal{J}$ is the set of government bonds outstanding in our sample period, i is a bank, $\Delta p_{j,t-T}$ is the change in market price of security j between t and T, and $Q_{i,j,t}$ is the amount held of security j by bank i at time t measured in nominal value.

We present the results of this computation in Table 7. Note that our calculations likely represent a lower bound for two reasons. First, they ignore bonds maturing between these months, as these stop being held and priced. In addition, other asset prices are also affected through equilibrium and portfolio rebalancing effects.[39] Compared with the LTRO in isolation, the *combined* price movements during the LTRO and the OMT constituted a sizable stealth recapitalization of peripheral banking sectors of about 7.2% of book equity in the first half of 2012.[40] The collateral trade, by increasing holdings, exposed banks further to the coming price increases, constituting an additional 1.8% of equity in profits. These numbers are economically large, even when compared with *direct* recapitalizations. For example, the U.S. Capital Purchase Program consisted of a $197.5 billion injection, equivalent to 16.5% of book equity (1.7% of total assets).[41]

5.4 Bank Behavior at LTRO1

In our empirical analysis, we mainly focus on LTRO uptake at the second and final allotment on February 29, 2012. For example, in Section 4.1, we show that banks bought government bonds between the announcement and LTRO2 and pledged them at LTRO2. Our choice

[39] As the value of government bonds increases and constraints are relaxed, financial intermediaries also become less likely to fire sell other assets, which in turn raises their prices. We do not quantify this portfolio balance channel. See Gertler and Karadi (2011).

[40] Acharya et al. (2016b) analyze the impact of OMT announcement on bank balance sheets and credit supply and find that the announcement caused windfall profits of 8% of total equity.

[41] The CPP was the direct equity purchase program of the Troubled Asset Relief Program (TARP). This figure corresponds to the October-December 2008 period, when the bulk of the funds were disbursed. Book equity and total assets are measured at the end of September 2008, the last week before the program announcement.

Stealth Recapitalization	Total	% Assets	% Equity
LTRO	583.6	0.10%	1.39%
LTRO + OMT	3023.3	0.53%	7.19%
Collateral Trade + OMT	775.1	0.14%	1.84%

Table 7: Collateral Trade Profits, Summary Statistics. This table shows summary statistics for profit measures defined in (7a), (7b), and (7c), aggregated across the entire banking system $\sum_{i \in N} SR_i$. The first column shows the total value in million euros. The second column shows the total value divided by total assets, and the third column shows the total value divided by total book equity.

of focusing on this second date is entirely driven by the observation that the increase in government bond holdings on bank balance sheets happened almost entirely in the first two months of 2012, as documented in Figure 2.

It is important to note that banks could have used both allotments to engage in the collateral trade; they could have bought eligible collateral securities in the 10 days after the announcement and pledged them at LTRO1 on December 21, 2011. Banks borrowed, in aggregate, €20.2 billion at LTRO1, compared with €26.8 billion at LTRO2, but used the first allotment to almost entirely roll over previous short-term ECB borrowing at the longer maturity.[42]

Why did banks use almost exclusively LTRO2 for the collateral trade? There are three possible explanations. First, there might have been a stigma associated with borrowing at LTRO1. If banks initially perceived borrowing from the LTRO as a bad signal during the first allotment, but such fears were dispelled by wide participation, this shift could potentially explain why they avoided borrowing in the first allotment, but undertook positive net borrowing during the second allotment (Andrade et al. (2015)).[43] Second, banks might not

[42]In Figure B.3 in the Appendix, we plot LTRO1 uptake against changes in short-term ECB borrowing and illustrate that there is a negative relationship between the two. The slope of the fitted regression line is very close to −1 and most institutions are very close to this line.

[43]There is a vast literature on the stigma associated with borrowing from the lender of last resort that is too large to be reviewed here. Borrowing from standing facilities, such as the discount window operated by the Federal Reserve in the U.S., may be seen as signaling funding and liquidity problems and may raise

have had enough time between the December 8 announcement and the December 21 allotment to buy eligible collateral in the secondary market. Third, banks might have decided to delay purchases of risky collateral to the new calendar year, to avoid showing their increased holdings of risky securities on their annual reports.

5.5 The Role of Central Bank Loan Maturity

Prior to the December 2011 LTRO announcement, the ECB was providing liquidity to banks, against the same types of collateral but at a much shorter maturity, typically two-week or three-month. In other words, the only difference between the LTRO and pre-existing facilities was the long maturity.

In a frictionless world, loan maturity should not matter. The three-year LTRO would be a redundant policy tool as banks would be indifferent between rolling over short-term central bank loans and obtaining a long-term loan, as long as there were no substantial differences in loan rates. On the other hand, in a world with uncertainty regarding the future role of the central bank as a liquidity provider, long maturity loans offer banks insurance against possible future changes in the stance of the central bank.[44] This mechanism was likely at work for the three-year LTRO that was widely tapped, as €1 trillion was allotted to approximately 800 eurozone banks.

Additionally, Portuguese banks were essentially excluded from wholesale funding markets at the time of the LTRO announcement. Their main source of non-deposit liquidity was therefore the ECB, which was only providing liquidity at short maturities. The LTRO thus

concerns regarding the health of the institution. Indeed, stigma was a major concern for policymakers during the design of other policy interventions, such as the TARP. See Bernanke (2015) for an insider account.

[44] For example, there was uncertainty regarding the continuation of the full-allotment procedure in the three years following the December 2011 LTRO announcement.

offered an opportunity for banks to diversify the maturity structure of their liabilities.

6 Conclusion

We analyze the design of lender of last resort interventions in the context of the largest liquidity injection in the history of central banking, namely the three-year LTRO adopted by the ECB in December 2011. We show that the provision of long-term liquidity incentivizes banks to engage in collateral trades by purchasing high-yield collateral securities with maturity shorter than the central bank loan, allowing them mitigate funding liquidity risks.

In the context of the eurozone crisis, banks almost exclusively used domestic government bonds to engage in this trade. On the one hand, our findings are consistent with a stabilizing effect on the banking sector (the reduction in yields of assets to which banks were already substantially exposed led to an implicit recapitalization) and the sovereign (the expansion in the demand for domestic government debt contributed to higher government bond prices) during a time of great distress. On the other hand, not only did this phenomenon intensify the bank-sovereign "doom loop," but this policy also effectively consisted of the indirect financing of government debt by the ECB, which may be at odds with the monetary authority mandate and raise a plethora of other questions.

Our results extend outside the euro area, as the importance of LTRO-like policies has expanded around the world, with the implementation of similar policies in countries such as the United States, the United Kingdom, Russia, and China. In the United Kingdom, the Bank of England and the Treasury launched the Funding for Lending Scheme in July 2012, offering loans with maturity up to four years "to incentivize banks and building societies to boost their lending to the UK real economy". In the United States, the Federal Reserve established the Term Auction Facility in December 2007, auctioning 28-day and 84-day collateralized loans to "address funding pressures". In Russia, the central bank conducted an LTRO-style policy in July 2013, dubbed "Russia QE" by the press, through 12-month maturity collateralized loans. The implicit objective of this operation was to stimulate demand not for sovereign debt but rather for corporate debt as well as to reduce demand pressure for short-term funding. In China, LTRO-style loans have been offered by the People's Bank of China, in exchange for collateral in the form of bonds issued by Chinese local governments.[45] This policy seems to be aimed primarily at assuaging liquidity problems faced by local banks, as well as minimizing the effect of a potential rollover crisis for over-indebted local governments. In this respect, it was adopted in a context that is very similar to the one faced by the ECB in late 2011.

Our analysis uncovers previously unstudied effects of central bank long-term collateralized lending to banks. These effects are especially interesting when compared with QE-style policies. In our setting, the monetary authority engages in indirect purchases of shorter-term assets. Increased demand leads to a steepening of the yield curve and to a reduction of the aggregate maturity gap, as banks increase the maturity of their liabilities. If these assets are public debt, the government will have an incentive to react to market conditions by issuing more short-term debt. In contrast, large-scale asset purchase programs such as the ones conducted by the Federal Reserve (QE, MEP) consist of direct purchases of longer-term assets, leading to a flattening of the yield curve and to a reduction of the aggregate maturity gap of the private sector, by reducing the average maturity of assets outstanding. For the Treasury, the incentives are the opposite, as it becomes more attractive to issue debt at longer maturities.

We believe that our findings contribute to the comparative analysis of unconventional monetary policy operations, by identifying previously unexplored effects that may be of

[45] The PBoC has always engaged in collateralized lending to banks as part of its regular conduct of monetary policy. However, this is the first time that it has accepted this type of debt as collateral and provided liquidity at a long maturity.

great interest to policymakers. The effects on the aggregate maturity gap of the private sector, yield curve, and government strategy may be important for the design of policies aimed at macroeconomic stabilization and the promotion of financial stability. These are very interesting avenues for future research.

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A A Model of the "Collateral Trade"

In this section, we develop a model of the "collateral trade". In the Online Appendix, we (i) include some derivations that we skip here and (ii) present a simple model of liquidity risk that explicitly takes into account margin calls.

A.1 Setup

The economy lasts for three periods, $t = 0, 1, 2$. It is populated by a continuum of domestic banks, international investors and the government. At the beginning of $t = 0$, the government issues short and long-term debt. This consists of zero-coupon bonds maturing at $t = 1$ and $t = 2$, respectively. This debt is initially purchased by domestic banks. Banks care only about their payoffs at the end of $t = 2$, when all assets have matured. At $t = 1$, short-term debt matures and banks can rebalance their long-term debt portfolios. International investors may purchase this long-term debt, but their valuation of the asset is uncertain. Thus the only source of uncertainty in the model is the price of long-term debt at $t = 1$. The timeline of the model and the sequence of events is depicted in Figure A.1.

Banks Banks are risk-neutral and care only about their profits at the end of $t = 2$

$$\mathcal{U} = \mathbb{E}_0[\pi_2] \tag{A.1}$$

where π_2 are profits at $t = 2$ that arise from portfolio choices made at $t = 1$. Banks enter this period with available resources W_1 (which can potentially be negative), and can either rebalance their long-term debt portfolio, b'_L, or store/borrow resources d. When $d \geq 0$, banks store resources at a unit return between $t = 1$ and $t = 2$. When $d < 0$, banks borrow from external funding markets at a unit cost $\kappa > 1$. We can write profits at $t = 2$ as

$$\pi_2 = b'_L + d\left\{\mathbb{1}[d \geq 0] + \kappa\mathbb{1}[d < 0]\right\}$$

and the flow of funds constraint for banks at $t = 1$ is

$$q_1 b'_L + d = W_1$$

where q_1 is the price of long-term debt at $t = 1$. Available resources W_1 come from choices made at $t = 0$. In the initial period, banks solve a more sophisticated portfolio allocation problem: they can purchase short-term bonds b_S, long-term bonds b_L, store cash c, or borrow from money markets/lender of last resort €. Both short-term bonds and cash yield a unit return, while money market borrowing has a unit cost of R. This means that available resources at $t = 1$ can be written as

$$W_1 = b_S + q_1 b_L + c - R\text{€}$$

At $t = 0$, the bank has some level of initial resources $W_0 > 0$ available.[46] The bank faces a budget constraint, and a collateral constraint for money market borrowing. The budget constraint at $t = 0$ is

$$W_0 + \text{€} = q_S b_S + q_L b_L + c \tag{A.2}$$

And the collateral constraint on external borrowing states that total borrowing € cannot exceed a weighted average of the value of pledgeable assets,

$$\text{€} \leq (1 - h_L) q_L b_L + (1 - h_S) q_S b_S \tag{A.3}$$

where the only pledgeable assets are government debt, of any maturity, and h_L, h_S are the haircuts on long and short-term debt, respectively. This collateral constraint is a modeling device to account for the fact that most wholesale and central bank borrowing is undertaken through repurchase agreements and public debt is a prime source of collateral for these contracts.

International Investors International investors are risk-neutral, deep-pocketed traders who operate in secondary markets for long-term debt at $t = 1$. They are willing to purchase any amount of debt, generating a perfectly elastic demand curve. There is, however, un-

[46] We can think of this wealth as being available funds from short-term investments that have just matured, i.e. $W_0 = D + E - L$, where D, E, L are deposits/debt, equity and loans/non-pledgeable assets, respectively.

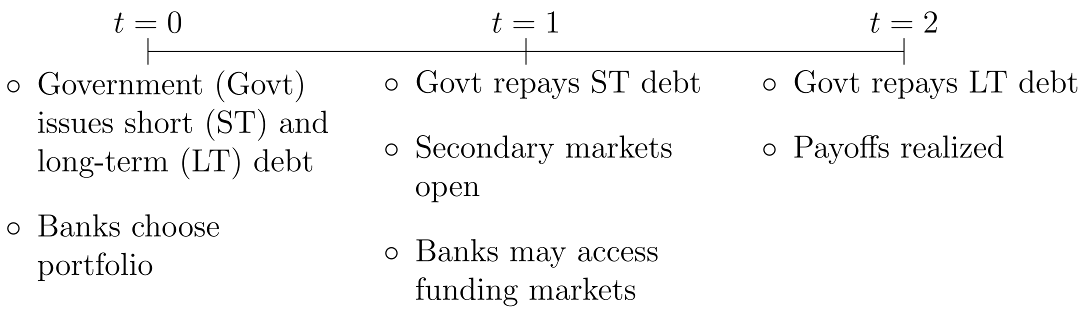

Figure A.1: Timeline for the Model.

certainty regarding their outside option or valuation, $a \sim F$. At $t = 1$, they are willing to purchase long-term debt if and only if they break even, thus pinning down the price. They purchase debt if and only if

$$q_1 \leq a$$

We assume that F, the distribution for a, has support $[\underline{q}, \bar{q}]$, where $\bar{q} < 1$ (so that interest rates are always strictly positive).

Government/Treasury The treasury manages public debt issuances for the government. We assume that the government seeks to issue a face value of B at $t = 0$, and the Treasury issues a fraction γ of short-term debt and a fraction $1 - \gamma$ of long-term debt. These fractions are taken as exogenous and there is no strategic behavior on the part of the fiscal authority for the moment.

A.2 Characterizing the Equilibrium

There are three markets: long-term debt at $t = 1$ and $t = 0$ and short-term debt at $t = 0$. At $t = 1$, the market for long-term debt features international investors on the buy side and domestic banks on the sell side. In equilibrium, the price must equal the inverse return on international investors' outside option,

$$q_1 = a$$

We describe the detailed solution to the banks' problem in periods $t = 1$ and $t = 0$ in the Online Appendix. We let $\kappa \to \infty$, the costs of accessing funding markets at $t = 1$ to become prohibitive. While stark, this assumption captures a motive to hold liquid reserves at any point in time (due to regulatory constraints, for example) and simplifies considerably the solution to the model. This effectively makes the bank risk-averse in the second period, equivalent to imposing a liquidity constraint that states that the bank must hold non-negative balances at $t = 1$.

An equilibrium in this model is a pair of prices (q_S, q_L), $t = 0$ bank policies $(b_L, b_S, c, €)$, and $t = 1$ bank policies $(b'_L(q_1), d(q_1))$, such that policies solve the optimization problems for banks at the respective periods and all markets clear: the secondary market for long-term debt at $t = 1$ and the primary markets for short and long-term debt at $t = 0$.

We proceed to characterize the equilibrium in terms of thresholds over the ratio of available resources to the face value of government debt $\omega \equiv \frac{W_0}{B}$ and the initial cost of borrowing R. The following proposition illustrates the possible regimes that can arise depending on the model's parameters.

Proposition 1. *The equilibrium is characterized as follows:*

1. *For $R\omega \geq \gamma + \tilde{q}(1-\gamma)$, banks do not borrow, $€ = \delta = \eta = 0$, and prices satisfy*

$$q_S = \frac{\omega}{\gamma + \tilde{q}(1-\gamma)}$$
$$q_L = \frac{\tilde{q}\omega}{\gamma + \tilde{q}(1-\gamma)}$$

2. *For $R\omega \in \left[\min\{(\tilde{q} - \underline{q})(1-\gamma), h_S\gamma + h_L\tilde{q}(1-\gamma)\}, \gamma + \tilde{q}(1-\gamma)\right]$, banks borrow, $€ > 0$, but no constraints are binding, $\delta = \eta = 0$, and prices satisfy*

$$q_S = \frac{1}{R}$$
$$q_L = \frac{\tilde{q}}{R}$$

3. *For $R\omega \in \left[(\tilde{q} - \underline{q})(1-\gamma), h_S\gamma + h_L\tilde{q}(1-\gamma)\right]$, the collateral constraint binds, $\delta > 0$,*

but the liquidity constraint does not, $\eta = 0$. *Prices solve the following system*

$$\omega = h_S q_S \gamma + h_L q_L (1-\gamma)$$
$$q_S = \frac{1}{R+\delta h_S}$$
$$q_L = \frac{\tilde{q}}{R+\delta h_L}$$

4. *For* $R\omega \in \left[h_S\gamma + h_L\tilde{q}(1-\gamma), (\tilde{q}-\underline{q})(1-\gamma)\right]$, *the liquidity constraint binds, but the collateral constraint does not. Prices satisfy*

$$q_S = \frac{1}{R}$$
$$q_L = \frac{\tilde{q}+\eta\underline{q}}{R(1+\eta)}$$

where

$$\eta = \frac{(\tilde{q}-\underline{q})(1-\gamma)}{R\omega} - 1$$

5. *For* $R\omega < \min\{(\tilde{q}-\underline{q})(1-\gamma), h_S\gamma + h_L\tilde{q}(1-\gamma)\}$, *both the liquidity and the collateral constraints bind. Prices satisfy,*

$$q_S = \frac{1}{R}\frac{h_L(\gamma+\underline{q}(1-\gamma)) - (1-h_L)R\omega}{\gamma(h_L-h_S)}$$
$$q_L = \frac{1}{R}\frac{(1-h_S)R\omega - h_S(\gamma+\underline{q}(1-\gamma))}{(1-\gamma)(h_L-h_S)}$$

The above proposition defines regions for the equilibrium depending on the value of $R\omega$. If the value of this term is very high, banks do not borrow and simply price government debt out of their initially available resources. This can be the case when resources are ample (ω is high), or when borrowing costs are prohibitive (R is high).

Once either R or ω decrease, banks start borrowing. There is a region when constraints do not bind, and banks simply borrow to purchase short-term and long-term debt at risk-neutral prices: there is complete pass-through of the costs of external financing to government yields. If either R or ω decrease further, one or more constraints start binding. For these regions, since either $\delta > 0$, or $\eta > 0$, or both, there will be a preference for short-term debt. This means that a transition from one of the previous regions will be associated with a larger increase (or smaller decrease) in the price of short-term debt, relative to long-term debt. That is, with a steepening of the yield curve.

We can use our stylized model to analyze the equilibrium effects of banks' portfolio choice on prices. We do this by letting the pre-allotment period correspond to a situation with dire wholesale funding conditions, high interest rate R_0, while the allotment period corresponds to an improvement of these conditions, $R_1 < R_0$, a lower interest rate on wholesale funding. While Portuguese banks could have potentially borrowed in wholesale markets at longer maturities, the interest rate was prohibitive. We thus model the LTRO as a decrease on the interest rate for wholesale funding at a maturity that is large enough such that it matches (or exceeds) the maturity of some of the assets that can be pledged as collateral (short-term bonds, which we interpret as bonds with maturity shorter than three years). We maintain throughout that haircuts are constant, and the haircut on short-term debt is smaller, $h_S < h_L$.[47]

In our model, for the same ω, if the decrease in R is large enough, the economy can experience a change in regime: in particular, the economy can switch from an unconstrained equilibrium to one where banks are constrained, and thus have a preference for short-term debt. Figure A.1 plots the slope of the yield curve as a function of R. For high levels of R, the bank is unconstrained and the slope of the yield curve behaves in the usual manner: if borrowing costs decrease, the slope decreases (yields become more compressed). However, if the decrease in R is large enough so as to bring the economy to an equilibrium where liquidity (or collateral) constraints bind, the sign of the relationship inverts: due to the preference for short-term debt induced by the constraint, a decrease in borrowing costs can actually *increase* the slope of the yield curve.

[47]During the allotment period, the haircuts applied by the Eurosystem to Portuguese bonds ranged from 5.5% for bonds with maturity less than one year to 10.5% for bonds with maturity greater than ten years.

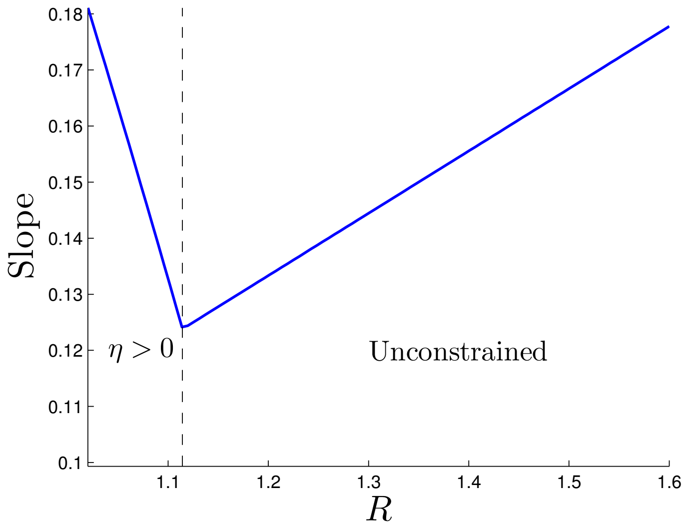

Figure A.1: Slope of the Yield Curve, Model. This figure plots the slope of the sovereign yield curve as a function of borrowing costs R. The dashed line indicates the transition from an unconstrained equilibrium to one where the liquidity constraint binds, $\eta > 0$.

A.3 Treasury Response and Equilibrium Effects

Our model can be extended to account for the response of the treasury (the debt management agency) and the total price effects given that response. In the spirit of Greenwood et al. (2015), we extend the model to endogenize the choice of γ, the maturity structure chosen by the treasury. Assume, as before, that the treasury needs to finance a total face value of B, but can now choose the maturity structure of sovereign debt. In particular, γ is now taken to be a control. We assume that the treasury's objective is to maximize the revenue that is raised from the issuance, $q_S\gamma B + q_L(1-\gamma)B$. Additionally, we also assume that the treasury has a preference for maturity diversification: in a frictionless world, it would issue a fraction $\bar{\gamma}$ of short-term debt, and a fraction $1-\bar{\gamma}$ of long-term debt, for reasons that we leave unmodelled.[48] We write the treasury's problem as

$$\max_{\gamma\in[0,1]} q_S\gamma B + q_L\gamma B - \frac{1}{2}B\phi(\gamma-\bar{\gamma})^2$$

where the last term captures the losses from deviating from the optimal exogenous maturity structure and ϕ captures the relative costs of deviating from this maturity structure. The solution to this problem is given by

$$\gamma = \bar{\gamma} + \frac{q_S - q_L}{\phi}$$

with $\gamma \in [0,1]$ at all times. The government sets the fraction of short-term debt equal to its unconstrained optimum plus an adjustment term that favors the cheaper maturity, divided by the cost of deviating from the optimal maturity structure.

The following result characterizes the full equilibrium of the model, allowing for government reaction, in a certain region of the equilibrium space.

Proposition 2. *Assume that ϕ is large enough and that banks are liquidity-constrained.Then, a decrease in R has the following effects:*

1. *$q_S/q_L \uparrow$, the slope of the yield curve increases*
2. *$\gamma \uparrow$, the government issues more short-term debt and banks purchase more short-term debt.*

The proposition establishes that in what we will consider to be the empirically relevant region of the equilibrium space, an improvement in borrowing conditions for banks (our way of modeling the LTRO) can lead to a steepening of the yield curve that is accompanied by a strategic reaction of the Treasury, increasing the supply of shorter term debt.

[48] The focus on total revenues as an objective can be motivated by the problem of a government that faces an exogenous stream of expenditures that need to be financed with distortionary taxes.

B Additional Plots

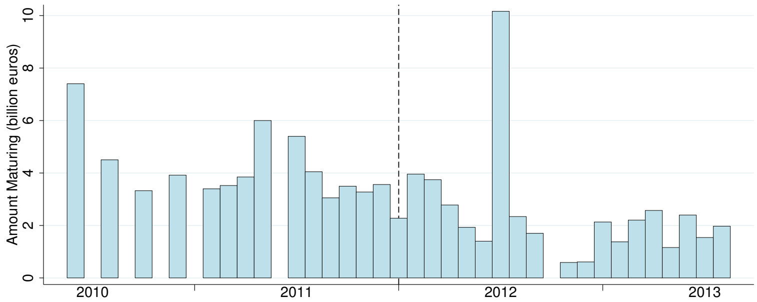

Figure B.1: Public Debt Maturing Volume. This figure shows monthly maturing volumes of Portuguese public debt (billion euros) from June 2010 to April 2013. Maturities and volumes from Bloomberg.

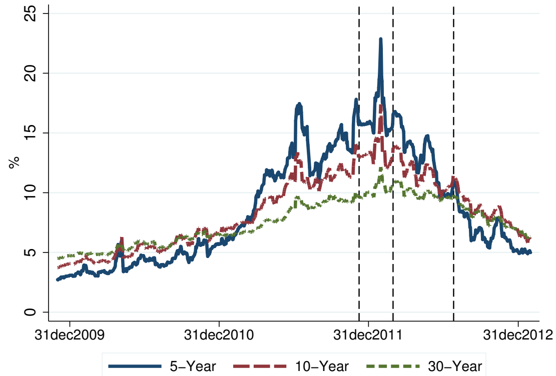

Figure B.2: Portuguese Sovereign Yields. These figures show the time series of Portuguese 5Y, 10Y, 30Y Sovereign Yields from November 2009 to January 2013. The dashed vertical lines correspond to (i) the LTRO announcement (December 8, 2011), (ii) the second LTRO allotment (February 29, 2012), and (iii) the OMT announcement (July 26, 2012).

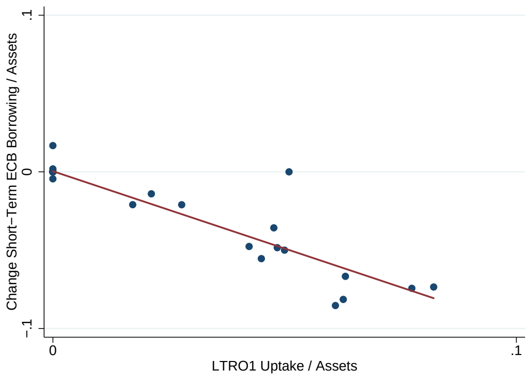

Figure B.3: LTRO1 Uptakes and Changes in Short-term Borrowing from the ECB. The figure plots total LTRO1 uptake against the change in short-term ECB borrowing between November 2011 and December 2011, as a percentage of assets in November 2011. The solid line is a standard regression line. Two outliers are not shown (but are included in the regression line) for illustrative purposes.

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