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The (Unintended?) Consequences of the Largest Liquidity Injection Ever*

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Abstract

The design of lender-of-last-resort interventions can exacerbate the bank-sovereign nexus. During sovereign crises, central bank provision of long-term liquidity incentivizes banks to purchase high-yield eligible collateral securities matching the maturity of the central bank loans. Using unique security-level data, we find that the European Central Bank's 3-year Long-Term Refinancing Operation caused Portuguese banks to purchase short-term domestic government bonds, equivalent to 10.6% of amounts outstanding, and pledge them to obtain central bank liquidity. The steepening of eurozone peripheral sovereign yield curves right after the policy announcement is consistent with the equilibrium effects of this "collateral trade."

JEL: E58, G21, G28, H63

Keywords: Lender of Last Resort, Bank-Sovereign Nexus, Collateral, Sovereign Debt, Eurozone Crisis

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1 Introduction

The collapse of the U.S. subprime mortgage market and the subsequent European sovereign debt crisis impaired financial intermediaries, which then transmitted the shocks to firms and households.[1] In the eurozone periphery, the crisis was also characterized by the "bank-sovereign nexus", as banks increased their holdings of risky domestic public debt, triggering a vicious cycle that threatened the stability of both the sovereign and the financial system. As part of their policy response, central banks extended collateralized loans to banks, effectively acting as lenders-of-last-resort (LOLR). While the rationale for these interventions is based on a vast literature, existing research provides little to no guidance on how central banks should design liquidity provisions, leaving policymakers in "unchartered waters" during crises.[2]

This paper examines the transmission of LOLR interventions and analyzes how their design affects bank holdings of eligible collateral securities. The context is the largest LOLR intervention ever conducted: the European Central Bank's (ECB) 3-year Long-Term Refinancing Operation (LTRO hereafter), implemented in December 2011 at the peak of the eurozone crisis.[3] Through this operation, the ECB extended the maturity of its liquidity provision from a few months to three years, with the stated goal to support bank lending and liquidity in the euro area money market.

[1] Chodorow-Reich (2014) and Acharya et al. (2018a) present evidence on the real effects of these crises.

[2] At the 2016 ECB Annual Research Conference, Mario Draghi (President of the ECB) said that 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 ECB actions had "inevitably moved ahead of academia during the crisis."

[3] Garcia-de-Andoain et al. (2016) discuss the ECB's role as an LOLR during the crisis.

Using data on security-level holdings by Portuguese banks from the country's central bank, Banco de Portugal (BdP), we find that the LTRO maturity extension induced banks to purchase high-yield eligible securities, in the form of domestic government bonds matching the maturity of the central bank loans, and pledge them to obtain central bank liquidity. Publicly available stress-test data shows that banks in peripheral countries such as Italy and Spain also expanded their domestic sovereign bond holdings, mostly via securities matching the maturity of ECB liquidity. The steepening of peripheral sovereign yield curves right after the LTRO announcement, driven by a collapse of short-term yields, is consistent with the equilibrium effects of this "collateral trade" on sovereign funding costs.

The contribution of this paper is twofold. First, it shows that central bank provision of long-term, but not short-term, liquidity to banks induces them to purchase high-yield securities. In the collateral trade, contrary to a carry trade, banks maintain their desired level of reserves and prefer bonds matching the maturity of the central bank loans. Second, it argues that, during sovereign crises, central bank liquidity can exacerbate the bank-sovereign nexus by inducing banks to buy domestic government bonds, lowering, in turn, sovereign borrowing costs.

The collateral trade works as follows. In an environment with costly external financing, banks hold liquid reserves as insurance against shocks. If the central bank provides liquidity against high-yield government bonds at more favorable terms than the private market, banks can use their reserves to purchase government bonds and pledge them at the central bank to replenish their original reserves. This strategy allows banks to profit if the bonds yield a return higher than the cost of the loan and maintain a desired level of reserves.

Banks minimize funding liquidity risk by matching the maturity of the bonds they buy with the maturity of central bank liquidity. Bonds maturing after the central bank loans might have a lower price by the time banks need to repay the central bank. Because eligible securities that have both a high yield and a very short maturity are scarce, the collateral trade is particularly attractive during long-term LOLR liquidity provisions. In equilibrium, by inducing a higher demand for short-term bonds, the collateral trade causes a drop in short-term sovereign yields, leading to a steepening of the yield curve.[4]

Formalized in a simple model, the collateral trade generates three predictions: (i) Banks "buy and borrow" as they purchase high-yield government bonds to borrow from the LOLR; (ii) the collateral trade is caused by the long maturity of LOLR liquidity; and (iii) the sovereign yield curve steepens, driven by a drop in short-term yields in response to the higher demand for short-term bonds. Starting from the observation that bank holdings of domestic government bonds increase from 16.4% to 20.2% of the amount outstanding during the three months around the LTRO allotment, we test the first two predictions and provide evidence consistent with the third prediction.[5]

The findings include the following: first, these purchases, in the cross section of banks, correlate one-to-one with LTRO borrowing and explain a large part of its cross-sectional variation (first prediction). Second, banks purchased government bonds *in response* to the LTRO by comparing, in a differences-in-differences specification, purchases of bonds maturing before ("short-term" bonds) and bonds maturing after ("long-term" bonds) the LTRO

[4]Given the maturity of the typical instruments of central banks and for the purpose of this analysis, maturities above three years are labeled as long-term, and below three years as short-term.

[5]Peripheral domestic government bonds — as opposed to other high-yield assets — are the most attractive asset for the collateral trade for three reasons. First, euro-denominated government bonds have a capital requirement of zero. Second, they have a high yield. Third, banks in peripheral countries can use *domestic* government bonds to "gamble for resurrection" and satisfy eventual government moral suasion.

loans, controlling for time-varying bank and bank-bond heterogeneity using fixed effects (second prediction). These results are economically significant. The LTRO caused a €5.1 billion increase in holdings of short-term bonds, equivalent to 10.6% of the amount outstanding. Consistent with the preference for short-term securities, the LTRO caused a €2.4 billion increase in holdings of long-term bonds, equivalent to 2.6% of the amount outstanding.

These claims are confirmed by three additional findings: (i) There is no effect in other periods, except for November 2011 when the ECB adopted a similar, but smaller, long-term liquidity injection; (ii) the results do not extend to institutions that have no access to the ECB (e.g., hedge funds, pension funds); and (iii) more LTRO borrowing is correlated with more collateral trade activity. Publicly available stress-test data suggests that these findings extend to the largest peripheral eurozone countries. Large banks in Italy and Spain increased their holdings of sovereign bonds, driven by short-term bonds, from €209 billion to €240 billion and from €162 billion to €171 billion, respectively, between December 2011 and June 2012.

Finally, consistent with the equilibrium effects of the collateral trade, it is shown that short-term yields dropped right after the LTRO announcement in peripheral — but not in core — eurozone countries, leading to a steepening of their sovereign yield curves (third prediction). Thanks to these price changes, the Italian, Spanish, and Portuguese sovereigns saved €10 billion, €3 billion, and €1 billion, respectively, in public debt issuance in the six months after the LTRO, a possibly unstated objective of the policy.[6] The collateral trade

[6] These findings echo the remarks of former French President Sarkozy at a December 9, 2011, press conference: "This means that each state can turn to its banks, which will have liquidity at their disposal."

was ex post very profitable for banks. Following the drop in peripheral yields in summer 2012, Portuguese banks realized profits on their bond holdings of €3.8 billion, or 9% of book equity.

These results on the role of the maturity of central bank liquidity fill a gap in the LOLR literature that has mostly focused on the rationale for the LOLR to exist (see Santos, 2006 for a survey) and the effects of LOLR interventions on market liquidity (Garcia-de-Andoain et al., 2016) and bank credit (Carpinelli and Crosignani, 2018; Andrade et al., forthcoming).[7]

This paper also contributes to the literature on the bank-sovereign nexus (Farhi and Tirole, 2018; Brunnermeier et al., 2016; Gennaioli et al., forthcoming, 2014; Leonello, forthcoming; Cooper and Nikolov, forthcoming; Crosignani, 2017; Acharya et al., 2014; Bolton and Jeanne, 2011; Broner et al., 2010). The literature on the eurozone crisis attributes bank purchases of domestic government bonds to moral suasion (Becker and Ivashina, 2018; Ongena et al., 2016; Altavilla et al., 2017; Uhlig, 2013; De Marco and Macchiavelli, 2016) or risk shifting (Crosignani, 2017). The collateral trade channel proposed in this paper is complementary to these explanations and explains banks' preference for short-term high-yield securities.[8]

Two papers are closely related to this one. First, Drechsler et al. (2016) show that,

[7]The LOLR theory literature has recently suggested that the LOLR should, in some cases, lend against low-quality collateral (Choi et al., 2018; Koulischer and Struyven, 2014). Our findings show that in these cases the choice of the maturity of LOLR liquidity crucially affects its transmission through banks.

[8]See Krishamurthy et al. (forthcoming) for a comprehensive analysis of ECB policies. The current paper also relates to the analysis of the effects of ECB policies on asset prices (Eser and Schwaab, 2016; Trebesch and Zettelmeyer, 2018), bank credit (van Bekkum et al., 2018; Heider et al., forthcoming; Acharya et al., 2018b; Andrade et al., forthcoming; Carpinelli and Crosignani, 2018; Garcia-Posada and Marchetti, 2016), firm financing (Grosse-Rueschkamp et al., 2018), and market liquidity (Garcia-de-Andoain et al., 2016; Pelizzon et al., 2016) and follows the literature on bank credit during the eurozone crisis (Popov and van Horen, 2016; De Marco, forthcoming; Bofondi et al., 2018; Bocola, 2016; Acharya et al., 2018a; Bottero et al., 2018).

before the LTRO, weakly capitalized banks borrowed more from the ECB and pledged riskier collateral than strongly capitalized ones. They document a reallocation of risky assets, including sovereign bonds, from strongly to weakly capitalized banks, consistent with a "risk-taking theory" of the LOLR. Second, Acharya and Steffen (2015) show that banks engaged in a carry trade funding purchases of peripheral sovereign bonds in short-term wholesale markets. They document that the bulk of purchases by peripheral banks happened in the first half of 2012, around the LTRO. In this paper, we (i) causally link the LTRO with these purchases and identify the collateral trade mechanism that — contrary to a carry trade — allows banks to maintain a desired level of reserves and (ii) show, thanks to granular data and the LTRO maturity extension, that the long LTRO maturity further induced banks to purchase short-term bonds, consistent with the steepening of sovereign curves right after the announcement.[9]

The paper proceeds as follows. Section 2 illustrates the collateral trade and its empirical predictions. Section 3 presents the empirical setting and the data. Section 4 presents the empirical analysis, and Section 5 further discusses the results. Section 6 concludes.

2 LOLR Liquidity and the Collateral Trade

The theory of the LOLR is intuitive. Banks hold fewer liquid assets than liquid liabilities and are therefore subject to runs. During a run, the central bank should act as a

[9]These two papers rely on very limited stress-test data: Five Italian, five Spanish, four Portuguese, two Irish, and zero Greek banks participated in the five stress tests conducted in March 2010, December 2010, September 2011, December 2011, and June 2012. The first paper uses these five dates and the second uses the first three dates. Existing studies that exploit security-level holdings analyze the risk-taking channel of monetary policy (Peydró et al., 2018) or focus on the portfolio choice – not in relation to ECB interventions – of banks in Germany (Abbassi et al., 2016; Buch et al., 2016; Hildebrand et al., 2012; Timmer, 2018).

LOLR, providing liquidity to banks that are illiquid but solvent, to prevent socially costly deleveraging and liquidations. According to the classical principle of Bagehot (1873), 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 in normal times – ensure that banks relatively unaffected by the run continue to obtain funding in the private market.

The prescription regarding collateral eligibility is, however, vague: The LOLR should accept collateral securities "that are considered safe in normal times" and valued at pre-panic prices. Moreover, the literature does not specify the maturity at which the LOLR should lend to banks. This paper argues that collateral eligibility and maturity matter for the transmission of LOLR liquidity, by showing that an LOLR that provides *long-term* liquidity accepting high-yield securities as collateral encourages banks to engage in a "collateral trade." This mechanism is intuitively described next, and a formal model is presented in the supplementary material.

2.1 The Collateral Trade

Consider an economy with costly external financing where banks hold liquid reserves for insurance motives. There is an LOLR that provides long-term liquidity collateralized by government bonds — safe securities in normal times but high-yielding during sovereign crises. During sovereign crises, banks can use their reserves to buy high-yield government bonds that can then be pledged to borrow from the LOLR and 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. A bank engaging in this trade using collateral with a maturity exceeding that of the LOLR loan is exposed to funding liquidity risk: If the pledged securities drop in price during the loan, not only may the bank receive a margin call from the LOLR, but the bond itself may be worth less by the time the loan expires. These scenarios force the bank to raise funds to either meet the margin call or repay the loan, which may be very costly during crises and increase uncertainty regarding liquidity management. If collateral securities mature before the loan, the risk associated with the margin call is lower, as the securities mature (become cash) before the loan is due.[10]

The eligibility of high-yield securities and the long maturity of LOLR loans make this trade particularly attractive. If the LOLR accepted only low-yield securities, the collateral trade would be less profitable. If the LOLR loans were short term, most eligible collateral securities would mature after the LOLR loan, exposing the bank to funding liquidity risk.[11] For a given supply of government bonds, the collateral trade causes the sovereign yield curve to steepen as banks demand more short-term bonds. In sum, if the LOLR provides long-term loans against high-yield government bonds, the collateral trade generates three predictions: (i) Banks buy high-yield government bonds to borrow from the LOLR (i.e., banks engaging in the collateral trade buy €1 of government bonds for every €1 borrowed from the LOLR); (ii) the LOLR causes purchases of high-yield short-term government bonds (more specifically, banks develop a preference for high-yield *short-term* government bonds in order to match

[10]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. A simple model of margin calls and the collateral trade is presented in the supplementary material.

[11]This intuition is clearly illustrated in the 2012 Annual Report of Banco Carregosa (a medium-sized Portuguese bank): "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."

the maturity of LOLR loans with the maturity of the asset pledged to secure them); and (iii) the sovereign yield curve steepens due to increased demand for short-term government bonds.

3 Data and Setting

We bring these predictions to the data in the context of the Portuguese financial sector during the ECB's 3-year LTRO announced in December 2011.[12]

3.1 Empirical Setting

Any eurozone bank can obtain a collateralized loan from the ECB. Provided it pledges sufficient collateral ("full allotment" policy), there is no limit on how much a bank can borrow. Eligible collateral includes government bonds, asset-backed securities, and bank and corporate bonds. Although every bank can borrow at the same interest rate, 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 one week or three months.[13]

As the sovereign crisis worsened in the second half of 2011, on December 8, 2011, the ECB announced two unprecedented 3-year loans — the 3-year LTRO — to "support bank lending and money market activity."[14] The announcement is closely followed by the allotments of

[12]See Reis (2013) for a detailed analysis of the Portuguese economy from 2000 to 2012.

[13]The full allotment was introduced in October 2008. The ECB usually offers main refinancing operations (MRO) loans with a one-week maturity and LTRO loans with a 3-month maturity. During the crisis, the ECB adopted extraordinary 6- and 12-month LTROs. Three 6-month LTROs were allotted in April 2010, May 2010, and August 2011. One 12-month LTRO was allotted in October 2011. See the supplementary material for details about the ECB collateral rules. In the main body, "LTRO" is used to refer to the December 2011 3-year LTRO.

[14]In the second half of 2011, peripheral banks suffered funding dry-ups (Chernenko and Sunderam, 2014). Sovereign credit default swap spreads of countries like Italy and Spain reached record highs in November 2011 and remained elevated until the Outright Monetary Transactions (OMT) program announcement in July 2012. See the LTRO announcement at www.ecb.europa.eu.

the first loan (LTRO1) on December 21 and, two months later, of the second loan (LTRO2) on February 29. The period between the announcement and LTRO2 is referred to as the "allotment period." Over 800 eurozone banks borrowed €1 trillion, making this the largest central bank liquidity injection ever.[15] More than two-thirds of ECB liquidity was allotted to banks located in peripheral countries where the LTRO long maturity and below-market haircuts were particularly attractive compared with private funding markets.[16]

Note that the main difference between the LTRO and preexisting facilities is its long maturity. Prior to the LTRO, the ECB provided liquidity to banks against the same types of collateral but at a much shorter maturity, typically two weeks or three months. In a frictionless world, loan maturity does not matter and the LTRO is redundant, as banks are indifferent between borrowing at a 3-year maturity and rolling over shorter-maturity borrowing. These two strategies are not equivalent if there is uncertainty about the ECB's future role as a liquidity provider, likely the case at the end of 2011, as the continuation of the ECB's full allotment policy and the future of the eurozone were both unclear.

3.2 Data

Our data set combines two proprietary data sets from BdP.[17] The first data set contains monthly bank-level balance sheet data of all Portuguese financial institutions that have access to the ECB – 81 banks and 10 savings institutions. As a complement, information is obtained

[15]To be clear, this was the largest liquidity injection ever to take place in such a short time frame (two calendar dates). The total size of other liquidity injection programs, such as the Federal Reserve's Quantitative Easing program, was ultimately larger, but took place over the course of several years.

[16]This ECB subsidy is discussed in Drechsler et al. (2016). Banks had to post collateral on the allotment date to obtain the LTRO loan. The interest rate on the LTRO is the average rate of the MRO loans (1% at the time) over the life of the operation, to be neutral compared with pre-existing short-term loans.

[17]A more detailed description of the data set is provided in the supplementary material.

on bank-level uptake of LTRO liquidity and ECB collateral pool by type: government debt, marketable assets, additional credit claims, and government-guaranteed bank bonds.[18]

The second data set contains monthly security-level holdings (book, face, and market value) of Portuguese government bonds by domestically regulated institutions. The sample also includes non-bank institutions such as mutual funds, hedge funds, and pension funds. More than 98% of the value of holdings in the data set are matched with bond-level information from Bloomberg such as yield, maturity, and amount issued. Note that no balance sheet characteristics (e.g., total assets) are observed for these non-bank institutions.

The institutions in the first data set (access to ECB liquidity) are referred to as "banks", and the institutions in the second data set only (no access to ECB liquidity) as "non-banks."

4 Empirical Analysis

We now bring the three predictions to the data. Section 4.1 and Section 4.2 test the first two predictions. Section 4.3 provides evidence consistent with the third prediction.

In the context of the eurozone debt crisis, peripheral government bonds, particularly domestic ones, are the most attractive type of high-yield security to engage in the collateral trade for several reasons. First, euro-denominated government bonds have a zero regulatory capital risk weight. Second, eurozone peripheral, but not core, government bonds have a high yield and therefore offer an attractive spread over the LTRO rate.[19] Third, in the presence of sovereign-bank linkages, *domestic* government bonds are even more attractive, as banks can

[18] Bank-level uptake is not publicly available (Bloomberg publishes self-reported, incomplete, information). See Crosignani et al. (2015) for more details about this data set.

[19] The supplementary material presents collateral trade spreads by country and maturity and shows that only peripheral government bonds have large and positive spreads during the LTRO allotment period.

use them to "gamble for resurrection", because they would not be able to survive a default by their sovereign in any case (Crosignani, 2017), and to satisfy eventual government moral suasion (Becker and Ivashina, 2018; Ongena et al., 2016).[20]

[Figure 1]

Figure 1 shows government bond holdings at face value of banks (who could access the LTRO). The vertical lines delimit the allotment period. The figure shows that Portuguese banks increased their holdings from €22.9 billion in November 2011 to €27.8 billion in February 2012, a change equivalent to 0.9% of total assets and 3.5% of public debt outstanding.[21]

4.1 Bank Buy-and-Borrow Behavior

The next step is to check whether banks purchased government bonds in the allotment period and used them to borrow at the LTRO (Prediction 1). Focus is on the second allotment because banks (i) have only two weeks to buy the bonds in the secondary market between the announcement and LTRO1, as opposed to three months before LTRO2; (ii) might want to avoid showing increased peripheral government bond holdings on the annual report (holdings as of December 31); and (iii) might fear that LTRO borrowing might send a bad signal to the market.[22]

Given that the type of securities pledged by banks at the ECB is not observed, we analyze

[20] Crosignani (2017) shows that, when sovereigns and banks tend to default in the same states of the world, limited liability leads banks to not internalize any losses from sovereign default in their portfolio choice.

[21] Banks increased their holdings of government bonds from 16.4% in November 2011 to 20.2% in February 2012 as a share of the amount outstanding and from 4.0% to 4.8% as a share of total assets. The supplementary material presents figures where holdings are normalized by total public debt outstanding and by total assets. It is also shown that, during the same period, holdings of non-banks (excluded from the LTRO) were stable.

[22] Consistent with our focus on LTRO2, most purchases of domestic government bonds occurred in January and February and banks used LTRO1 mostly to rollover previous short-term ECB funding. Andrade et al. (forthcoming) suggest that French banks might have been concerned that borrowing at LTRO1, but not at LTRO2, might have sent a bad signal to the market.

the correlation in the cross section of banks between changes in holdings of eligible collateral and LTRO2 borrowing. Formally, the following regression is estimated on the subsample of banks:

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

where the dependent variable is LTRO2 uptake, $\Delta\text{EligColl}_{\text{Feb12-Nov11}}$ is a vector of changes in holdings of eligible collateral during the allotment period (one change per asset class), and $\text{TotalCollateral}_{\text{Nov11}}$ is the stock of eligible collateral in November 2011, as banks might have used their preexisting collateral to access the LTRO. Changes are measured between November 2011 and February 2012. All variables are normalized by bank assets in November 2011, and collateral measures are haircut adjusted.[23]

Four asset classes of ECB-eligible collateral are observed in the data: domestic government bonds, additional credit claims, government-guaranteed bank bonds, and other marketable assets (e.g., asset-backed securities, corporate and bank bonds, and foreign government bonds). If banks engaged in the collateral trade using one specific asset class, (i) the related changes in holdings should explain a large part of the cross-sectional variation in LTRO2 uptake and (ii) the related β coefficient should be close to 1.[24]

[Table 1]

Table 1 shows estimation results, measuring changes in holdings using either face values (column (1)) or market values (column (2)), as bank borrowing capacity at the ECB depends

[23] The collateral variables are net of the haircut imposed by the ECB. If a bank purchased during this period 100 units of a security that is eligible to serve as collateral at a haircut of x%, our measure is $100 \times (1 - x)$.

[24] While banks could borrow at the LTRO using their existing holdings of collateral in November 2011, the collateral trade implies *buy*-and-borrow behavior and has therefore no prediction for the coefficient γ.

on the market value of collateral assets, but market values might simply reflect price movements and not changes in actual holdings. Consistent with the buy-and-borrow behavior, all coefficients on changes in holdings are statistically significant and close to 1.[25]

The last column reports the semi-partial R-squared that captures the marginal information each variable provides about LTRO2.[26] Domestic government bonds have by far the largest marginal contribution, with a semi-partial R-squared of 30.5%, compared with 10% for other marketable securities and less than 4% for other asset classes, consistent with government bonds being the most important type of ECB-eligible collateral.[27]

The fitted values of (1) can be aggregated to estimate how much of the uptake at LTRO2 these factors can account for. In a regression that uses only the changes in domestic government debt, the predicted aggregate uptake is 61.4% of the actual uptake. This prediction jumps to 93% when the lagged stock of collateral is included.

4.2 LTRO Causes the Collateral Trade

We now test whether banks increased their government bond holdings *in response* to the LTRO (Prediction 2). Section 2 suggests that banks have an incentive to purchase securities maturing before the LTRO2 loan in February 2015. Hereafter, these securities are referred to as "short-term" bonds.

[25] The supplementary material shows that these estimates are robust to controlling for changes in a wide range of balance sheet components during this period.

[26] Given a set of covariates $\{x_n\}_{n=1}^{N}$, the semi-partial R-square of variable x_n captures the information in x_n about the dependent variable that is orthogonal to the other covariates.

[27] Government bonds accounted for 47.3% of total collateral pledged to the ECB in 2011, versus 3.2% of regional government bonds, 14.8% of unconvered bank bonds, 12.1% of covered bank bonds, 9.6% of corporate bonds, 7.7% of asset backed securities, and 5.4% of other marketable assets. Only six banks in the sample held government-guaranteed bank bonds, and these holdings were markedly smaller than other asset classes. Additional credit claims became a non-negligible type of collateral of Portuguese banks only after March 2012. There is no finer disaggregation of marketable assets other than government bonds.

The first step is to measure bank-level changes in government bond holdings of different maturities. This variable requires particular care, as one needs to take into account that large banks likely buy more bonds (normalize by bank size) and that the amounts of short- and long-term bonds outstanding change over time as new bonds are issued and existing bonds mature (normalize by amounts outstanding).[28] To this end, the following variable is defined

$$\widetilde{\text{Holdings}}_{i,m,t} = \frac{\frac{\text{Govt. Bond Holdings}_{i,m,t}}{\text{Amount Outstanding}_{m,t}}}{\frac{\text{Assets}_{i,t}}{\text{Total Assets}_t}} \tag{2}$$

This variable measures the share of public debt outstanding of maturity m held by bank i in month t, divided by the size of bank i relative to the size of the banking sector.[29] The numerator is the share of government bonds outstanding with (residual) maturity m held by institution i. The denominator scales the numerator by size. These measurements are not affected by movements in prices, as both holdings and amounts outstanding are measured in face value.

Prediction 2 is tested in two steps. The first is to estimate the following specifications

[28] Consider the following example. Bank A and Bank B buy €50 in short-term and €50 in long-term government bonds. If Bank A is larger than Bank B, holdings should be by bank assets to take into account that Bank B has a stronger preference relative to its size. Assume also that there are €200 short-term and €400 long-term government bonds outstanding. By simply looking at bank holdings, even if normalized by size, the two banks do not seem to favor a specific maturity even though they are effectively concentrating on short maturities relative to other investors. The stocks of short- and long-term public debt outstanding in November 2011 are €50.5 billion and €89.3 billion, respectively.

[29] m is discretized into six bins based on the bond's residual maturity on February 2012: 0-0.5, 0.5-1, 1-3, 3-5, 5-10, and 10+ years. The first three bins are labeled short-term and the last three long-term.

in the subsample of banks (which have access to ECB liquidity):

$$\widetilde{\text{Holdings}}_{i,m,t|m \in \text{Short}} = \alpha + \beta_{\text{Short}} \text{Post}_t + \eta_i + \mu_m + \epsilon_{i,m,t} \tag{3a}$$

$$\widetilde{\text{Holdings}}_{i,m,t|m \in \text{Long}} = \alpha + \beta_{\text{Long}} \text{Post}_t + \eta_i + \mu_m + \epsilon_{i,m,t} \tag{3b}$$

where the dependent variable is the normalized holdings of short- and long-term government bonds in (3a) and (3b), respectively. The sample runs from June 2011 to May 2012; Post_t is a dummy equal to 1 on and after December 2011; and η_i and μ_m are bank and maturity fixed effects, respectively.[30] These two regressions analyze whether banks purchased more short- and long-term government bonds after the announcement relative to the pre-announcement period.

The second step is to estimate the following differences-in-differences specification:

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

where Short_m is a dummy variable equal to 1 for sovereign bonds maturing on or before February 2015, $\eta_{i,t}$ are bank-time fixed effects, and $\xi_{i,m}$ are bank-maturity fixed effects.

[Table 2]

Columns (1)-(2) in Table 2 show that banks increased both short- and long-term government bond holdings after the announcement. Consistent with Prediction 2, the coefficient is larger for short-term bonds. This difference is confirmed by the differences-in-differences

[30] The sample ends in May 2012, not overlapping with Draghi's July 26, 2012, OMT announcement.

specification in columns (3)-(5), where the coefficient of interest is positive, significant, and stable.[31] Column (5) includes bank-time and bank-maturity fixed effects, therefore ruling out several alternative explanations. For example, bank-time fixed effects ensure that the results are not driven by highly leveraged or politically connected banks, and bank-maturity fixed effects ensure that the results are not driven by bank-level preference for specific maturities, such as large banks demanding short-term bonds for regulatory purposes.

4.2.1 Aggregate Effects

The LTRO had an economically significant effect on the demand for government debt, especially at short maturities. The aggregate effect of the LTRO on the demand for government bonds is calculated using the results of the first two columns of Table 2. For each bank-maturity observation in February 2012, the demand boost is given by

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

where $\hat{\beta}_{\text{Short}}$ and $\hat{\beta}_{\text{Long}}$ are the estimates in (3a) and (3b). The result is the effect of the announcement on the demand for maturity m by bank i, measured in euros. Aggregating these amounts across banks implies that the LTRO boosted demand for short-term bonds by €5.1 billion, or 10.6% of the amount outstanding. For long-term bonds, the demand boost was €2.4 billion, or 2.6% of the amount outstanding, leading to a total boost of €7.5 billion, or 5.4% of the amount outstanding. Relative to the size of the banking sector, holdings

[31] The supplementary material presents estimation results for two alternative versions of (4). First, the share of total public debt outstanding of maturity m held by bank i is used as a dependent variable. Second, the same dependent variable as in (2) is used, but keeping Amount Outstanding$_{m,t}$ and Total Assets$_t$ fixed at their December 2011-February 2012 means.

increased by 1.3% of assets: 0.9% for short-term and 0.4% for long-term bonds.

4.2.2 Placebo Test

To address the potential concern that the described effect might also be present in periods other than the treatment period — which would suggest that the results might not be driven by the long maturity of central bank liquidity provision — the application of the treatment is simulated in every month from December 2010 to June 2012. Interestingly, at the end of October 2011, a weaker treatment was actually in place as the ECB adopted a 12-month operation, long enough to allow banks to buy bonds with matching or lower maturities.[32]

The following specification is estimated separately for every month τ between January 2011 and June 2012, effectively comparing each month to the rest of the sample period:

$$\widetilde{\text{Holdings}}_{i,m,t} = \alpha + \beta_\tau \mathbb{I}_{t,\tau} \times \text{Short}_m + \eta_{i,t} + \xi_{i,m} + \epsilon_{i,m,t} \tag{5}$$

where $\mathbb{I}_{t,\tau}$ is a monthly indicator variable equal to 1 if $t = \tau$ and 0 otherwise, $\eta_{i,t}$ are bank-time fixed effects, and $\xi_{i,m}$ are bank-maturity fixed effects. Short_m is a dummy equal to 1 for bonds in the first three maturity categories in February 2012.

[Figure 2]

Figure 2 plots the coefficients of the interaction term for each separate regression and

[32] The 3-year maturity of the LTRO expanded the set of securities attractive for the collateral trade. Previous operations were "too short term" given the distribution of residual maturities for government bonds. In particular, three 1-year LTROs were allotted in June 2009, December 2009, and October 2011. The first two operations happened during a period of relatively low sovereign stress when the collateral trade was less attractive. There are no sufficient monthly observations that do not overlap with the December 2011 3-year LTRO to re-estimate specifications (3a), (3b), (4) around the October 2011 1-year LTRO. In addition, bank-level 1-year LTRO uptake is not observed, therefore preventing us from estimating (1) around the October 2011 1-year LTRO.

the 95% confidence interval. Before the LTRO, the coefficient is stable, close to zero, or even negative.[33] It becomes positive in November 2011, capturing the effect of the 1-year operation settled at the end of October. The coefficient becomes positive during the allotment period when the collateral trade induced banks to purchase short-term bonds. As banks kept these bonds on their balance sheets, the coefficient remains positive after the allotment period.

4.2.3 Non-Banks as a Control Group

Our identification strategy relies on the assumption that in the absence of the LTRO, banks would not have purchased more (short-term) government bonds after the announcement. The plausibility of this assumption is checked by analyzing the behavior of non-banks that do not have access to ECB liquidity. In particular, (4) is estimated in the subsample of non-banks, in addition to estimating the following specification:

$$\frac{\text{Govt. Bond Holdings}_{i,m,t}}{\text{Amount Outstanding}_{m,t}} = \alpha + \beta \text{Post}_t \times \text{Short}_m \times \text{Access}_i + \eta_{i,t} + \xi_{i,m} + \mu_{m,t} + \epsilon_{i,m,t} \quad (6)$$

Specification (6) is estimated over the full sample (banks and non-banks), where Access_i is a dummy equal to 1 if institution i is a bank. The regression is saturated with institution-time, institution-maturity, and time-maturity fixed effects. The dependent variable is no longer normalized by the size of the institution, as assets for non-banks are not observed.

[Table 3]

In column (1) of Table 3, specification (4) is estimated in the subsample of non-banks. The estimated coefficient is close to zero and not statistically significant, evidence that in-

[33] Given that the placebo specification compares *each month* to the rest of the sample period, the negative coefficients before the LTRO should be interpreted relative to the other months in the sample.

stitutions with no access to the ECB did not purchase more short-term bonds after the announcement. In columns (2)-(5), (6) is estimated for the full sample, with progressively more stringent fixed effects. In these specifications the triple interaction coefficient is positive, stable, and statistically significant, suggesting that institutions with access to the LTRO purchased more short- than long-term bonds after the announcement, compared with institutions with no access. In the last column, (6) is estimated in the subsample of bonds maturing in a 4-year narrow window around the LTRO maturity. The results hold in this restricted subsample where short- and long-term bonds have similar residual maturities.

4.2.4 Intensive Margin

The collateral trade suggests a positive correlation between how much a bank borrowed at the LTRO and its collateral trade activity. We define $\text{Intensity}_i = \frac{\text{LTRO}_i}{\text{Assets}_i}$, where the numerator is bank i LTRO borrowing and the denominator is assets of bank i in November 2011. (3a), (3b), and (4) are then adapted to include this new variable:

$$\widetilde{\text{Holdings}}_{i,m,t|m\in\text{Short}} = \alpha + \beta \text{Post}_t \times \text{Intensity}_i + \eta_i + \xi_t + \epsilon_{i,t} \tag{7a}$$

$$\widetilde{\text{Holdings}}_{i,m,t|m\in\text{Long}} = \alpha + \beta \text{Post}_t \times \text{Intensity}_i + \eta_i + \xi_t + \epsilon_{i,t} \tag{7b}$$

$$\widetilde{\text{Holdings}}_{i,m,t} = \alpha + \beta \text{Post}_t \times \text{Short}_m \times \text{Intensity}_i + \eta_{i,t} + \xi_{i,m} + \nu_{t,m} + \epsilon_{i,m,t} \tag{7c}$$

where (7c) includes bank-time, bank-maturity, and maturity-time fixed effects.

[Table 4]

Columns (1)-(2) of Table 4 show that banks that borrowed more at the LTRO purchased more government bonds — especially short-term — compared with banks that borrowed less. The coefficient of interest in columns (3)-(6) is positive, stable, and significant, confirming that the correlation between LTRO borrowing and holdings is stronger for short-term bonds.[34]

4.2.5 External Validity

Finally, the data suggests that banks in Italy and Spain also likely engaged in the collateral trade.[35] Figure 3 shows holdings of GIIPS (Greece, Ireland, Italy, Portugal, and Spain) and non-GIIPS sovereign bonds held by Italian (left) and Spanish (right) banks in September 2011, December 2011, and June 2012 – the three stress-test dates around the LTRO for which the European Banking Authority (EBA) has made data publicly available.[36]

[Figure 3]

Italian and Spanish banks increased their sovereign bond holdings from €209 billion to €240 billion and from €162 billion to €171 billion, respectively, between December 2011 and June 2012. The bar charts show holdings of bonds of comparable maturities around the LTRO 3-year maturity: 1- to 3-year maturity holdings (blue diagonal lined bars) and 3- to 5-year maturity holdings (green solid bars). Consistent with the collateral trade, the sizable increase in holdings is driven by GIIPS bonds with 1- to 3-year maturities, just shorter than the LTRO maturity.[37]

While this evidence is consistent with the collateral trade, the stress test data are too limited to formally test the predictions for countries other than Portugal. First, the EBA

[34] The supplementary material shows Figure 2 for specification (7c), confirming that LTRO borrowing and purchases of sovereign bonds are positively correlated from November 2011 onward.

[35] Santos (2017) provides an excellent narrative of the Spanish banking crisis between 2008 and 2012. Carpinelli and Crosignani (2018) analyze the effect of the LTRO on bank lending in Italy.

[36] The EBA is responsible for conducting stress tests on systemically important financial institutions in the European Union. The data are available on the EBA website.

[37] The supplementary material shows that (i) the findings are mostly driven by domestic bonds; and (ii) the findings do not extend to core countries like Germany and France, where banks could in general borrow in the private market at more favorable terms compared with the LTRO, could not use (low-yield) domestic government bonds to risk shift, and were likely not subject to government moral suasion.

sample is limited to a handful of very large banks in each country.[38] Second, holdings are available on only a few stress-test dates, preventing us from checking whether changes in holdings coincide with the LTRO. Finally, the EBA does not report bank-level LTRO uptake.

4.3 Effect on Government Bond Yields

This section provides evidence consistent with the steepening of the sovereign yield curve (Prediction 3) by analyzing government bond yields across eurozone countries.[39] The collateral trade is more profitable if banks purchase *high-yield* bonds, especially if domestic, due to underpricing of default risk by domestic banks. The "collateral trade spread," defined as the difference between the 3-year sovereign yield and the LTRO rate during the allotment period, was close to zero or negative in core countries and large and positive in peripheral countries (3.72%, 2.39%, and 15.32% in Italy, Spain, and Portugal, respectively).[40] Hence a steepening of the yield curve should be observed in peripheral, but not in core, countries.

[Figure 4]

Figure 4 plots the evolution of the slope of the sovereign yield curves – defined as the 10-year minus the 1-year yield – for three peripheral (Italy, Spain, and Portugal) and three core (Germany, France, and the Netherlands) countries between June 2011 and May 2012. A structural break corresponding to the LTRO announcement is observed (dashed vertical line): The slopes for Italy and Spain decrease before and rises by about 300 basis points after.[41]

[38]Five Italian banks, four Spanish banks, four Portuguese banks, three Irish banks, and no Greek banks participated in the September 2011, December 2011, and June 2012 EBA stress tests.

[39]For a given supply of bonds, this prediction is the result of market segmentation in the spirit of Vayanos and Vila (2009), as bonds of different maturities are imperfect substitutes. A structural model, needed to carefully characterize the equilibrium effects of the collateral trade, goes beyond the scope of this paper.

[40]The supplementary material shows collateral trade spreads across maturities for several countries.

[41]The Portuguese slope is not available for the entire sample. However, pre- and post-announcement observations are consistent with a steepening during the LTRO period.

The opposite is true for Germany and the Netherlands, where each slope declines over this period. France experiences a modest steepening that begins well before the announcement.

We rule out that the steepening in peripheral countries is driven by changes in the supply of government bonds. Analysis of public debt issuance from June 2011 to May 2012 reveals that the supply of sovereign bonds was approximately constant across maturities for Italy and Spain. In Portugal, issuance of short-term public debt increased after the announcement, which would go against the results, as short-term yields should *rise* in response to a higher supply of short-term sovereign bonds.[42] The change in the slope on the day of the LTRO announcement also rules out that the observed pattern of sovereign yields might be driven by other ongoing ECB programs such as the Securities Markets Programme (SMP).[43]

In a frictionless world, the steepening of the yield curve should happen on the announcement date rather than gradually over the following few months. The gradual change observed in the data is likely due to the low liquidity in sovereign bond markets during this period and constraints affecting peripheral banks, among the most active participants in these markets. In sum, a non-negligible component of prices is likely due to binding constraints, liquidity premia, and other factors beyond the expected discounted values of securities' cash flows.

This evidence is complemented by analyzing whether short-term yields fall in peripheral relative to core countries in a narrow window around the LTRO announcement. The following

[42] The supplementary material shows monthly public debt issuance in Portugal, Italy, and Spain.

[43] Krishamurthy et al. (forthcoming) show that the average residual maturity of Portuguese bonds in the SMP portfolio was approximately five years during 2011, suggesting that most purchases were made at longer maturities. The contemporaneous SMP effect would therefore flatten, not steepen, the yield curve.

specification is estimated on the 14 business days from November 29 to December 19[44]:

$$y_{i,t}^{(m)} = \alpha + \beta_{(m)} \text{Post}_t \times \text{Risk}_i + \eta_i + \delta_t + \epsilon_{i,t} \tag{8}$$

where $y_{i,t}^{(m)}$ is the sovereign yield for country i at day t at maturity m; Post_t is a post-announcement dummy; Risk_i is a measure of sovereign risk; and η_i and δ_t are country and day fixed effects, respectively. Sovereign risk is measured using a dummy equal to 1 if the country is peripheral and the log of the 5-year yield on November 28. Separate regressions are estimated for each maturity term m.[45]

[Figure 5]

Figure 5 shows the estimates for the $\beta_{(m)}$ coefficient as a function of maturity m, using the peripheral dummy (left) and the log yield (right). The figure shows that (i) short-term yields in peripheral countries fell after the announcement relative to short-term yields in core countries and (ii) long-term yields in peripheral countries increased after the announcement relative to long-term yields in core countries.[46] Thanks to these price changes, Italy, Spain, and Portugal saved €10 billion, €3 billion, and €1 billion, respectively, in their public debt issuance in the six months after the LTRO, a possibly unstated objective of the policy.[47]

[44] Our results are robust to changing this window. In the supplementary material, we find a stark reduction of sovereign yields matching the maturity of ECB liquidity also around the October 1Y-LTRO announcement.

[45] The sample includes all eurozone countries except Greece (for which government bond yields are unavailable). By focusing on a short window around the announcement, bond supply is given, as issuance calendars are pre-determined and bond maturities are known. A manual check reveals that there were no changes to the issuance calendar between November 29 and December 19 for Italy, Ireland, Portugal, or Spain.

[46] While both short-term and long-term peripheral yields decreased after the LTRO announcement, short-term yields decreased more than long-term yields.

[47] This number is based on the following calculation: (8) generates a collection of estimates $\hat{\beta}^{(m)}$, which can be used to compute counterfactual yields $y_{i,t}^{(m),cf} = y_{i,t}^{(m)} - \hat{\beta}^{(m)} Post_t \times Risk_i$. For each issuance between December 8, 2011 (LTRO announcement), and July 26, 2012 (OMT speech), savings are computed by assuming that amounts issued are constant and only principal payments change with yields (bonds are

5 Discussion

The previous analysis gives rise to three questions. How did banks fund the collateral trade? Which banks engaged in the collateral trade? How much did banks profit from it?

5.1 Funding the Collateral Trade

In a standard carry trade, banks buy securities after securing funding, but in the collateral trade, banks buy the securities *before* pledging them at the central bank. Table 5 aggregates the balance sheets of the sample banks in November 2011 (before the announcement) and March 2012 (after LTRO2) and shows levels and changes for several balance sheet items.[48] It is observed that (i) the aggregate balance sheet size increased from €571 billion to €583 billion; (ii) wholesale funding increased through security issuance; (iii) book equity was stable; and (iv) private credit, particularly for non-financial firms, fell by around €4 billion. Taken together, these findings suggest that the collateral trade was likely funded by an increase in borrowing and a decrease in private credit.

[Table 5]

5.2 Bank Heterogeneity

While *all* banks should have taken advantage of the collateral trade, only 15 large banks, responsible for 83% of LTRO borrowing in Portugal and usually counterparties of ECB open market operations, engaged in this trade.[49] In this group, banks that purchased more

treated as zero coupon and discounted using Eonia/OIS). Savings are then summed for each country.

[48] As LTRO2 was allotted on February 29 but settled on March 1, March is used as the post-LTRO snapshot.

[49] The supplementary material presents correlations between balance sheet characteristics of these 15 large banks and their collateral trade activity.

bonds tend to be smaller, have lower leverage, and hold more securities, suggesting that banks with easier access to funding engaged more in the collateral trade. These findings are consistent with Carpinelli and Crosignani (2018), who find that Italian banks with less runnable liabilities purchased more government bonds in this period.

5.3 Collateral Trade Profits

As prices of peripheral government bonds substantially increased following the July 2012 OMT announcement, banks realized sizable profits on both their existing bond holdings and the collateral trade.[50] The change in value between November 2011 and August 2012 of the November 2011 government bond portfolio constituted an indirect recapitalization of Portuguese banks of €3 billion, or 7.2% of book equity.[51] The collateral trade exposed banks further to the coming price increases, constituting an additional €0.8 billion, or 1.8% of equity in profits.[52]

These calculations likely represent a lower bound, as bonds maturing between these months are ignored, and other asset prices are also affected through equilibrium and portfolio rebalancing effects.[53] 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).[54]

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[50] These profits constituted a "stealth recapitalization" in the sense of Brunnermeier and Sannikov (2016).

[51] Acharya et al. (2018b) find that the OMT announcement caused gains of 8% of equity for banks.

[52] Formally, these two measures are $\sum_{j\in\mathcal{J}} \Delta p_{j,\text{Nov11-Aug12}} \times Q_{i,j,\text{Nov11}}$ and $\sum_{j\in\mathcal{J}} \Delta p_{j,\text{Feb12-Aug12}} \times \Delta Q_{i,j,\text{Nov11-Feb12}}$, where j is a security, $\mathcal{J}$ is the set of government bonds outstanding in the sample period, i is a bank, $\Delta p_{j,t-T}$ is the change in market price of j between t and T, and $Q_{i,j,t}$ is the face value of security j held by i at t. We compute the mark-to-market profits on the banking and trading book to capture the true portfolio value should the bank decide to sell these bonds or pledge them in repo operations.

[53] 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 the bonds' prices.

[54] This number corresponds to the October-December 2008 period, when most of the funds of the Capital Purchase Program (the direct equity purchase program of the Troubled Asset Relief Program) were disbursed.

6 Conclusion

In December 2011, the ECB announced the 3-year Long-Term Refinancing Operation, then the largest liquidity injection in the history of central banking. This intervention is used to analyze the design of lender-of-last-resort interventions. The findings suggest that the provision of long-term liquidity induced banks to engage in a collateral trade by purchasing high-yield eligible collateral securities with maturity equal to or shorter than the central bank loan in order to mitigate the risk associated with this trade.

While purely positive, this analysis sheds light on the trade-offs of this type of interventions. On the one hand, the findings suggest a stabilizing effect on the banking sector (profits led to an implicit recapitalization) and the sovereign (lower yields due to higher demand for bonds) during a time of great distress. On the other hand, as banks almost exclusively used domestic bonds, this policy intensified the bank-sovereign "doom loop."

These findings also contribute to the comparative analysis of unconventional monetary policies, such as large-scale asset purchases (LSAP). In our setting, the central bank engages in *indirect* purchases of short-term assets. Increased demand leads to a steepening of the yield curve and to a reduction of the aggregate maturity mismatch of the private sector, as banks increase the maturity of their liabilities. In contrast, LSAP programs consist of *direct* purchases of longer-term assets, leading to a flattening of the yield curve and to a reduction of the aggregate maturity mismatch, by reducing the average maturity of assets outstanding.

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Figures

Figure 1: Holdings of Domestic Government Debt. This figure plots the evolution of domestic government bonds held by Portuguese banks from June 2011 to June 2012. Quantity is measured as the face value in billions of euro. The two vertical dashed lines delimit the LTRO allotment period. The supplementary material shows that the figure is robust to normalizations by total assets and total public debt outstanding.

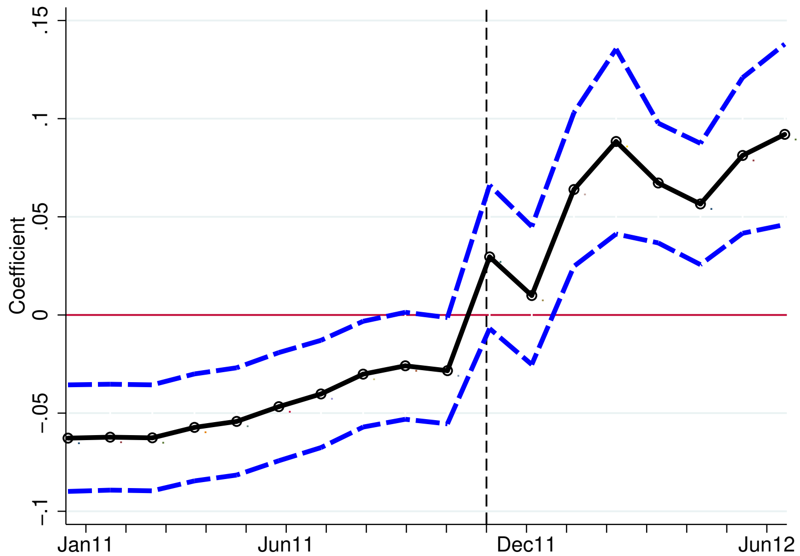

Figure 2: Placebo Test. This figure plots interaction coefficients from specification (5) estimated from January 2011 to June 2012. The dashed lines delimit the 95% confidence interval. Standard errors are double clustered at the bank-maturity and month levels. The dashed vertical line indicates the date of the LTRO announcement.

Sovereign Bond Holdings of Italian and Spanish Banks

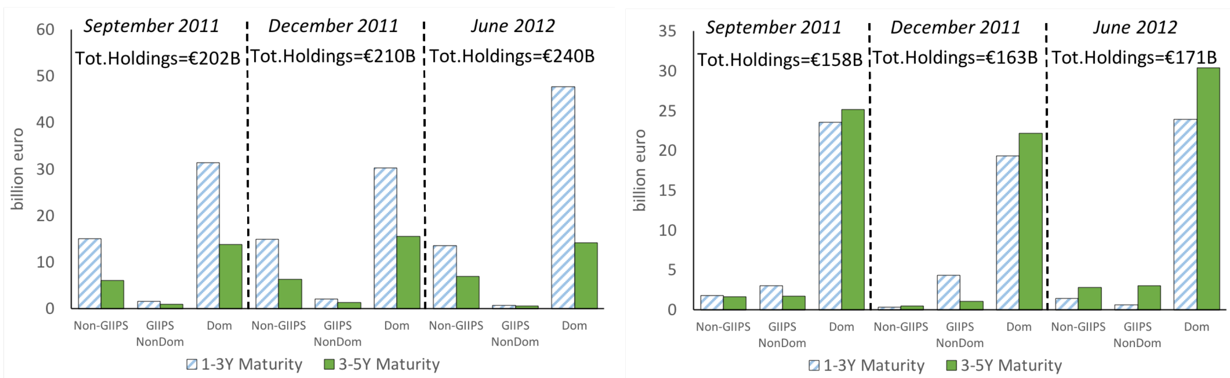

Figure 3: The Collateral Trade in Italy and Spain. This figure shows holdings of sovereign bonds of 1-3Y maturity (blue diagonal lined bars) and 3-5Y maturity (green solid bars) by Italian banks (left panel) and Spanish banks (right panel) at the time of the three EBA stress tests of September 2011, December 2011, and June 2012. Holdings are measured in billions of euro and disaggregated in holdings of GIIPS sovereign bonds and non-GIIPS sovereign bonds.

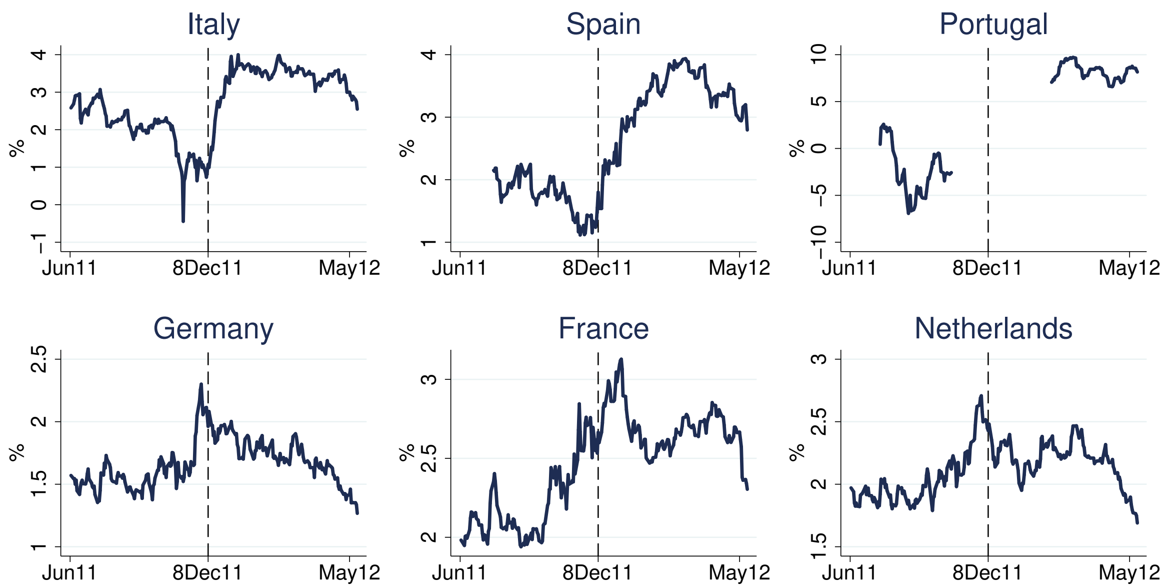

Figure 4: Slope of the Sovereign Yield Curve. This figure plots daily time series for the slope of the sovereign yield curve in three peripheral (Italy, Spain, and Portugal) and three core (Germany, France, and the Netherlands) countries. The slope is defined as the 10-year yield minus the 1-year yield. The dashed vertical line indicates the LTRO announcement. Portuguese yield data are not available from Bloomberg for parts of the sample.

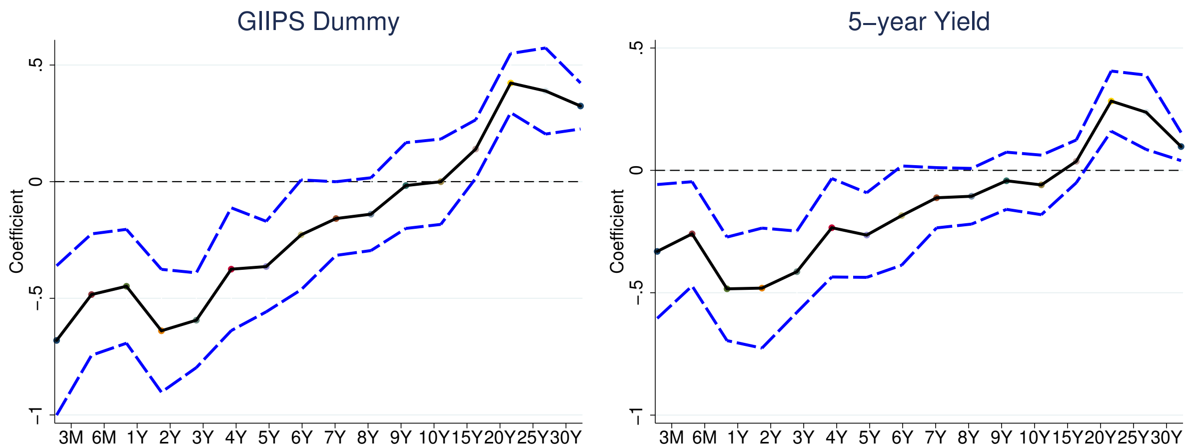

Figure 5: Yield Curve Steepening. This figure plots the $\beta_{(m)}$ estimates of specification (8) as a function of maturity (m). Regressions are estimated separately for each maturity; the sample period is daily from November 29 to December 19, 2011; and sample countries are the Netherlands, Portugal, Spain, France, Ireland, Belgium, Germany, Italy, Austria, Finland, Cyprus, Slovakia, and Slovenia. In the left panel, Risk is a dummy equal to 1 for Ireland, Italy, Spain, and Portugal. In the right panel, Risk is the log of the 5-year yield on November 28, 2011. In the supplementary material, we replicate this figure for the 1-Year LTRO allotted in October 2011. Dashed lines delimit the 99% confidence interval. Standard errors are robust. Source: Bloomberg.

Tables

LHS Var.: LTRO2	(1)	(2)	Semi-Partial R^2
ΔGovt (Face Value)	0.933***		
	(0.091)		
ΔGovt (Market Value)		1.034***	30.5%
		(0.098)	
ΔGGBB	1.196**	1.229**	3.2%
	(0.583)	(0.553)	
ΔACC	0.837***	0.838***	0.8%
	(0.031)	(0.030)	
ΔOtherMarketable	0.802***	0.801***	10.0%
	(0.036)	(0.035)	
$\text{TotalCollateral}_{\text{Nov11}}$	0.218*	0.221*	1.9%
	(0.131)	(0.125)	
Observations	68	68	
R-squared	0.960	0.962	

Table 1: Bank Buy-and-Borrow Behavior. This table presents the estimation results for specification (1). The dependent variable is the 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, government-guaranteed bank bonds (GGBB), additional credit claims (ACC), and other marketable securities. All variables are normalized by bank assets in November 2011. All measures of collateral are adjusted for the respective ECB haircuts. Column (1) measures changes in government bond holdings using face values, while column (2) uses market values. Column (3) reports the semi-partial R-squared of the independent variables in column (2). The supplementary material presents a version of this regression with additional controls. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

LHS Var.: $\widetilde{\text{Holdings}}_{i,m,t}$	(1)	(2)	(3)	(4)	(5)
Post	0.323**	0.081**			
	(0.118)	(0.032)			
Post × Short			0.245**	0.245**	0.242**
			(0.107)	(0.081)	(0.098)
Bank FE	✓	✓	✓		
Maturity FE	✓	✓	✓	✓	
Time FE			✓		
Bank-Time FE				✓	✓
Bank-Maturity FE					✓
Specification	(3a)	(3b)	(4)	(4)	(4)
Sample Bonds	Short-Term	Long-Term	Full Sample	Full Sample	Full Sample
Observations	2,478	2,478	4,956	4,956	4,950
R-Squared	0.346	0.524	0.258	0.337	0.686

Table 2: LTRO and Government Bond Purchases. This table presents the results of specifications (3a) in column (1), (3b) in column (2), and (4) in columns (3)-(5). The dependent variable is the share of total public debt outstanding of maturity m held by bank i divided by the total assets of bank i relative to the assets of the financial sector. Independent variables include a Post dummy equal to 1 on and after December 2011 and a Short dummy equal to 1 if the government bond portfolio matures on or before February 2015 (LTRO maturity). Columns (1) and (2) include only bonds maturing on or before February 2015 and after February 2015, respectively. The sample period includes 12 months and runs at a monthly frequency from June 2011 to May 2012. This regression includes only institutions with access to the LTRO (banks and savings institutions). Standard errors in parentheses are double-clustered at the bank-maturity and month levels. The supplementary material shows estimation results with standard errors double clustered at the bank and month levels. The supplementary material shows estimation results using the share of total public debt outstanding of maturity m held by bank i as a dependent variable. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

LHS Var.: $\frac{\text{Govt. Bond Holdings}_{i,m,t}}{\text{Amount Outstanding}_{m,t}}$	(1)	(2)	(3)	(4)	(5)	(6)
Post×Short×Access		0.332**	0.332**	0.327**	0.327**	0.104**
		(0.149)	(0.129)	(0.140)	(0.139)	(0.042)
Post×Short	-0.003	-0.003***	-0.003***	-0.003		
	(0.002)	(0.000)	(0.000)	(0.002)		
Short×Access		0.188**	0.188**			
		(0.078)	(0.069)			
Post×Access		0.044***				
		(0.004)				
Entity FE		✓				
Time FE		✓				
Maturity FE		✓	✓			
Entity-Time FE	✓		✓	✓	✓	✓
Entity-Maturity FE	✓			✓	✓	✓
Maturity-Time FE					✓	✓
Specification	(4)	(6)	(6)	(6)	(6)	(6)
Sample Institutions	Non-Banks	Full	Full	Full	Full	Full
Sample Bonds	Full	Full	Full	Full	Full	1-5Y
Observations	27,372	32,376	32,376	32,322	32,322	10,774
R-squared	0.944	0.300	0.386	0.698	0.700	0.964

Table 3: Access to ECB Liquidity and Government Bond Purchases. Column (1) of this table replicates specification (4) for the subsample of non-banks. Columns (2)-(5) present the results of specification (6), estimated in the full sample of banks and non-banks. Column (6) presents the results of specification (6), estimated in the subsample of bonds with residual maturity of 1-5 years. The dependent variable is the share of total public debt outstanding of maturity m held by institution i, not normalized by assets. Independent variables include a Post_t dummy equal to 1 on and after December 2011, a Short_m dummy equal to 1 if the government bond portfolio matures on or before February 2015 (LTRO maturity), and a Access_i dummy equal to 1 for institutions that have access to ECB liquidity (banks). The sample period runs monthly from June 2011 to May 2012. Standard errors in parentheses are double-clustered at the bank-maturity and month levels. * p<0.10, ** p<0.05, *** p<0.01.

LHS Var.: $\widetilde{\text{Holdings}}_{i,m,t}$	(1)	(2)	(3)	(4)	(5)	(6)
Post × Intensity	0.086***	0.019***				
	(0.017)	(0.004)				
Post × Short × Intensity			0.067***	0.067***	0.067***	0.067***
			(0.012)	(0.011)	(0.014)	(0.015)
Bank FE	✓	✓	✓			
Time FE	✓	✓	✓			
Maturity FE	✓	✓	✓	✓		
Bank-Time FE				✓	✓	✓
Bank-Maturity FE					✓	✓
Time-Maturity FE						✓
Specification	(7a)	(7b)	(7c)	(7c)	(7c)	(7c)
Sample Bonds	Short-Term	Long-Term	Full	Full	Full	Full
Observations	2,466	2,466	4,932	4,932	4,932	4,932
R-squared	0.409	0.548	0.361	0.401	0.702	0.707

Table 4: LTRO and Government Bond Purchases: Intensive Margin. This table presents the results of specifications (7a), (7b), and (7c). The dependent variable is the share of total public debt outstanding of maturity m held by bank i divided by the total assets of bank i relative to the assets of the financial sector. Columns (1) and (2) include only bonds maturing on or before February 2015 and after February 2015, respectively. Columns (3)-(6) include all bonds. This regression includes only entities with access to LTRO, i.e., banks. Independent variables include a Post_t dummy equal to 1 on and after December 2011, a Short_m dummy equal to 1 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 November 2011. The sample is monthly from June 2011 to May 2012. Standard errors in parentheses are double-clustered at the bank and month levels. The supplementary material shows estimation results with standard errors double-clustered at the bank-maturity and month levels. * p<0.10, ** p<0.05, *** p<0.01.

	Nov11 €M	Mar12 €M	Change €M	Change % Assets
Total Assets	571,235	580,021	8,786	1.5
Cash	1,603	1,496	-107	0.0
Securities	139,879	150,715	10,836	1.9
Equities	24,930	26,823	1,894	0.3
Total Private Credit	292,830	285,194	-7,636	-1.3
Lending to Firms	121,363	115,492	-5,871	-1.0
Lending to Households	143,149	141,937	-1,212	-0.2
Lending to Banks	69,778	75,174	5,396	0.9
Other Assets	42,216	40,619	-1,596	-0.3
Total Liabilities	571,235	580,021	8,786	1.5
Equity	42,045	43,717	1,672	0.3
Securities Issued	90,809	94,947	4,138	0.7
ECB Total	45,724	56,450	10,727	1.9
Borrowing from Banks	164,448	156,781	-7,667	-1.3
Deposits	195,481	197,118	1,637	0.3
Repo	7,760	6,045	-1,715	-0.3
Other Liabilities	24,968	24,964	-5	0.0

Table 5: Banking Sector Aggregate Balance Sheet. This table shows the aggregate banking sector balance sheet in November 2011 and March 2012. Quantities are in millions of euros. The last column displays the change as a % of assets in November 2011.

Supplementary Material

In this appendix, we present a model of the collateral trade (section A); develop an additional simple model of the collateral trade taking into account that the central bank may trigger margin calls (section B); illustrate the dataset construction (section C); illustrate the ECB collateral framework (section D); present additional figures (section E); and present additional tables (section F).

A Model of the Collateral Trade

In this section, we develop a stylized model of the collateral trade. We first characterize the equilibrium in the absence of an LOLR, and then introduce a facility that can be used by banks to purchase sovereign debt at different maturities. We show that the model is able to generate the empirical predictions that we test, in the context of an optimizing agents, partial equilibrium framework.

Model Setup The economy lasts for two periods, $t = 0, 1$, and is populated by a continuum of domestic banks, international investors, and a government. At the beginning of $t = 0$, banks can borrow from the ECB and invest in short- and long-term bonds. short-term bonds and ECB borrowing both mature at $t = 1$, while long-term bonds do not.

International investors have downward sloping demand curves for short- and long-term bonds at $t = 0$. At $t = 1$, they have a stochastic valuation for long-term bonds, which determines their price.

Banks are risk-neutral and care about their profits at $t = 1$, which are given by the value of long-term debt $q_L^1 b_L$ (where b_L are units and q_L^1 is the stochastic price), the value of maturing short-term b_S, and the value of LTRO repayments $R€$, where € is the amount borrowed from the ECB and R is the ECB interest rate. We introduce the following liquidity constraint in the bank's problem: we assume that the revenues from sovereign bond trading must be sufficient to cover ECB repayments; otherwise, the bank needs to access international funding markets, which is costly. We assume that the bank pays a cost $\kappa > 1$ per unit borrowed in these funding markets. Expected profits at $t = 1$ are therefore given by

$$\mathbb{E}\pi_1 = \mathbb{E}\left\{q_L^1 b_L + b_S - R€ + \kappa \min[0, q_L^1 b_L + b_S - R€]\right\} \tag{1}$$

Banks face a budget constraint at $t = 0$, stating that the value of purchased debt cannot exceed available resources ω plus ECB borrowing,

$$q_S b_S + q_L b_L \leq \omega + € \tag{2}$$

We assume that government bonds are in fixed supply at $t = 0$, given by B_S, B_L. At $t = 0$, international investors have demand curves of the type

$$b_i^* = \beta_i + \frac{\alpha_i}{q_i}, i = \{L, S\}$$

At $t = 1$, we assume that these investors have a random valuation for long-term debt, given by $q_L^1 \sim F[\underline{q}, \bar{q}]$, that generates a perfectly elastic demand, pinning down the price. We also assume that $\beta_i < B_i, i = \{L, S\}$.

Banks choose $(b_S, b_L, €)$ to maximize 1 subject to 2. We make two simplifying assumptions:

1. Accessing international funding markets is prohibitively costly, $\kappa \to \infty$.

2. The lower bound of the support for international investors' valuation is zero, $\underline{q} = 0$.

The first assumption is equivalent to assuming a form of infinite risk-aversion for the bank, and it effectively imposes that the bank avoids having a shortfall between bond portfolio revenues and ECB repayments in any state of the world, in particular for the worst possible realization of q_L^1,

$$\underline{q} b_L + b_S - R€ \geq 0 \tag{3}$$

The second assumption is not essential for our results, but it greatly simplifies the algebra. It implies that the liquidity constraint takes the following form

$$b_S - R€ \geq 0$$

Bank Portfolio Problem Let $\mu = \mathbb{E} q_L^1$. We can then write the bank's Lagrangian as

$$\mathcal{L} = \mu b_L + b_S - R€ + \lambda[\omega + € - q_L b_L - q_S b_S] + \eta[b_S - R€]$$

The bank's first-order conditions are

$$b_L : \mu - \lambda q_L = 0$$

$$b_S : 1 - \lambda q_S + \eta = 0$$

$$€ : -R + \lambda - \eta R = 0$$

And the market-clearing conditions are

$$b_i + b_i^* = B_i, i = \{L, S\}$$

Case 1: No LTRO Let us assume first that there is no LTRO facility, so that $€ = \eta = 0$. Define $\mathcal{B} = B_S + \mu B_L$ as the stock of "discounted" government debt. Then, we can show that the equilibrium is as follows:

$$\begin{aligned}
q_S &= \frac{\omega + \alpha_S + \alpha_L}{\mathcal{B} - \beta_S - \mu\beta_L} \\
q_L &= \mu\frac{\omega + \alpha_S + \alpha_L}{\mathcal{B} - \beta_S - \mu\beta_L} \\
b_S &= \frac{(\omega + \alpha_L)(B_S - \beta_S) - \alpha_S\mu(B_L - \beta_L)}{\omega + \alpha_S + \alpha_L} \\
b_L &= \frac{(\omega + \alpha_S)\mu(B_L - \beta_L) - \alpha_L(B_S - \beta_S)}{\mu(\omega + \alpha_S + \alpha_L)}
\end{aligned}$$

We can show that the slope of the yield curve is given by

$$\begin{aligned}
\text{slope} &= \frac{1}{q_L} - \frac{1}{q_S} \\
&= \frac{\mathcal{B} - \beta_S - \mu\beta_L}{\omega + \alpha_S + \alpha_L}\left(\frac{1}{\mu} - 1\right)
\end{aligned}$$

Case 2: LTRO, Liquidity Constraint Binding Let us now assume that the ECB introduces the LTRO facility and that banks borrow enough such that their liquidity constraint binds. This implies that $\eta > 0$. We can then characterize the equilibrium as

$$
\begin{aligned}
q_S &= \frac{1}{R} \\
q_L &= \frac{\omega + \alpha_L}{B_L - \beta_L} \\
b_S &= B_S - \beta_S - \alpha_S R \\
b_L &= \frac{\omega}{\omega + \alpha_L}(B_L - \beta_L) \\
€ &= \frac{B_S - \beta_S}{R} - \alpha_S \\
\eta &= \frac{\mu(B_L - \beta_L)}{R(\omega + \alpha_L)} - 1
\end{aligned}
$$

And we can show that the slope is given by

$$\text{slope} = \frac{B_L - \beta_L}{\omega + \alpha_L} - R$$

Finally, a sufficient condition for the liquidty constraint to bind is to have

$$\mu \frac{B_L - \beta_L}{\omega + \alpha_L} > R$$

Testable Predictions

Recall that the main predictions that we test empirically are the following:

1. Banks buy high-yield government bonds to borrow at the LOLR.

2. The LOLR causes purchases of high-yield short-term government bonds.

3. The sovereign yield curve steepens.

While Prediction 1 is borne by design, we can show that the LTRO equilibrium generates Predictions 2 and 3.

Prediction 2 To check this prediction, we compare the equilibrium b_S under the LTRO to the equilibrium b_S in the absence of the LTRO:

$$\begin{aligned}\Delta(b_S) &= b_S^{\text{LTRO}} - b_S^{\text{no LTRO}} \\ &= B_S - \beta_S - \alpha_S R - \frac{(\omega + \alpha_L)(B_S - \beta_S) - \alpha_S \mu (B_L - \beta_L)}{\omega + \alpha_S + \alpha_L} \\ &= \alpha_S \left(\frac{\mathcal{B} - \beta_S - \mu \beta_L}{\omega + \alpha_S + \alpha_L} - R \right)\end{aligned}$$

A sufficient condition to have $\Delta(b_S) > 0$ is

$$\mu \frac{B_L - \beta_L}{\omega + \alpha_L + \alpha_S} > R$$

and recall that the sufficient condition for the liquidity constraint to bind was $\mu \frac{B_L - \beta_L}{\omega + \alpha_L} > R$. Therefore, as long as the liquidity constraint is binding, and α_S is small enough,[1] the introduction of the LTRO yields $\Delta(b_S) > 0$ — that is, domestic banks purchase more short-term bonds when the LTRO facility is introduced, at a sufficiently low interest rate. We can

[1] In particular, we need $\alpha_S \leq \frac{\omega + \alpha_L}{R} \left[\mu \frac{B_L - \beta_L}{\omega + \alpha_L} - R \right]$.

also see what happens to the demand for long-term bonds:

$$\begin{aligned}\Delta(b_L) &= b_L^{\text{LTRO}} - b_L^{\text{no LTRO}} \\ &= \frac{\omega}{\omega+\alpha_L}(B_L-\beta_L) - \frac{(\omega+\alpha_S)\mu(B_L-\beta_L)-\alpha_L(B_S-\beta_S)}{\mu(\omega+\alpha_S+\alpha_L)} \\ &= \frac{\alpha_L}{\omega+\alpha_S+\alpha_L}\left[\frac{1}{\mu}(B_S-\beta_S) - \frac{\alpha_S}{\alpha_L+\omega}(B_L-\beta_L)\right] \\ &\equiv \Phi\end{aligned}$$

This condition cannot be unambiguously signed. For different model parametrizations, demand for long-term bonds can either rise or fall with the introduction of the LTRO.

Prediction 3 The introduction of the LTRO generates a steepening of the yield curve if and only if

$$\begin{aligned}\Delta(\text{slope}) &= \text{slope}^{\text{LTRO}} - \text{slope}^{\text{no LTRO}} \\ &= \frac{B_L-\beta_L}{\omega+\alpha_L} - R - \frac{\mathcal{B}-\beta_S-\mu\beta_L}{\omega+\alpha_S+\alpha_L}\left(\frac{1}{\mu}-1\right) \\ &= \frac{(B_L-\beta_L)\left(\mu+\frac{\alpha_S}{\omega+\alpha_L}\right)-(B_S-\beta_S)\left(\frac{1}{\mu}-1\right)}{\omega+\alpha_S+\alpha_L} - R \\ &= \frac{\mathcal{B}-\frac{\Phi}{\alpha_L}}{\omega+\alpha_S+\alpha_L} - R\end{aligned}$$

It is easy to show that this expression is positive for low enough R and as long as $\mu > \underline{\mu}$ is bounded below. Note also that this condition is more likely to hold when the following occur:

1. Available bank resources ω are lower.

2. The ratio of long-term to short-term government debt (net of foreign demand) $\frac{B_L - \beta_L}{B_S - \beta_S}$ is higher.

Both were arguably true for the case of the Portuguese banking system and maturity structure of sovereign debt around the time of the introduction of the LTRO.

Additionally, notice that a fall in the demand for long-term bonds caused by the introduction of the LTRO, $\Phi < 0$, is *sufficient, but not necessary* for a steepening of the yield curve.

Finally, note that an alternative way to model the LTRO is as a fall in the cost of borrowing at maturities that match those of short-term government bonds, $R \downarrow$. Notice that, as long as banks are liquidity constrained, a fall in R triggers a steepening of the yield curve.

B Model of Margin Calls and the Collateral Trade

Consider a risk-neutral investor that lives for three periods, $t = 0, 1, 2$, and can choose at $t = 0$ to undertake a leveraged investment on either a short-term bond maturing at $t = 1$, a medium-term bond maturing at $t = 2$, or a long-term bond that does not mature in the investor's lifetime. The investor can partially finance this investment with a collateralized loan that matures at $t = 2$. If the value of the collateral falls (or the collateral matures) before the loan is due, the investor is subject to a margin call and needs to raise sufficient liquidity to compensate the lender for this shortfall. We assume that raising liquidity is costly: each unit of liquidity raised at $t = 1$ costs r at $t = 2$.

The bonds are priced by deep-pocketed, risk-neutral investors with discount factor $\eta < 1$. This means that the price of a bond with maturity s is η^s at $t = 0$. At each subsequent period $t = 1, 2$, with probability α, these investors may receive a preference shock that lowers their discount factor permanently by a factor of $\rho^- < \eta$ or raises their discount factor permanently by a factor of $\rho^+ > \eta$. Thus the price of a bond with maturity s at $t = 1$ becomes $(\rho^x \eta)^s$ after shock $x \in \{-, +\}$. This revaluation may trigger a margin call for longer-maturity bonds. We assume that $\alpha\rho^- + (1 - \alpha)\rho^+ < 1$ so that the yield curve is always upward sloping (longer-term bonds are cheaper). This means that the frictionless yields for each of the bonds are

$$
\begin{aligned}
y_S &= \frac{1}{\eta} \\
y_M &= \frac{1}{\eta^2} \\
y_L &= \frac{\alpha\rho^- + (1 - \alpha)\rho^+}{\eta^2}
\end{aligned}
$$

Let us analyze separately the payoffs of investing in a short-, medium- and long-term bond. Let $h \in (0,1)$ denote the haircut on collateral and R the interest rate on the LTRO loan. Since we want to focus on the relative preference for different maturities, and not on the desirability of the carry trade *per se*, we assume that $\eta < 1 + R$ so that an unconstrained carry trade is always profitable at any maturity. We assume that there is storage with return unity.[2]

A short-term bond costs η at $t = 0$ and is completely riskless, yielding 1 at $t = 1$. The bank invests by borrowing $h\eta$. Since the collateral matures before the loan, the bank is requested to deposit $h\eta$ at $t = 1$. Since $1 > h\eta$, this margin call is inconsequential and the bank does not need to raise any external liquidity. It receives the margin call deposit at $t = 2$ and repays the loan plus interest. The total profit from this trade is

$$\pi_S = -\eta + h\eta + (1 - h\eta) + [h\eta - (1 + R)h\eta] = 1 - \eta - Rh\eta$$

Given the bank's initial capital, $k < \eta^3$, it can purchase a quantity equal to $\frac{k}{(1-h)\eta}$, and so the profit of this trade is equal to

$$\pi_S = \frac{k}{1-h}\left[\frac{1}{\eta} - 1 - Rh\right]$$

Similarly, we can show that the profits for investing in medium- and long-term bonds are

[2] Basically, the investor can save for a net return of zero and borrow for a net cost of r.

given by

$$\pi_M = \frac{k}{1-h}\left[\frac{1+\alpha r h \rho^- \eta}{\eta^2} - 1 - Rh - \alpha r h\right]$$
$$\pi_L = \frac{k}{1-h}\left[\frac{\alpha\rho^-\eta + (1-\alpha)\rho^+\eta + \alpha r h(\rho^-)^2\eta^2}{\eta^3} - 1 - Rh - \alpha r h\right]$$

We can show that $\pi_L \leq \pi_M$ if

$$\alpha r h \rho^- \eta(1-\rho^-\eta) \geq \alpha\rho^- + (1-\alpha)\rho^+ - 1$$

So that, if the probability of a downwards revaluation (and the magnitude of that revaluation) is high enough, and exceeds the return benefits of investing in a long-term bond, the investor may prefer to invest in a medium-term bond. We can derive similar conditions, under which $\pi_L \leq \pi_S$. They are mainly related to liquidity risk: the short-term investment exposes the bank to no type of liquidity risk whatsoever. The medium-term bond exposes the bank to margin call risk, with probability α. The long-term bond exposes the bank to both margin call *and* funding liquidity risk at the final period, since the bond's payoff (its price on the secondary market) may be uncertain. Since there is no discounting, the unconstrained, risk-neutral investor would simply prefer the bond that offers the ex-ante higher return, which is the long-term bond by assumption. Due to liquidity risk, emanating both from margin calls and uncertain prices at loan maturity, the investor may prefer to invest in shorter-term bonds.[3]

[3] Our analysis is robust to adding an additional period, so that the investor would obtain a certain payoff

C Dataset Construction

Our final dataset is the merger of two proprietary datasets.

1. Monetary and Financial Statistics (MFS), a proprietary dataset from the BdP that includes monthly balance sheet data for all monetary and financial institutions regulated by the BdP. We have data on book values, disaggregated by type of asset/liability, type of counterparty, geographical location of the counterparty, and, for some assets and liabilities, maturity.[4] Monetary and financial institutions are divided in three categories: banks, savings institutions, and money market mutual funds. Most of the institutions are banks; savings institutions is an obsolescent category that applies only to agricultural credit cooperatives. Money market funds are small given the undeveloped nature of the Portuguese market for money funds. More specifically, the different dimensions for which data are available are: (i) asset category: banknotes and coins, loans and equivalent (with repricing dates up to 1 year, 1 to 5 years, more than 5 years), securities except equity holdings (up to 1 year, 1 to 2 years, more than 2 years), equity holdings, physical assets, and other assets (of which derivatives); (ii) counterparty's geographical area: Portugal, Germany, Austria, Belgium, Cyprus, Slovenia, Spain, Es-

from the long-term bond. This would, however, still entail funding risk at loan maturity, since the investor would need to either sell the bond (as in our setup) or raise costly external funds to repay the loan.

[4]Maturity, as classified by the MFS, refers to next residual repricing maturity, or time left until the next repricing date. Lending, for example, is disaggregated as lending with maturity less than 1 year, between 1 and 5 years, and more than 5 years. This measure of maturity does not coincide with contractual residual maturity if the contract is repriced at a frequency lower than its contractual maturity. Due to the institutional characteristics of the Portuguese financial markets, most long-term loans such as mortgages are floating rate loans, indexed to some reference rate such as the Euribor. This means that they are classified as short-term loans in our dataset.

tonia, Finland, France, Greece, the Netherlands, Ireland, Italy, Latvia, Luxembourg, Malta, Slovakia, the European Monetary Union excluding Portugal, non-EMU countries, and the ECB; and (iii) the counterparty's institutional sector: monetary and financial institutions, social security administration, local government, regional government, insurance and pension funds, private individuals, central government, other financial intermediaries, non-financial firms, and other sectors. For the other side of the balance sheet, the counterparty classification is the same, and the liability categories are demand deposits, deposits redeemable at notice (less than 90 days, more than 90 days), other deposit equivalents (less than 1 year, 1 to 5 years, more than 5 years), repurchase agreements, securities (up to 1 year, more than 1 year), other liabilities, and capital and reserves. Crosignani et al. (2015) describes this dataset in more detail and analyzes the evolution of the balance sheets for the Portuguese monetary financial sector during the full sample period.

2. *Sistema Integrado de Estatísticas de Títulos* (SIET), another proprietary dataset from the BdP, which contains monthly information on quantity (face value), book value, and market value for all ISINs that refer to debt instruments issued by the Portuguese central government and a few public companies, and that are owned by financial institutions domiciled in Portugal. This dataset corresponds to the universe of financial institutions in Portugal, conditional on them owning any of these securities. It includes several types of institutions, including monetary and financial institutions, mutual funds, hedge funds, pension funds, and brokerage companies.

For the MFS dataset, we keep the following information for each bank, in each period:

assets, cash and equivalents, lending, lending to households, lending to non-financial firms, holdings of non-equity securities, holdings of government debt, holdings of Portuguese government debt, holdings of GIIPS government debt, holdings of equity securities, and other assets. For the other side of the balance sheet: equity and reserves, demand deposits, savings deposits, time deposits, repo, securities, other liabilities, short-term (less than 1 year) borrowing from the central bank, medium-term (1-2 years) borrowing from the central bank, and long-term (more than 2 years) borrowing from the central bank.

For the SIET dataset, we keep its original structure, a three-dimensional panel (j, i, t), where j is an ISIN, owned by institution i at time t. For each observation, the SIET gives us quantity (face value), market value, and book value. The latter is only available for certain institutions, but we use it only for consistency purposes.

Note that while the datasets intersect, neither is contained in each other: the MFS includes monetary financial institutions that may not own any Portuguese sovereign debt securities and thus are excluded from the SIET dataset, while the SIET dataset includes other types of institutions that are not included in the MFS dataset, such as pension funds.

References

Crosignani, M., M. Faria-e-Castro, and L. Fonseca (2015): "The Portuguese Banking System during the Sovereign Debt Crisis," *Banco de Portugal Economic Studies*, 1, 43–80.

D ECB Collateral Framework and the LTRO

Eligible collateral at the ECB falls in two broad asset classes: marketable assets and non-marketable assets. The first comprises debt instruments such as unsecured bonds, asset-backed securities, and covered bank bonds. The second class includes fixed-term deposits from eligible monetary policy counterparties, credit claims (bank loans), and non-marketable retail mortgage-backed debt instruments. The LTRO period was characterized by an expansion of the eligible collateral. On the day of the announcement of the operations, the ECB also announced collateral availability by allowing riskier asset-backed securities and allowing national central banks (NCBs) to temporarily allow additional credit claims that satisfy their specific criteria, as long as the risks of this acceptance were assumed by the given NCB.

On February 9, 20 days before the second allotment, BdP detailed the criteria for Portugal regarding these additional credit claims. Portfolios of mortgage-backed loans and other loans to households, as well as of loans to non-financial corporations, became increasingly pledgeable as collateral. The expansion of these rules also suggests banks were collateral scarce at the time of the first allotment. Although we do not have asset-level data on the holdings of these classes of assets by banks, we rely on aggregate measures of pledged collateral for each bank. These measures include non-marketable assets whose risk was borne by the Eurosystem, additional credit claims (ACCs), government guaranteed bank bonds (GG-BBs) issued from a government fund expanded around the time of the troika intervention in mid-2011, and other marketable assets.

E Additional Figures

Figure E.1: Holdings of Domestic Government Debt, Normalized by Assets. This figure plots the evolution of domestic government bonds held by banks, divided by total assets, from June 2011 to June 2012. The two vertical dashed lines delimit the LTRO allotment period.

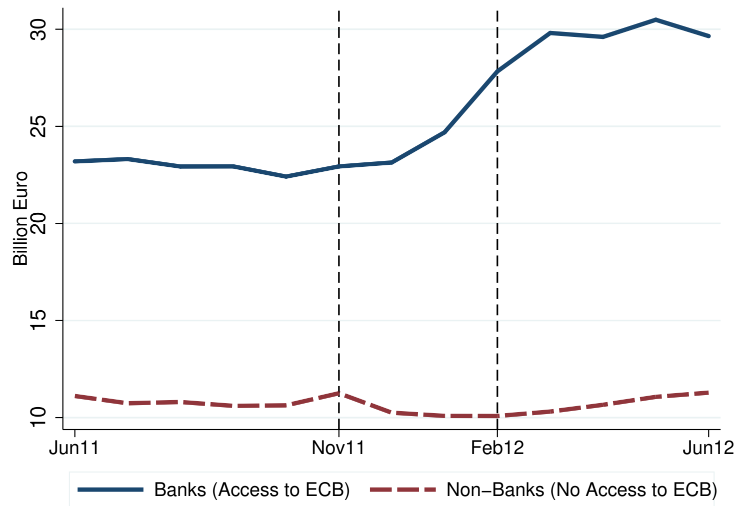

Figure E.2: Holdings of Domestic Government Debt. This figure plots the evolution of domestic government bonds held by banks (solid line) and non-banks (horizontal dashed line) from June 2011 to June 2012. Quantity is measured as the face value in billions of euro. We cannot normalize quantities in the figure by total assets, as we do not observe assets of non-banks. The two vertical dashed lines delimit the allotment period.

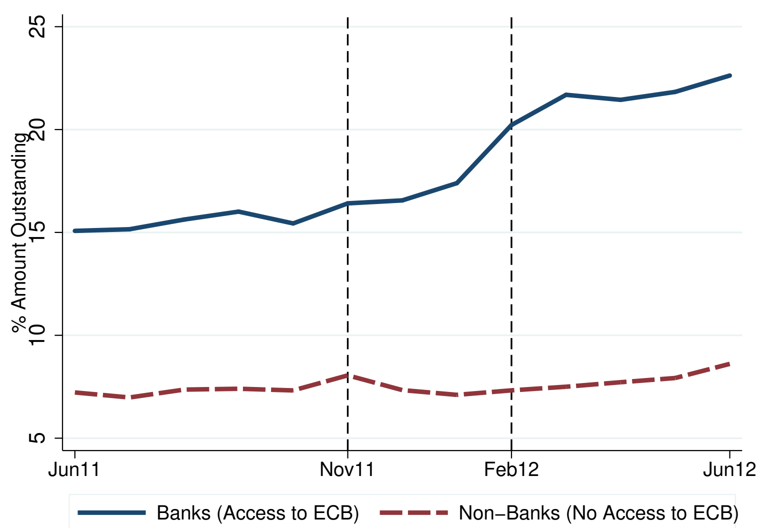

Figure E.3: Holdings of Domestic Government Debt, Normalized by Amount Outstanding. This figure plots the evolution of domestic government bonds held by banks (solid line) and non-banks (dashed line) from June 2011 to June 2012, normalized by the stock of public debt outstanding. The two vertical dashed lines delimit the LTRO allotment period.

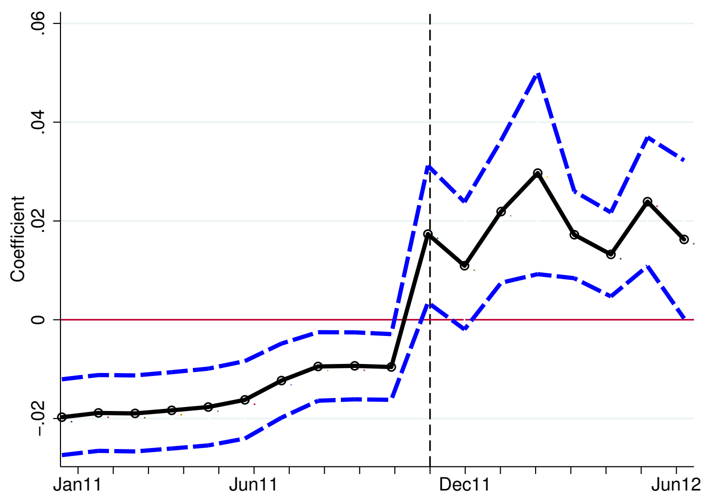

Figure E.4: Placebo Test, Intensive Margin. This figure plots interaction coefficients from a modified version of specification (4), where the interaction term is further multiplied by *Intensity*. The sample period is from January 2011 to June 2012. The horizontal dashed lines delimit the 95% confidence interval. Standard errors are double clustered at the bank-maturity and month levels. The dashed vertical line indicates the last date before the LTRO announcement.

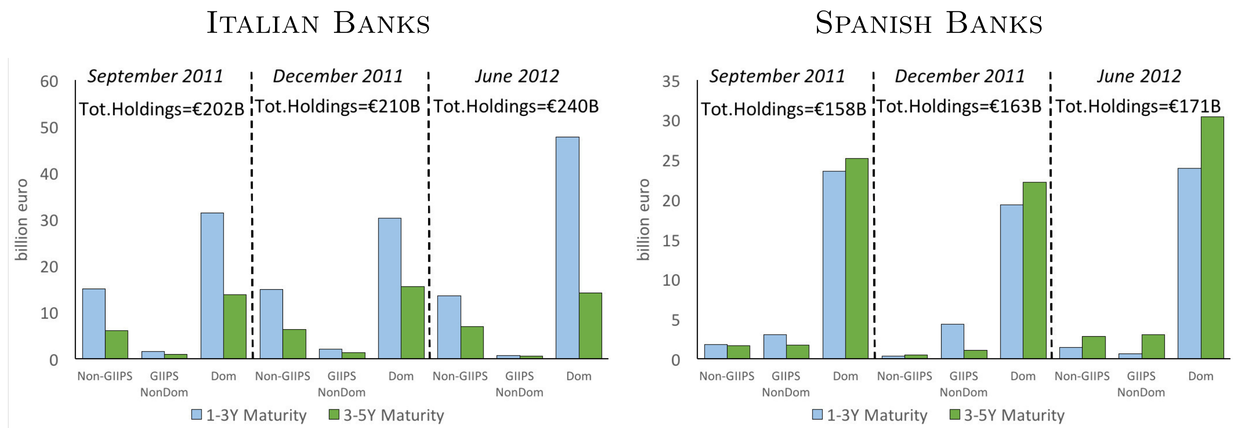

Figure E.5: The Collateral Trade in Italy and Spain: Non-GIIPS, GIIPS Non-Domestic, and Domestic Holdings. This figure shows holdings of sovereign bonds of 1-3Y maturity (blue bars) and 3-5Y maturity (green bars) by Italian banks (left panel) and Spanish banks (right panel) at the time of the three stress tests of September 2011, December 2011, and June 2012. Holdings are in billions of euro and disaggregated into holdings of non-GIIPS, GIIPS non-domestic, and domestic sovereign bonds.

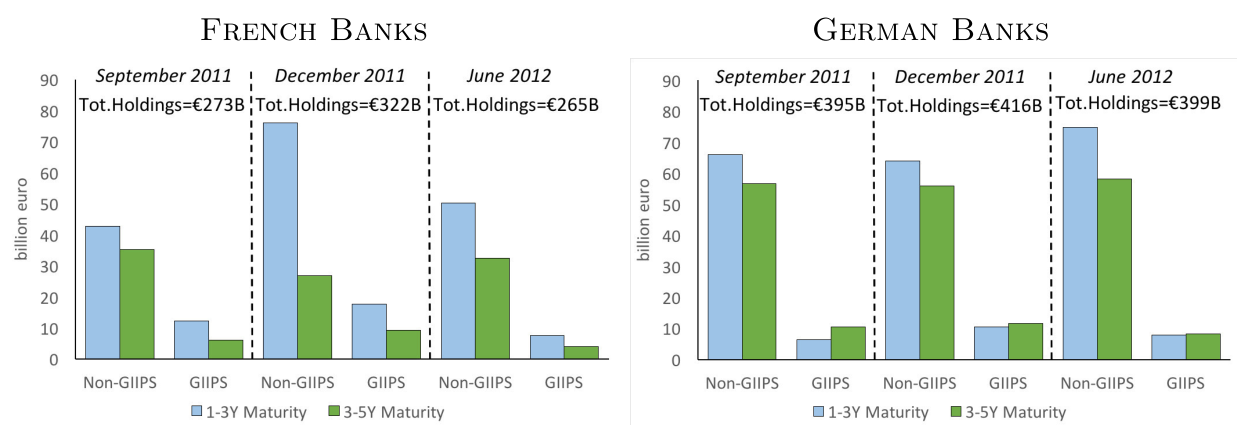

Figure E.6: The Collateral Trade in France and Germany. This figure shows holdings of sovereign bonds of 1-3Y maturity (blue bars) and 3-5Y maturity (green bars) by French banks (left panel) and German banks (right panel) at the time of the three stress tests of September 2011, December 2011, and June 2012. Holdings are measured in billions of euro and disaggregated into holdings of GIIPS and non-GIIPS sovereign bonds.

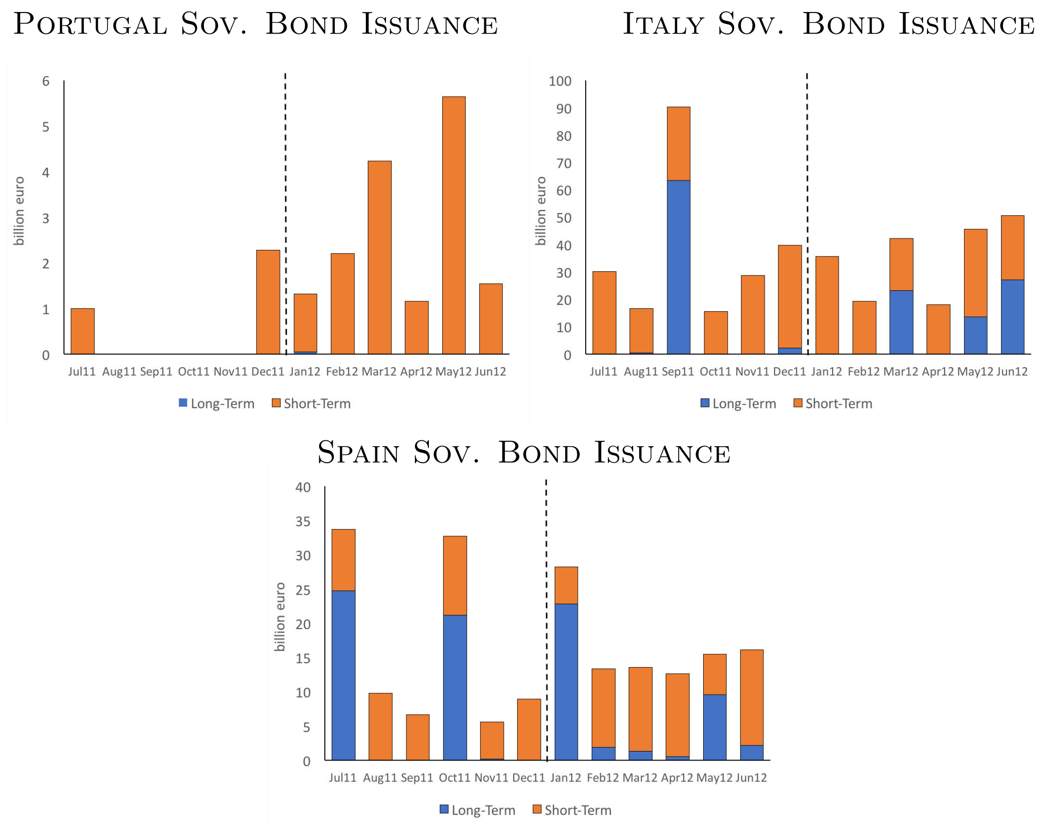

Figure E.7: Public Debt Issuance. This figure shows monthly public debt issuance (billions of euro) in Portugal, Italy, and Spain. The blue (orange) bars correspond to issuance maturing after (before) the LTRO. The vertical dashed line is the LTRO announcement. Source: Bloomberg.

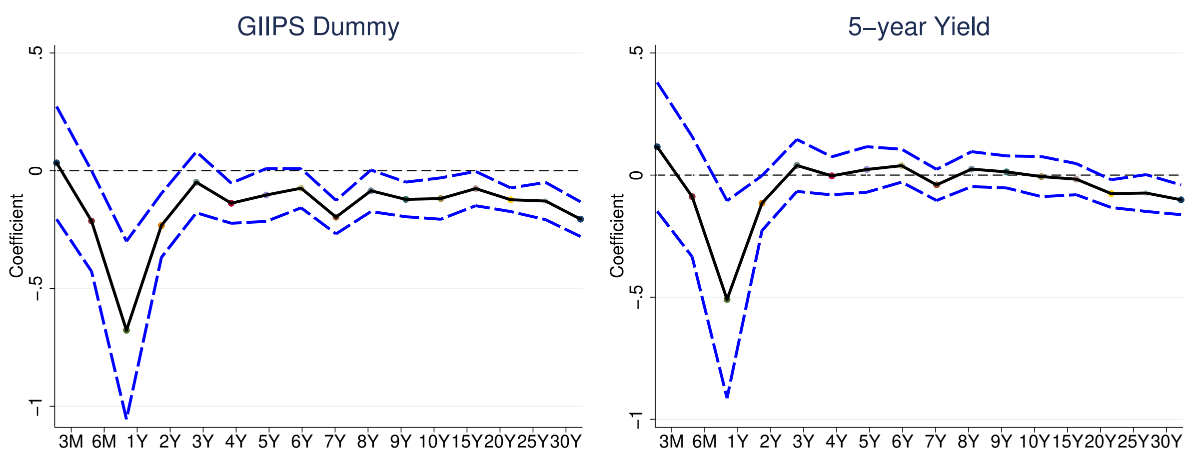

Figure E.8: Yield Curve Steepening, October 2011 1-Year LTRO. This figure plots the $\beta_{(m)}$ estimates of specification (7) as a function of maturity (m). Regressions are estimated separately for each maturity; the sample period is daily from September 27 to October 17, 2011 (the announcement date is October 6); and sample countries are the Netherlands, Portugal, Spain, France, Ireland, Belgium, Germany, Italy, Austria, Finland, Cyprus, Slovakia, and Slovenia. In the left panel, Risk is a dummy equal to 1 for Ireland, Italy, Spain, and Portugal. In the right panel, Risk is the log of the 5-year yield on September 26, 2011. Dashed lines delimit the 99% confidence interval. Standard errors are robust. Source: Bloomberg.

F Additional Tables

	3mo	6mo	1Y	2Y	3Y	5Y	10Y	15Y	30Y
Peripheral Countries									
Italy	0.65	1.47	2.00	3.06	3.72	4.33	5.26	5.47	5.56
Spain	0.27	0.87	1.33	2.08	2.39	3.11	4.24	4.86	5.00
Portugal	2.90	3.53	N/A	12.85	15.32	14.76	11.91	12.52	8.94
Ireland	N/A	N/A	N/A	4.86	N/A	5.39	N/A	6.46	N/A
Greece	N/A	N/A	408.52	N/A	N/A	48.69	30.74	26.58	N/A
Core Countries									
Germany	-1.04	-1.01	-0.94	-0.79	-0.63	-0.15	0.90	1.42	1.48
France	-0.90	N/A	-0.65	-0.25	0.07	0.87	2.07	2.48	2.71
Austria	N/A	N/A	N/A	-0.16	0.16	1.13	2.01	2.40	N/A
Finland	N/A	N/A	-0.95	-0.68	-0.44	0.10	1.34	1.72	N/A
Netherlands	N/A	-1.00	N/A	-0.72	-0.32	N/A	1.27	1.41	1.58

Table F.1: Collateral Trade Spreads. This table shows collateral trade spreads (%) for govenment bonds of each country at different maturities. The collateral trade spread is calculated as the difference between the average daily government bond yields (from December 8, 2011, to February 28, 2012) and the LTRO rate. We use 1% as the LTRO rate, as the rate for main refinancing operations at the time of the policy announcement was 1% and the LTRO rate was fixed as the average rate of the main refinancing operations over the life of the respective operation. N/As correspond to missing data in Bloomberg. Source: Bloomberg.

LHS Var.: LTRO2	(1)	(2)	(3)	(4)	(5)
ΔGovt (Face Value)		1.089***		0.933***	
		(0.010)		(0.091)	
ΔGovt (Market Value)			1.207***		1.034***
			(0.009)		(0.098)
ΔGGBB	1.575***	2.012***	2.060***	1.196**	1.229**
	(0.300)	(0.260)	(0.200)	(0.583)	(0.553)
ΔACC	0.935***	0.800***	0.800***	0.837***	0.838***
	(0.320)	(0.038)	(0.037)	(0.031)	(0.030)
ΔOtherMarketable	1.062**	0.793***	0.792***	0.802***	0.801***
	(0.441)	(0.047)	(0.046)	(0.036)	(0.035)
Total $\text{Collateral}_{\text{Nov11}}$				0.218*	0.221*
				(0.131)	(0.125)
Observations	68	68	68	68	68
R-squared	0.187	0.941	0.943	0.960	0.962

Table F.2: Banks' Buy-and-Borrow Behavior, Robustness. This table presents the estimation results for versions of specification (1). Columns (4) and (5) correspond to Columns (1) and (2) of Table 1 in the main text. 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, government guaranteed bank bonds (GGBB), additional credit claims (ACC), and other marketable securities. All variables are normalized by bank assets in November 2011. All independent variables are haircut-adjusted. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

LHS Var.: LTRO2	(1)	(2)	(3)	(4)	(5)
Δ Govt (Face Value)		0.822***		0.738***	
		(0.174)		(0.219)	
Δ Govt (Market Value)			1.013***		0.948***
			(0.207)		(0.184)
Δ GGBB	2.662**	2.698**	2.763**	1.715**	1.762**
	(1.126)	(1.157)	(1.139)	(0.694)	(0.666)
Δ ACC	0.859***	0.820***	0.815***	0.864***	0.859***
	(0.049)	(0.051)	(0.051)	(0.049)	(0.049)
Δ Other Marketable	0.793***	0.790***	0.790***	0.813***	0.813***
	(0.048)	(0.052)	(0.052)	(0.049)	(0.050)
Total $\text{Collateral}_{\text{Nov11}}$				0.250*	0.254*
				(0.139)	(0.133)
Δ Cash	-0.625	0.522	0.405	2.485	2.451
	(5.441)	(2.910)	(2.943)	(2.845)	(2.747)
Δ Non-Govt Bonds	-0.931***	-0.234*	-0.155	-0.135	-0.031
	(0.053)	(0.135)	(0.140)	(0.200)	(0.142)
Δ Equity Holdings	0.006	-0.129	-0.143	-0.336*	-0.357**
	(0.140)	(0.123)	(0.121)	(0.170)	(0.155)
Δ Non-PT Govt Bonds	-0.750***	-0.062	0.022	-0.288	-0.185
	(0.258)	(0.300)	(0.307)	(0.309)	(0.292)
Δ Lending	-0.884***	-0.222*	-0.146	-0.124	-0.025
	(0.041)	(0.124)	(0.130)	(0.193)	(0.137)
Δ Book Equity	0.791***	0.131	0.054	0.148	0.050
	(0.152)	(0.206)	(0.214)	(0.213)	(0.170)
Δ Securities Issued	0.051	-0.445	-0.514	-0.470	-0.555
	(1.046)	(1.012)	(1.014)	(0.622)	(0.620)
Δ Demand Deposits	0.772***	0.196*	0.124	0.131	0.040
	(0.086)	(0.115)	(0.120)	(0.176)	(0.129)
Δ Saving Deposits	1.721**	0.631	0.362	0.387	0.088
	(0.683)	(0.742)	(0.737)	(0.531)	(0.501)
Δ Time Deposits	0.935***	0.234*	0.154	0.137	0.033
	(0.040)	(0.133)	(0.138)	(0.206)	(0.145)
Δ Repo Borrowing	0.398*	0.071	0.032	-0.011	-0.062
	(0.216)	(0.320)	(0.346)	(0.227)	(0.257)
Balance Sheet Controls	✓	✓	✓	✓	✓
Observations	68	68	68	68	68
R-squared	0.935	0.947	0.948	0.968	0.970

Table F.3: Banks' Buy-and-Borrow Behavior, Robustness. This table presents the estimation results for versions of specification (1) that include bank-level controls. 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, the stock of eligible collateral in November 2011, and changes in balance sheet components (assets and liabilities). Eligible collateral includes domestic government bonds, government guaranteed bank bonds (GGBB), additional credit claims (ACC), and other marketable securities. The bank-level controls are changes in balance sheet variables. Assets include: cash, non-sovereign bond holdings, equity holdings, non-domestic sovereign bond holdings, and loans. Liabilities include: book equity, securities issued, demand deposits, saving deposits, time deposits, and repos. All variables are normalized by bank assets in November 2011. The collateral independent variables are haircut-adjusted. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

LHS Var.: $\widetilde{\text{Holdings}}_{i,m,t}$	(1)	(2)	(3)	(4)	(5)
Post	0.323*	0.081*			
	(0.154)	(0.044)			
Post × Short			0.245**	0.245**	0.242*
			(0.104)	(0.104)	(0.128)
Bank FE	✓	✓	✓		
Maturity FE	✓	✓	✓	✓	
Time FE			✓		
Bank-Time FE				✓	✓
Bank-Maturity FE					✓
Specification	(3a)	(3b)	(4)	(4)	(4)
Sample Bonds	Short-Term	Long-Term	Full Sample	Full Sample	Full Sample
Observations	2,478	2,478	4,956	4,956	4,950
R-squared	0.346	0.524	0.258	0.337	0.686

Table F.4: LTRO and Government Bond Purchases, Alternative Clustering. This table presents the results of specifications (3a) in column (1), (3b) in column (2), and (4) in columns (3)-(5). The dependent variable is the share of total public debt outstanding of maturity m held by bank i divided by the assets of bank i relative to the assets of the financial sector. Independent variables include a Post dummy equal to 1 on and after December 2011 and a Short dummy equal to 1 if the government bond portfolio matures on or before February 2015. Column (1) and column (2) include only bonds maturing on or before or after February 2015, respectively. The sample period includes 12 months and runs at a monthly frequency from June 2011 to May 2012. The sample includes only banks. Standard errors double clustered at the bank and month levels are in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

LHS: $\text{Holdings}_{i,m,t}/\text{AmtOutstanding}_{m,t}$	(1)	(2)	(3)	(4)	(5)
Post	0.371**	0.047*			
	(0.157)	(0.024)			
Post × Short			0.329**	0.329**	0.324**
			(0.149)	(0.129)	(0.140)
Bank FE	✓	✓	✓		
Maturity FE	✓	✓	✓	✓	
Time FE			✓		
Bank-Time FE				✓	✓
Bank-Maturity FE					✓
Specification	(3a)	(3b)	(4)	(4)	(4)
Sample Bonds	Short-Term	Long-Term	Full Sample	Full Sample	Full Sample
Observations	2,478	2,478	4,956	4,956	4,950
R-squared	0.402	0.507	0.285	0.375	0.679

Table F.5: LTRO and Government Bond Purchases, Alternative Dependent Variable. This table presents the results of specifications (3a) in column (1), (3b) in column (2), and (4) in columns (3)-(5). The dependent variable is the share of total public debt outstanding of maturity m held by bank i. Independent variables include a Post dummy equal to 1 on and after December 2011 and a Short dummy equal to 1 if the government bond portfolio matures on or before February 2015. Column (1) and column (2) only include bonds maturing on or before and after February 2015, respectively. The sample period includes 12 months and runs at a monthly frequency from June 2011 to May 2012. The sample includes only banks. Standard errors double clustered at the bank-maturity and month levels are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

LHS Var.: $\frac{\text{GovtBondHoldings}_{i,m,t}/\overline{\text{Amount Outstanding}}_m}{\text{Assets}_{i,t}/\overline{\text{Total Assets}}}$	(1)	(2)	(3)	(4)	(5)
Post	0.363**	0.077**			
	(0.151)	(0.031)			
Post × Short			0.289*	0.289**	0.286**
			(0.136)	(0.115)	(0.129)
Bank FE	✓	✓	✓		
Maturity FE	✓	✓	✓	✓	
Time FE			✓		
Bank-Time FE				✓	✓
Bank-Maturity FE					✓
Specification	(3a)	(3b)	(4)	(4)	(4)
Sample Bonds	Short-Term	Long-Term	Full Sample	Full Sample	Full Sample
Observations	2,478	2,478	4,956	4,956	4,950
R-squared	0.303	0.525	0.222	0.299	0.592

Table F.6: LTRO and Government Bond Purchases, Alternative Dependent Variable (2). This table presents the results of specifications (3a) in column (1), (3b) in column (2), and (4) in columns (3)-(5). The dependent variable is the share of total public debt outstanding of maturity m held by bank i divided by the assets of bank i relative to the assets of the financial sector. The amount outstanding in each maturity m and the assets of the financial sector are taken at their mean between December 2011 and February 2012. Independent variables include a Post dummy equal to 1 on and after December 2011 and a Short dummy equal to 1 if the government bond portfolio matures on or before February 2015. Column (1) and column (2) include only bonds maturing on or before and after February 2015, respectively. The sample period includes 12 months and runs at a monthly frequency from June 2011 to May 2012. The sample includes only banks. Standard errors double clustered at the bank-maturity and month levels are in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

LHS Var.: $\widetilde{\text{Holdings}}_{i,m,t}$	(1)	(2)	(3)	(4)	(5)	(6)
Post × Intensity	0.086***	0.019*				
	(0.028)	(0.009)				
Post × Short × Intensity			0.067**	0.067**	0.067*	0.067*
			(0.027)	(0.027)	(0.034)	(0.034)
Bank FE	✓	✓	✓			
Time FE	✓	✓	✓			
Maturity FE	✓	✓	✓	✓		
Bank-Time FE				✓	✓	✓
Bank-Maturity FE					✓	✓
Time-Maturity FE						✓
Specification	(7a)	(7b)	(7c)	(7c)	(7c)	(7c)
Sample Bonds	Short-Term	Long-Term	Full	Full	Full	Full
Observations	2,466	2,466	4,932	4,932	4,932	4,932
R-squared	0.409	0.548	0.361	0.401	0.702	0.707

Table F.7: LTRO and Government Bond Purchases: Intensive Margin, Alternative Clustering. This table presents the results of specifications (7a), (7b), and (7c). The dependent variable is the share of total public debt outstanding of maturity m held by bank i divided by the assets of bank i relative to the assets of the financial sector. Columns (1) and (2) include only bonds maturing on or before February 2015 and after February 2015, respectively. Columns (3)-(6) include all bonds. Independent variables include a Post_t dummy equal to 1 on and after December 2011, a Short_m dummy equal to 1 if the government bond portfolio matures on or before February 2015, and an Intensity_i variable equal to LTRO borrowing divided by assets in November 2011. The sample period includes 12 months and runs at a monthly frequency from June 2011 to May 2012. The sample includes only banks. Standard errors double clustered at the bank-maturity and month levels are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Variable (BS)	**Unit**	Sample: No Trade **Nov11 Mean**	Sample: Trade> 0 **Nov11 Mean**	Sample: Trade> 0 $corr(BS, Trade)$
Number of Banks		54	15	
Total Assets	bn euro	2.4	29.4	−53.2 %
Leverage	A/E	6.0	11.0	−21.1 %
Securities	% Assets	10.6	25.4	41.8 %
Govt. Bonds	% Assets	2.3	6.3	51.6 %
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 %
Deposits	% Assets	29.8	30.7	−14.3 %
Short-term Funding	% Assets	57.7	59.8	26.4 %

Table F.8: Bank Characteristics and Government Bond Purchases. This table shows bank characteristics and collateral trade activity. The third (fourth) column shows cross-sectional means in November 2011 for the group of banks with zero (strictly positive) collateral trade activity. The fifth column shows the correlation between each balance sheet variable and the collateral trade activity in the subsample of institutions that have strictly 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. Short-term funding refers to securities issued with a maturity of less than one year, short-term deposits, and repurchase agreements. In the last column, total assets is the natural logarithm of total assets.