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How Banks Respond to Distress: Shifting Risks in Europe's Banking Union

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Abstract

This paper uses granular bond portfolio data to study how banking systems across the European Union (EU) adjust their asset holdings in response to regulatory solvency shocks. We also study the impact of these shocks at financial intermediaries on the prices of bonds in their portfolio. Despite the creation of a Single Supervisory Mechanism (SSM) in the EU, we find that risk-shifting interacts with regulatory arbitrage motives to explain how banks adjust their portfolios after adverse solvency shocks. After regulatory solvency declines, banks increase their exposure to domestic bonds, including higher yielding but zero risk-weight sovereign bonds. The increase in banking system risk might therefore be even larger than the decline in risk-weighted solvency ratios suggests. Distress in the banking system also feeds back onto bond prices. Bonds owned by less-well capitalized banking systems trade at a discount relative to otherwise similar bonds owned by better capitalized intermediaries.

Keywords: Bank capital, portfolio allocation, risk shifting, SSM

JEL classifications: G11, G12, G15, G21

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1 Introduction

The presence of government guarantees and the free-rider problem among dispersed creditors are often cited as motivations for financial regulation designed to limit bank-risk taking and represent the interests of creditors when bank solvency declines (Dewatripont and Tirole 1994). But the recent joint distress of banks and sovereigns within the European Union (EU) and the ensuing cross-border spill-overs across EU member states suggest that effective financial regulation might also need to represent the collective interests of member states within a currency union. In the absence of such regulations, the expectation of assistance or debt forgiveness from other member states can weaken an individual sovereign's incentives to limit risk taking within its own banking system, as the individual sovereign would share the potential cost of this risk-taking with other members of the currency union. Moreover, the more robust "collective government guarantee" provided by the currency union can increase bank-risk taking incentives (Farhi and Tirole 2018).

The potential costs of letting supervisory standards slip on the part of sovereigns and increased bank risk-taking incentives can be particularly large when the solvency of the banking system declines. Well-known arguments predict that rather than rebalance their portfolio towards "safer" assets in order to avoid failure – the flight to safety hypothesis (Holmström and Tirole 1997; Thakor 1996) – lightly supervised distressed banks might gamble or shift into riskier assets in search of higher yield – the risk shifting hypothesis. In one form of this hypothesis, distressed banks might increase their exposure to assets whose returns are highly positively correlated with the survival of the bank, such as domestic assets. Also, regulatory arbitrage can combine with the risk-shifting hypothesis and induce distressed banks to increase their holdings of higher yielding but zero risk-weight sovereign debt in order to "search for yield". Together, these actions can fragment or "renationalize" a currency union and render banking systems less diversified and riskier than their regulatory solvency ratios suggest.[1]

[1] There is a large theoretical literature on bank behavior in times of distress – see the discussions in Gorton and Winton (2003), Freixas, Rochet, and Parigi (2004), and Boyd and Hakenes (2014); Admati et al. (2018) discuss these issues more generally within corporate finance. Discussions that center on

Therefore, in order to represent better the interests of member states and internalize the cross-border implications of bank-risk taking, the EU agreed to a historic banking union or single supervisory mechanism (SSM) across member states in 2014.[2] Using granular bond-level data, this new regulatory environment provides an attractive setting to evaluate theories about how solvency shocks influence banks' risk-taking within a banking union.[3] In addition, we also study the consequences of these portfolio adjustments at banks on asset prices, including those of domestic government debt. Banking systems account for a large volume of bond holdings in the EU, and this empirical setting can help reveal how the solvency of financial intermediaries might influence liquidity and pricing in bond markets.

A major challenge in empirically distinguishing between various theoretical predictions and understanding the effectiveness of supra-national financial regulation in curtailing bank-risk taking is that unobserved economic conditions that cause regulatory solvency shocks also affect the distribution of asset returns. And any portfolio rebalancing after a solvency shock could reflect bankers' changing beliefs about expected asset returns induced by economic unobservables rather than reflecting the causal response to the solvency shock itself. Endogenous matching between country-banking systems and security types could also lead to biased estimates. Because of superior information for example, some banking systems might specialize in trading certain securities. But this specialization on account of latent information could also determine both the pattern of solvency shocks the banking system experiences and its asset choices, leading again to biased inference. Economic theory observes that information differences can pose even more fundamental inference challenges. Because domestic banks might be relatively better informed about domestic assets, domestic banks might earn higher risk adjusted returns on these assets. And any increase in "home-bias" after an adverse shock could reflect a "flight to safety" rather than risk-shifting (Van Nieuwerburgh and Veldkamp 2009).

regulatory approaches aimed at addressing these bank responses include Dewatripont and Tirole (2012), Hanson, Kashyap, and Stein (2011) and Kashyap, Rajan, and Stein (2008).

[2] The closest precedent is the Federal Reserve Act of 1913 after the 1907 panic, which also made the Fed a joint regulator of member banks across the United States (Meltzer 2003).

[3] Much of the research on banking unions has taken place in the context of the United States – see for example Agarwal et al. (2014) and Eisenbach, Lucca, and Townsend (2019).

The security-level data on banks' bond holdings can help address these identification concerns. With this level of granularity, the baseline specifications can non-parametrically absorb time-varying shocks to a bond's returns. This implies that for two banking systems that hold the same bond, we can study how regulatory solvency shocks to one of these systems shapes its holdings of the bond at the intensive margin relative to the other banking system (Khwaja and Mian 2008). We can also use non-parametric controls to address endogenous matching concerns. The security-level data itself begins in 2014 Q1 and extends through end-2017, containing considerable variation in solvency shocks as well as changes in financial regulation, including new capital and liquidity regulations.

We find that even within the new Single Supervisory Mechanism (SSM), risk-shifting appears to be the most attractive interpretation of bank behavior after adverse solvency shocks. Using the granular bond data, regressions at the security-level show that after a regulatory solvency shock, banking systems reduce their exposure to high yielding foreign private sector debt. Instead, banks "re-nationalize" their portfolio by increasing their exposure to lower yielding domestic private sector debt. These domestic bonds co-vary positively with the banking system's survival, and thus help banking systems' maximize their expected returns, conditional on survival. Moreover, consistent with the risk-shifting hypothesis, for the same sized shock, the move into domestic debt is significantly stronger among banking systems that are already closer to insolvency.

In particular, for the full sample, a one percentage point decline in the Tier 1 equity to risk weighted assets ratio suggests a 0.16 percentage point increase in the banking system's holdings of domestic low-yielding private sector bonds, along with a 0.04 percentage point drop in its holdings of foreign high-yielding private sector bonds.[4] Among banking systems that have below median capitalization, the same one percentage point negative solvency shock suggests a 0.20 percentage point increase in the net position in domestic low-yielding private sector debt; but for the better capitalized system, this adjustment margin is statistically insignificant. We also find that even within the SSM, risk shifting interacts with

[4] Tier 1 equity allows a bank to absorb losses on an ongoing basis, see `https://www.bis.org/press/p981027.htm`.

regulatory arbitrage. While all EU government debt has a zero regulatory risk weight, a negative solvency shock leads banks to primarily increase their exposure to their own domestic sovereign. But within this category, banks move towards higher yielding more illiquid debt. A one percentage point decline in the Tier 1 equity to risk weighted assets ratio suggests a 0.40 percentage point increase in a banking system's holdings of higher yielding – longer duration – domestic government debt.

Informational advantages are an unlikely explanation for these results. Among industrialized economies, the valuation of sovereign debt does not usually require specialized inside knowledge, and domestic banks would not be expected to have a relative valuation advantage for this asset class, especially after an adverse solvency shock. Other tests using private sector bonds also weigh against the information hypothesis. We find that banks seek out not the thinly traded bonds, for which domestic banks might have an information advantage, but the liquid large capitalization bonds. These latter bonds are relatively information rich, require much less valuation expertise, and importantly for the risk shifting hypothesis, are most likely to positively co-vary with the survival of the domestic banking system. Perhaps more telling, the evidence also suggests that banking systems actually increase their exposure to domestic bank bonds after an adverse solvency shock to the domestic banking system. Clearly, the performance of domestic bank debt is most highly correlated with the performance of the domestic banking system. And this result is consistent with the idea that distressed banks herd, collectively buying each other's debt, in order to increase the risk of failing together and precipitating a collective bailout (Acharya and Yorulmazer 2007).

While the granular data can help address omitted variable bias, a key objection to these results is that shocks to regulatory solvency might proxy for shocks to the "fundamental" health of the bank, such as an asset quality shock, that ultimately explain these adjustment margins. To address this concern, we exploit a key feature of European capital regulation during the sample period. The leverage ratio, the ratio of Tier 1 equity to total assets, is also positively correlated with the fundamental health of the bank, but was not introduced into European banking regulation until the very end of our sample – January 2018. Moreover, rather than being a binding constraint, it was designed as a "backstop" to the risk weighted requirements.[5] Thus, if shocks to regulatory solvency proxy for other unobserved shocks that ultimately explain the pattern of adjustment, then replacing the change in the Tier 1 equity to risk weighted assets ratio with the change in the leverage ratio should yield approximately similar results. We find, however, that changes in the leverage ratio do not explain banking systems' portfolio adjustments.[6]

The evidence suggests that regulatory solvency shocks can induce banks to shift into riskier assets, such as longer duration domestic sovereign debt, and away from foreign assets. This potentially makes the bank riskier than its risk-weighted solvency ratios might suggest, and these risks can in turn be transferred onto the bank's assets. That is, beginning with Grossman and Miller (1988) prominent arguments observe that the solvency of financial intermediaries can influence liquidity and pricing in the markets in which they operate. In one key channel, because undercapitalized financial institutions might be forced to liquidate assets at a discount in the future, this liquidation "overhang" can depress the current prices of assets owned by troubled institutions. In our setting, these theories predict that bonds predominantly owned by less-well capitalized financial intermediaries should trade at a discount relative to otherwise similar bonds owned by intermediaries further away from regulatory insolvency. Using detailed bond controls that help address concerns about endogenous matching and unobserved time-varying shocks, we find that a bond's yield increases when the bond's weighted exposure to less-well capitalized banking systems increases. A one percentage point decline in the weighted average solvency of the banks that own a bond is associated with a 0.19 percentage point increase in a bond's yield.

Use the detailed data on the nationality and sector of both the bond and its owner to address remaining endogeneity concerns, we examine the mechanisms through which solvency shocks affect bond prices. The logic of these tests builds on the fact that EU

[5] See `https://www.bis.org/publ/bcbs189\_dec2010.htm`.

[6] Arguably, the leverage ratio may even be a better measure of the fundamental health of the bank than the Tier 1 equity ratio, because banks have an incentive to artificially increase the latter by manipulating their risk weights (Mariathasan and Merrouche 2014).

regulations during the sample period leave domestic governments responsible for banking system bailout obligations. Therefore, shocks to the regulatory solvency of the banking system increase both the liquidation risk of domestic government bonds held by this banking system as well as the contingent liabilities of the domestic government (Acharya, Drechsler, and Schnabl 2014). Both these forces in turn would depress domestic government bond prices. In contrast, since foreign governments within the EU do not directly insure other countries' banking systems, foreign government bonds are only subject to liquidation risk after adverse solvency shocks to the banking system.[7] In keeping with this logic, we find that adverse solvency shocks to a banking system increase the yields of domestic as well as foreign government bonds. But the impact of solvency shocks on domestic government bond yields is nearly twice as large as the impact on foreign government bonds. Government debt plays an important role in the liquidity of financial markets, including as a "high quality liquid asset" in banking regulation, and this "transfer of risk" from distressed banks to government debt can impede markets from functioning properly (Holmström, Hildebrand, and Von Thadden (2015), BCBS (2013)).

Taken together, these results are supportive of theories that emphasize the risk-shifting motive in explaining bank behavior after adverse solvency shocks. This evidence also shows that risk-shifting not only impacts the riskiness of the banking system, but can spill over onto the prices of the assets into which distressed banks shift. Moreover, while we cannot construct counterfactual scenarios to assess the overall effectiveness of the SSM, this evidence suggests that at least in its current form, the SSM does not seem to have completely addressed bank risk-taking incentives and the resulting re-nationalization of credit flows within the EU after adverse solvency shocks.

This paper proceeds as follows. Section 2 places this paper in the context of the related literature; Section 3 describes the empirical framework and data, while Section 4 presents the main results; Section 5 concludes.

[7] To be sure, European regulations now allow for a single resolution mechanism (SRM), which centralizes bank bailout policies within the ECB `https://ec.europa.eu/info/business-economy-euro/banking-and-finance/banking-union/single-resolution-mechanism_en`. However, it remains unclear whether the SRM limits an individual sovereign from bailing out its own financial system.

2 Related Literature

The EU banking and subsequent sovereign debt crises that began in 2008 has generated a rapidly growing theoretical and empirical literature. A major theme in the theoretical literature is that the health of the sovereign and the domestic financial systems are closely interrelated, and that this interrelationship can amplify adverse shocks. Because domestic sovereign debt is an important source of liquid assets for domestic banking systems, declining sovereign credit worthiness impairs the functioning of the domestic banking system. This increase in bank distress can then curtail the supply of credit – a credit crunch – and also increase expectations of a bank bailout. The resulting credit crunch and the increased expectations of government expenditures, including on bank bailouts, increase the expected issuances of sovereign debt and the risk premium on that debt, putting further pressure on sovereign yields and creating a "doom" or "diabolical loop" that feeds back onto the banking system (Brunnermeier et al. 2016; Acharya, Drechsler, and Schnabl 2014; Farhi and Tirole 2018).

Some of these arguments also predict that this feedback or doom loop can create perverse incentives on the part of domestic banks. In a version of the risk-shifting argument, because deposit insurance removes creditor discipline and limited liability limits bank shareholder losses, distressed banks have powerful incentives to increase their exposure to assets that payoff when the banks survive (Diamond and Rajan 2011; Jensen and Meckling 1976). Domestic assets, and in particular domestic government bonds, evince the highest positive correlation with the domestic banking's system's survival, and these risk-shifting argument predicts that banking systems will increase their exposure to these assets after adverse solvency shocks (Crosignani 2017). A related argument observes that capital regulation creates incentives for regulatory arbitrage in which domestic government bonds become an even more attractive asset into which undercapitalized banks can risk-shift: Domestic government bonds both payoff in the state of the world in which domestic banks survive, and these bonds also incur no regulatory capital charge.

Thus, a worsening of domestic sovereign credit worthiness that leads to losses at domestic banks might induce these banks to perversely purchase even more domestic sovereign debt. Banks might also seek out longer duration domestic sovereign debt to reach for yield and generate additional income. The increased "home bias" associated with this version of risk-shifting makes the banking system less diversified and potentially disrupts lending relationships across the EU. Increased "reach for yield" behavior also makes the banking system more exposed to interest rate risk. In contrast, the "flight-to-safety" hypothesis predicts that banks that experience negative solvency shocks might both deleverage through asset sales and rebalance their asset holdings towards "safe" assets, like German and US government debt, in order to avoid failure (Holmström and Tirole 1997; Thakor 1996).

The empirical literature has made some progress in measuring the importance of the risk shifting motive in fostering these feedback loops, but there remains much uncertainty over the interpretation of these results.[8] Using data from the 2008-2015 period – before the ECB moved to centralized regulation and supervision across the European Union – several studies suggest that poorly capitalized banks tend to increase their purchases of domestic sovereign debt. This evidence is sometimes interpreted as either moral suasion – government pressure on banks to buy domestic sovereign debt – or risk-shifting. For example, Altavilla, Pagano, and Simonelli (2017) use monthly bank level data showing that banks increase their purchases of domestic public debt, especially when ECB liquidity injections reduce funding costs; they interpret this evidence as consistent with moral suasion. Earlier in the crisis, Acharya and Steffen (2015) interpret the positive factor loadings of bank stock returns on periphery bond returns as evidence of risk-shifting. While using higher frequency data, Ongena, Popov, and Van Horen (2019) document that domestic banks with weaker balance sheets or those that received government support were more likely to help domestic governments roll-over public debt – a result that is consistent with moral suasion.

Unobserved demand, as well as other factors that affect the future distribution of asset

[8] There is a voluminous empirical literature from past crises on the effects of banking sector solvency shocks. See Kane (1989) on the U.S. savings and loans crisis. Peek and Rosengren (2000) and Hoshi, Kashyap, and Scharfstein (1990) are two classic references on the Japanese banking crises of the 1990s.

returns present key challenges to interpreting the evidence. Notably, in periods of crisis, the demand for external finance from the non-financial sector might be limited, leaving public debt as the main asset in which domestic banks can invest. Thus, any association between solvency shocks at banks and their increased holdings of domestic sovereign debt could reflect a lack of demand for credit in the non-financial sector. Public debt might also offer higher risk adjusted returns, especially to domestic creditors, as governments are often unwilling to default on domestic creditors (Broner et al. 2014; Gennaioli, Martin, and Rossi 2014).

Differences in information between domestic and foreign banks also make it difficult to tell apart the flight-to-safety and risk-shifting hypotheses. Some models predict that because domestic banks are likely better informed about domestic assets than their foreign competitors, domestic banks earn higher risk adjusted returns on these assets (Van Nieuwerburgh and Veldkamp 2009). Thus, rather than reflecting risk-shifting, an increase in "home-bias" in the portfolio of domestic banks after an adverse shock could reflect a flight-to safety, as domestic banks exploit their comparative information advantage in domestic assets to create safer portfolios. Some of the recent studies using more granular data reflect this nuance. Data from Italy at the security-level, which can help non-parametrically control for some of these latent factors, present more nuanced results, showing that less-well capitalized banks appear to shift into less risky assets (Peydro, Polo, and Sette 2017). Security-level evidence in Timmer (2018) also suggests more complex bank responses, as less well capitalized German banks decrease their exposure to poorly performing assets.

Notwithstanding the difficulties in interpreting the evidence, the belief that bank risk shifting, done with the tacit approval of domestic supervisory authorities and governments, might help drive a doom loop led to the creation of the European banking union in 2014. In January 2014, the EU largely harmonized all banking regulations across EU member states, so that all supervisors operate with the same regulatory rule book. Moreover, from November 2014 onwards, banking supervision was centralized within the ECB. All the banking systems in our sample therefore operate with a consistent set of regulations, and unlike even the United States, the banks are for most of our sample supervised by the same institution – the ECB. The ECB also operates as a lender of last resort, though bailout decisions are jointly determined by the Single Resolution Board and the sovereign of each of the banking systems. This institutional setting of a single supervisory mechanism provides a helpful environment to identify theories of risk shifting and study the impact of this behavior. Theories of moral suasion and related forms of financial repression are often observationally identical to risk-shifting. These former theories depend on the coordination between supervisory authorities and governments, so that distressed banking systems can act in the government's interests while benefiting from supervisory forbearance. This forbearance can take a range of forms, from more favorable interpretations of regulations to the advantageous timing of bank exams.[9] But the regulatory and supervisory harmonization created by the SSM renders this type of coordination between supervisory authorities and governments much more difficult compared to pre-2014 – the period covered by most studies.[10] Using security level data also allows us to construct empirical tests that are robust to unobserved demand shocks, and other time-varying factors that can affect the interpretation of the evidence.

Equally important, we also extend the existing literature by focusing on the impact of these solvency shocks on the pricing of bonds – an issue that has received much less attention in the empirical literature but is of significant importance. Arguably the banking sector's purchases of domestic sovereign and other debt can help reduce yields (Uhlig 2014). But an influential literature also observes that because of the risk of future fire-sales, bonds predominantly owned by less-well capitalized intermediaries can trade at a discount relative to otherwise similar bonds owned by intermediaries further away from regulatory insolvency (Grossman and Miller 1988; Allen and Gale 2005). This feedback from intermediary solvency onto asset prices in the economy is also an important feature of recent macro models (He and Krishnamurthy 2013; Brunnermeier and Sannikov 2014). And our security-level data, which afford a number of non-parametric controls, can help identify

[9] In the case of the U.S., Agarwal et al. (2014) show that political economy considerations can induce subnational supervisors (i.e., states) to inconsistently apply bank regulations relative to federal authorities.

[10] See `https://eba.europa.eu/regulation-and-policy/single-rulebook` for more information about this regulatory harmonization.

this feedback mechanism. In sum, our empirical setting provides the first opportunity to evaluate the risk shifting hypothesis and its impact on bond pricing within the newly created SSM. The next section describes the empirical framework and data in greater detail.

3 Empirical Framework and Data

3.1 Empirical Framework

To investigate how banking systems respond to solvency shocks at the intensive margin, we estimate the following baseline equation:

$$\begin{aligned}\Delta Holdings_{ijt} &= \alpha_{it} + \beta_{ij} + \beta_G I_G \Delta Tier1_{jt} + \beta_D I_D \Delta Tier1_{jt} + \beta_H I_H \Delta Tier1_{jt} \\ &+ \beta_{GD} I_G I_D \Delta Tier1_{jt} + \beta_{GH} I_G I_H \Delta Tier1_{jt} + \beta_{DH} I_D I_H \Delta Tier1_{jt} \\ &+ \beta_{GDH} I_G I_D I_H \Delta Tier1_{jt} + \Delta Tier1_{jt} + e_{ijt}. \qquad (1)\end{aligned}$$

The dependent variable, $\Delta Holdings_{ijt}$, is the quarter-on-quarter percentage point change in banking system's j holdings of security i at time t, where we measure holdings as a percentage of the total outstanding amount of security i. The dependent variable therefore measures changes quantity of securities held at the intensive margin rather than changes in their market price. The variable $\Delta Tier1_{jt}$ is the percentage point change in the Tier 1 capital to risk weighted assets ratio of the banking system j at time t relative to the preceding quarter. During the sample period, European supervisors did not use the leverage ratio – the ratio of Tier 1 capital to total assets – and $\Delta Tier1_{jt}$ is the standard regulatory measure of changes in solvency based on the risk weighting of a bank's assets. Since banks engage in capital planning and can anticipate their regulatory solvency ratios in the short term, this ratio enters contemporaneously in the baseline specification.

Equation (1) uses a series of indicator variables and interaction terms to discriminate among the principal and sometimes overlapping theories on how banks might adjust their asset holdings in response to adverse shocks. The simplest versions of the risk-shifting hypothesis predict that banks might rebalance towards riskier, higher yielding assets when their regulatory solvency declines. We thus use an indicator variable, I_H, that equals 1 if a security's yield is above the median in that quarter-security type and 0 otherwise.

For example, for a domestic government bond this indicator variable would equal one if its yield in the current quarter exceeds the median yield on domestic government bonds in the same quarter. The coefficient β_H thus measures how a banking system adjusts its holdings of "higher risk" bonds after a change in solvency. If β_H is negative, it would suggest that a decline in regulatory solvency is associated with a relative increase in a banking system's holdings of higher yield bonds.

Capital regulations constrain a bank management's risk-taking choices. But within these regulatory constraints, management can substitute to riskier higher yielding assets after an adverse shock (i.e., regulatory arbitrage). Banks seeking to economize on capital might for example shift into government bonds carrying a zero risk weight, and we use an indicator variable I_G that equals 1 if a security is a government bond and 0 otherwise to capture this adjustment dimension. If β_G is negative then, all else constant, it would suggest that a decline in regulatory solvency is associated with a relative increase in a banking system's holdings of government bonds. But within the category of government debt, banks might risk-shift by moving into longer duration or riskier bonds in search of higher yield. We thus include an interaction term, $I_G I_H$, to measure this response. It equals 1 when the bond is both government and high yielding, and 0 otherwise; in turn the coefficient, β_{GH}, measures the impact of a solvency shock on this adjustment margin.

Also, a key prediction from the risk shifting literature is that distressed banks might increase their exposure to assets whose returns co-vary positively with the bank's own survival. Intuitively, in the state of the world where the bank survives, bank shareholders also benefit from the asset's higher returns. But in the state of the world where the bank fails, limited liability caps losses if the asset returns are also poor, making assets with a positive return covariance particularly attractive vehicles in which to shift risk. To measure this adjustment dimension, we build on the idea that relative to foreign bonds, the covariance between domestic bond returns and the domestic banking system's probability of survival is much more highly correlated. We thus classify securities based on whether the issuer is domestic, I_D, and the coefficient, β_D, measures the relative rebalancing towards domestic bonds in the portfolio.

As before, we also include a number of interaction terms to measure how a banking system might risk-shift within the category of domestic bonds. Notably, domestic, higher yielding government debt is an attractive risk-shifting asset after an adverse shock. EU government debt carries zero risk weight; domestic government debt evinces the highest covariance with the domestic banking system's survival probability; while the additional yield helps the bank earn higher profits if the government survives. The triple interaction term: $I_G I_D I_H$ models this adjustment margin.

Throughout, we include all the subcomponents of the various interactions; the linear components of the interaction terms are absorbed in the bond-by-year-quarter and bond-by-banking system fixed effect. The subcomponents of the interaction terms themselves also model important adjustment dimensions. Notably, the banking system could risk-shift into domestic non-government debt after an adverse solvency shock. But capital regulation can constrain management's ability to increase the bank's holdings of higher yielding domestic assets, as these tend to also have higher risk-weights. The term $I_D I_H$ thus measures the extent to which banks purchase additional domestic higher yielding assets after adverse shocks.

The granularity of the data and the use of time-varying fixed effects are important for the identification strategy. Latent economic shocks can affect both the solvency of a country's banking system and the expected future payoff of specific securities, biasing estimates of β_G, β_D and β_H. An unobserved adverse economic shock could for example deplete bank equity and at the same time reduce the attractiveness of private sector bonds, causing banks to rotate into sovereign bonds. Such a portfolio readjustment would be observationally identical to various forms of the risk-shifting hypothesis, and most existing studies based on balance sheet aggregates would have difficulty distinguishing between this risk-shifting motive versus latent shocks.

Fortunately, because we use security-level data, we can use security by year-quarter-fixed effects in the baseline specification to non-parametrically absorb time varying shocks that might simultaneously determine the attractiveness of a security and solvency shocks. Intuitively, this within security exercise estimates how two separate banking systems adjust their holdings of the same security in the same quarter in response to the variation in the banking systems' solvency ratios. A related concern centers on endogenous matching between country-banking systems and securities. Some banking systems might for example specialize in certain securities, either because of superior information or historical accident. But these latent factors could also determine the pattern of solvency shocks to the banking system, leading again to biased inference. We thus include country-banking system by security fixed effect to absorb the time invariant factors that might lead certain banking systems to prefer specific securities. We next describe the data in greater detail.

3.2 Data

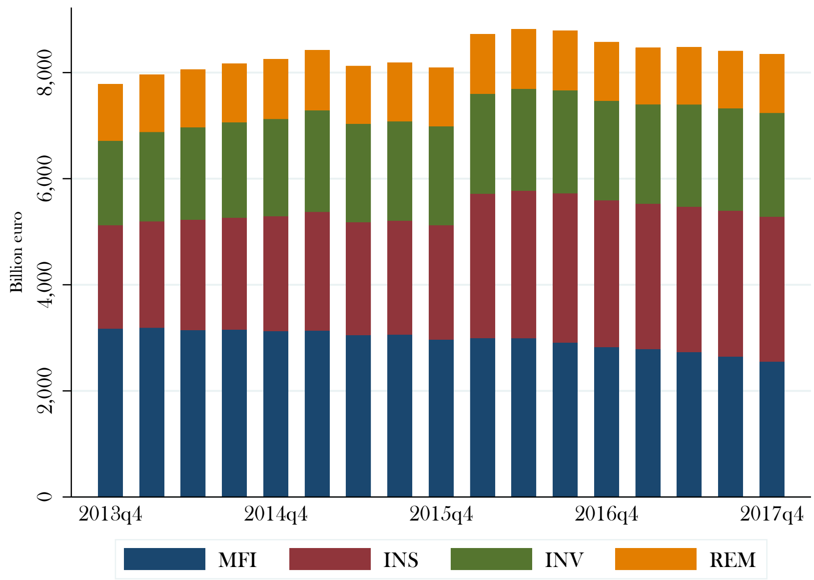
We use the Sector module of the Securities Holdings Statistics (SHS). This confidential dataset from the European System of Central Banks (ESCB) contains detailed information on the holdings of long-term – maturity in excess of one year – debt securities by euro area residents, reported on a quarterly basis.[11] Each observation in the dataset corresponds to an ownership position in a bond identified by its unique International Securities Identification Number (ISIN). Owners are reported on a country-sector level of aggregation. With this data, we can for example identify the Spanish banking system's ownership of a bond in a given quarter that is issued by the German government. Similarly, for the same German government bond, we can also observe the share that is owned by households in Belgium.

Our sample begins in 2013 Q4, when the ECB started to collect the data, and ends in 2017 Q4. Figure 1 plots the total value of bond holdings in the dataset over the sample

[11] The SHS dataset that we use does not include holdings by the Eurosystem itself (i.e., asset purchase programs). A detailed description of the dataset can be found on the website of the ECB: `https://www.ecb.europa.eu/stats/financial\_markets\_and\_interest\_rates/securities\_holdings/html/index.en.html`.

period. The panels in Figure 2 show the composition of ownership and issuances across 9 broad sectors and 18 EU countries that are covered by the dataset. From panel A, German and French nationals account for about 15 percent each of the long-term bond holdings in the EU, with Italian nationals, the third largest group, owning about 5 percent of bonds in the EU. Panel B shows however that outstanding issuances are somewhat more smoothly distributed, with German, French and Italian nationals accounting for about 18 percent each of all outstanding bond issuances. Spanish and Dutch nationals round out the top 5, with issuances around 10 percent of the total volume.

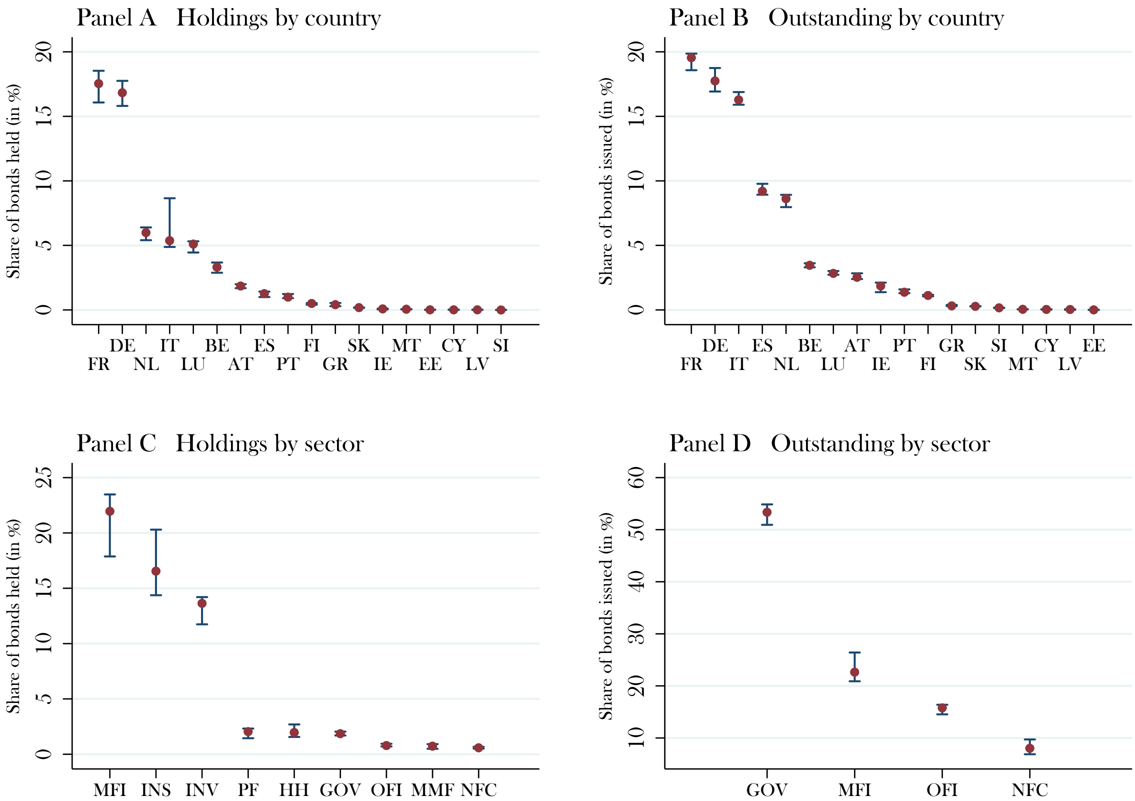
Figure 1: Value of bond holdings by sector over time



Note: the bars indicate the market value all euro denominated bonds held by monetary and financial institutions (MFI), insurance companies (INS), investment firms (INV), and remaining sectors (REM).

Panel C shows that for most of the sample period, banks (i.e., monetary and financial institutions) are the major holders of bonds in the EU, and on average they hold about 18 percent of the market capitalization of bonds in the dataset. The figure also shows that this aggregate ownership share remains relatively constant, fluctuating between 15 and 19 percent. Investment funds (about 14 percent on average) and insurance companies (about 13 percent on average) are the other main holders of bonds in the EU. Panel D shows that

Figure 2: Share of bond holdings and outstanding by country and by sector



Note: the dots indicates the mean values and the endpoints of the whiskers represent the minimum and maximum values. Countries are: Austria (AT), Belgium (BE), Cyprus (CY), Germany (DE), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU), Latvia (LV), Malta (MT), Netherlands (NL), Portugal (PT), Slovenia (SI), and Slovakia (SK). Sectors are: monetary and financial institutions (MFI), insurance companies (INS), investment firms (INV), pension funds (PF), governments (GOV), households (HH), other financial institutions (OFI), money market funds (MMF) and non-financial corporations (NFC). The ratio's in Panel C will be lower than what one would expect from Figure 1 because of non-euro area holders.

government bonds dominate the market capitalization of all bonds in the dataset, followed at considerable distance by bonds issued by banking systems.

Table 1 summarizes some of the key variables. It shows that while the typical banking system increased its net holdings of bonds at the beginning of the sample period, net holdings declined on average by 0.025 percentage points in the final quarter of 2017; there is also significant variation over the sample period, as the standard deviation of changes in net holdings is around 1.8 percentage points over the whole sample. The average yield to maturity also varied over the sample period, dropping from 2.4 percent in 2014 Q1 to about 0.3 percent by end 2017. Throughout, both the original and residual maturities contracted somewhat.

Table 1: Descriptive statistics

	2014 Q1			2017 Q4			Total			
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Obs
ΔHoldings %	.104	.004	1.962	−.025	.000	1.504	−.001	.000	1.846	289,786
Yield to maturity	2.396	1.313	4.352	.345	.110	1.163	.926	.375	2.304	289,786
Original maturity (days)	4341	2755	4823	3818	2586	3630	3937	2557	4179	289,786
Residual maturity (days)	2656	1310	4448	2157	1362	3209	2320	1333	3807	289,786
Government bonds in MFI holdings (%)	59.1	57.1	20.5	64.1	59.7	19.2	62.4	64.0	20.7	228
Domestic bonds in MFI holdings (%)	37.1	42.5	32.5	34.6	36.7	30.4	37.3	38.8	29.7	228

Note: the statistics are calculated for the sample used in our main regression specification, as displayed in Column 2 of Table 3.

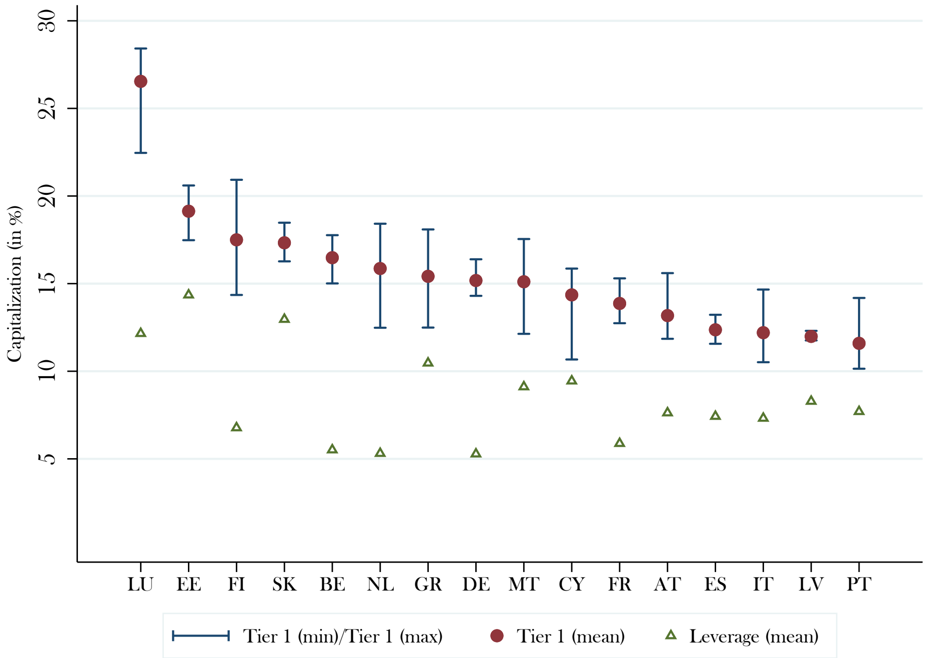
Finally, we combine the securities data with data from the ECB's Statistical Data Warehouse (SDW) on the balance sheets of national banking systems. Up until the end of our sample in 2017 Q4, European regulatory authorities relied on the ratio of Tier 1 equity to risk weighted assets to assess bank solvency. Starting in 2018 Q1, European regulators supplemented this risk weighted ratio with the leverage ratio – the ratio of Tier 1 equity to total assets. We obtain both ratios for all national banking systems in our sample, focusing on domestic bank groups and excluding foreign controlled subsidiaries and branches. Figure 3 shows that Tier 1 equity ratios differ considerably across banking systems. They are highest for Luxembourg, equaling about 27 percent on average. Moreover, Tier 1 equity ratios are higher than leverage ratios, which reflects that risk weighted assets are generally lower than total assets, because risk weights are typically less than hundred percent.

4 Main Results

4.1 Bond holdings

The first three columns of Table 2 illustrate the low power that tests using aggregate data have in distinguishing between various theories of how banks respond to distress.

Figure 3: Banking system capitalization by country



Note: the dots indicate the mean values by national banking system of Tier 1 equity as a percentage of risk weighted assets (i.e., the Tier 1 ratio), with the minimum and maximum values as the endpoints. The triangles indicate the mean values of Tier 1 equity as a percentage of assets (i.e., the Leverage ratio). Countries are: Austria (AT), Belgium (BE), Cyprus (CY), Germany (DE), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU), Latvia (LV), Malta (MT), Netherlands (NL), Portugal (PT), Slovenia (SI), and Slovakia (SK).

These columns aggregate the security-level data and show the simple bivariate correlations between the three principal dimensions through which banks might adjust their portfolios in response to a change in Tier 1 ratios for a panel of country-banking systems. The dependent variable in Column 1 is the change in the share of domestic securities in a country-banking system's bond portfolio in a given quarter. Controlling for country fixed effects, the Tier 1 coefficient is statistically insignificant. Column 2 uses the change in the share of government bonds in the portfolio, while Column 3 uses the change in the share of high yielding bonds in the country-banking system's bond portfolio in a given quarter. In all three columns, there is no evidence that changes in regulatory solvency are associated with portfolio rebalancing either towards government, domestic or higher yielding assets.

Table 2: From aggregate to bond-level data

Variables	(1) Domestic Holdings (Δshare)	(2) Government Holdings (Δshare)	(3) High Yield Holdings (Δshare)	(4) ΔHoldings	(5) ΔHoldings	(6) ΔHoldings
ΔTier 1	-0.4749	-0.6501	-0.2208	0.0009	0.0042	-0.0103
	(0.7391)	(0.5140)	(1.1393)	(0.0065)	(0.0057)	(0.0067)
Government#ΔTier 1				-0.0291**		
				(0.0148)		
Domestic#ΔTier 1					-0.1295***	
					(0.0358)	
High yield#ΔTier 1						0.0263*
						(0.0141)
Observations	237	237	237	324,069	324,069	291,420
R-squared	0.0048	0.0056	0.0002	0.4251	0.4251	0.4256
Banking system FE	Yes	Yes	Yes			
Bond x Time-period FE				Yes	Yes	Yes
Bond x Banking system FE				Yes	Yes	Yes

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. The dependent variable in Column 1 is the quarter on quarter change in domestic bond holdings as a percentage of a banking system's total bond holdings. Column 2 uses the change in the share of government bond holdings, and Column 3 uses the change in the share of high-yield bond holdings. The dependent variable in Columns 4 to 6 is the quarter on quarter change in a banking system's holdings of an individual bond i as a percentage of the total amount outstanding of this bond. Standard errors in Columns 4-6 are clustered at the bond level.

Columns 4–6 of Table 2 use the disaggregated security-level data to estimate a parsimonious version of Equation (1), along with security by year-quarter fixed effects and security by country-banking system fixed effects. There is now significant evidence that banks adjust their bond portfolio holdings in response to regulatory solvency shocks. The dependent variable in Columns 4–6 is the quarter-on-quarter change in a banking system's position in a specific bond. From Column 4, a one percentage point decline in a banking system's Tier 1 ratio is associated with a 0.03 percentage point increase in the banking system's holdings of government bonds.

Note that because Column 4 uses security by year-quarter fixed effects, it absorbs time-varying shocks to each security's expected returns, thereby estimating the likely causal effect of the regulatory solvency shock on the banking system's portfolio adjustment. Put differently, for two otherwise separate banking systems that hold the same government bond, Column 4 suggests that the banking system that suffers a decline in its solvency ratio increases its holdings of the government security relative to the unaffected banking system.

Column 5 suggests that adjustment to solvency shocks also occurs along the “domestic” dimension. In this case, a one percentage point decrease in the change in the Tier 1 equity ratio is associated with a 0.13 percentage point increase in the banking system’s holdings of domestically issued bonds. This result is consistent with the risk-shifting hypothesis, whereby domestic banking-systems purchase domestic assets because of the high correlation between domestic assets and their own performance. The moral suasion hypothesis – banking systems in need of forbearance purchase domestic assets to curry favor with domestic authorities – could also explain these results. Three factors weigh against the moral suasion interpretation. First, the shift to centralized supervision and regulation within the ECB limits the influence of national governments and banking supervisors on their banks. Second, these intensive margins changes in bond holdings are unlikely to be large enough to matter for domestic firms. Third, rolling over maturing bank loans that otherwise could be difficult to refinance would seem a likelier conduit for moral suasion than buying bonds in secondary markets.

In keeping with the idea that regulation and centralized supervision might limit the simplest manifestations of the risk-shifting incentive, Column 6 shows that a one percentage point drop in the Tier 1 risk weighted solvency ratio is associated with 0.03 percentage point average decline in a banking system’s position in “high yielding” bonds. This suggests that the enforcement of risk-weighted capital requirements by supervisory authorities might limit the scope for the simplest forms of risk-shifting, barring banks from increasing their exposure to the riskiest asset class after adverse solvency shocks. Note that there are no regulations that limit a bank’s exposure to OECD sovereign debt, or to domestic assets.[12]

To tell apart better the different hypotheses, Table 3 jointly includes the interaction terms for the different types of bond characteristics. From Column 1, the individual terms

[12] Basel regulations on concentration or exposure risks can be found at `https://www.bis.org/press/p140415.htm`

Table 3: Changes in solvency and bond holdings

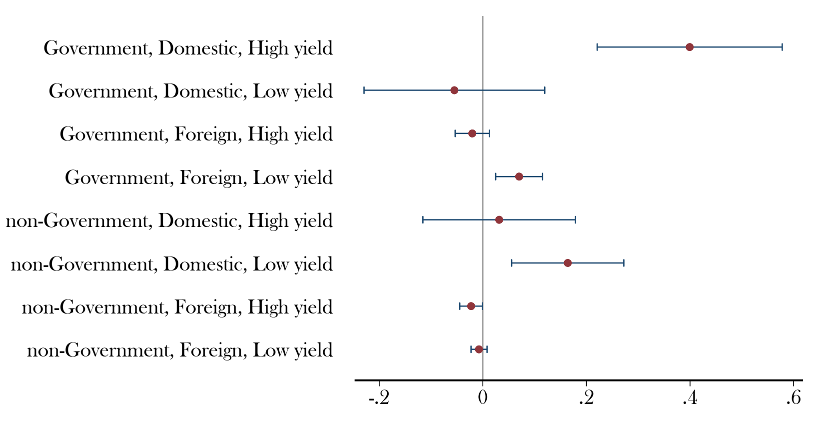
	Tier 1 / Risk Weighted Assets		Tier 1 / Assets
Variables	ΔHoldings (1)	ΔHoldings (2)	ΔHoldings (3)
ΔCapitalisation	0.0042	0.0074	0.0053
	(0.0070)	(0.0079)	(0.0139)
Government#ΔCapitalisation	-0.0336**	-0.0775***	-0.0089
	(0.0155)	(0.0244)	(0.0461)
Domestic#ΔCapitalisation	-0.1374***	-0.1714***	-0.0743
	(0.0374)	(0.0559)	(0.0780)
High yield#ΔCapitalisation	0.0373***	0.0153	0.0285
	(0.0143)	(0.0136)	(0.0299)
High yield#Government#ΔCapitalisation		0.0753**	-0.0140
		(0.0315)	(0.0694)
High yield#Domestic#ΔCapitalisation		0.1172	-0.1385
		(0.0932)	(0.1464)
Government#Domestic#ΔCapitalisation		0.2964***	-0.0410
		(0.1101)	(0.1507)
High yield#Government#Domestic#ΔCapitalisation		-0.6619***	-0.0170
		(0.1617)	(0.2309)
Observations	291,420	289,786	289,786
R-squared	0.4257	0.4267	0.4266
Bond x Banking system FE	Yes	Yes	Yes
Bond x Time-period FE	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1. Column 2 estimates Equation (1). The dependent variable is the quarter on quarter change in a banking system's holdings of an individual bond i as a percentage of the total amount outstanding of this bond. Standard errors are clustered at the bond level. Columns 1 and 2 use ratio of Tier 1 equity to risk weighted assets (i.e., the Tier 1 ratio) as the measure of bank capitalization, and Column 3 replaces this measure with Tier 1 equity to total assets (i.e., the Leverage ratio).

remain statistically significant, and their point estimates are somewhat more pronounced than in Table 2. For example, a one percentage point drop in the Tier 1 risk weighted solvency ratio is associated with about a 0.04 percentage point average decline in a banking system's position in "high yielding" bonds.

Column 2 focuses in greater detail on the overlapping dimensions through which adjustment of banks to distress might occur. As described in Equation (1), this more granular specification allows the adjustment margin to additionally depend on whether the bond is both high yield and government; high yield and domestic; government and domestic; and finally, high yield, government and domestic. The latter category is especially important, as it models the joint importance of the regulatory arbitrage and risk-shifting hypothesis in the adjustment process.

Figure 4: Effect on bond holdings of a decline in the Tier 1 ratio



There is evidence that faced with adverse solvency shocks, banking systems exploit the fact that capital regulations place a zero risk weight on sovereign debt. Despite the move to the SSM, banking systems appear to exploit this feature of capital regulation by shifting into higher yielding domestic government debt after an adverse solvency shock. Figure 4 shows that a one percentage point decline in the Tier 1 to risk weighted assets ratio suggests a 0.40 percentage point increase in a banking system's holdings of high yielding domestic government debt. Higher yielding domestic sovereign debt is generally longer duration debt, and while we cannot observe the banking system's hedging activities, this asset substitution suggests that solvency ratios could underestimate the overall riskiness of the banking system.

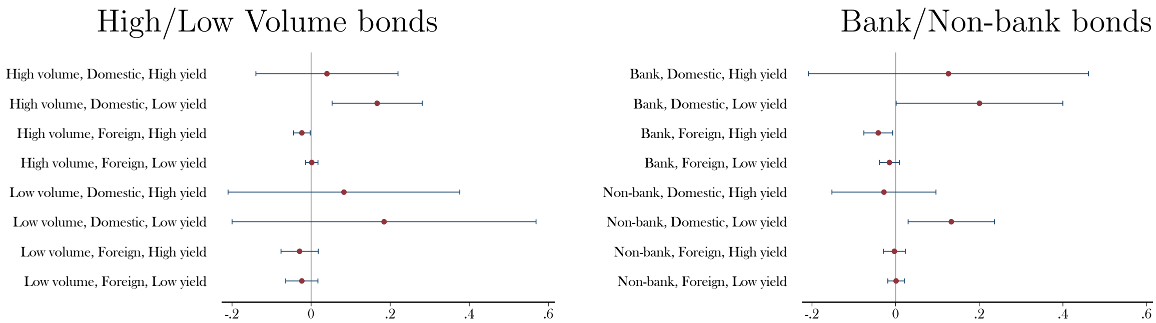
While holdings of sovereign debt are not constrained by capital regulations, there is also further evidence of risk-shifting within the constraints of capital regulation. A one percentage point decline in the Tier 1 to risk weighted assets ratio suggests a 0.16 percentage point increase in the banking system's holdings of low yielding domestic assets. Note that low yielding domestic assets are highly correlated with the solvency of the domestic banking system; in the relatively extreme circumstances under which these assets default, the domestic banking system is likely to be in default as well. These assets are therefore especially attractive for risk shifting purposes. Moreover, the risk weights used in capital regulations limit the ability of distressed banks to gamble by buying higher-yielding private sector assets. Indeed, banks reduce their exposure to private sector, high yielding foreign debt. To wit, after an adverse solvency shock, banks appear to adjust their bond portfolio in order to economize on regulatory capital and gamble on the performance of domestic assets by increasing the home bias in their bond portfolio.

Rather than reflecting risk-shifting, this greater home bias in the banking system's bond portfolio after a solvency shock is also consistent with models of endogenous information acquisition (Van Nieuwerburgh and Veldkamp 2009). Because domestic banks are likely better informed about domestic assets than their foreign competitors, these models predict that domestic banks might exploit their comparative information advantage in domestic assets to create "safer" portfolios that overweight on domestic assets after an adverse shock – a "flight to safety". Weighing against this information interpretation is the fact that domestic banks would not be expected to have any relative valuation advantage for sovereign debt, especially after an adverse solvency shock. But differences in capitalization among private sector bonds also provide another means of evaluating this information narrative.

If indeed information differences explain this home bias result, then this information narrative would also predict that domestic banks would disproportionately increase their exposure to small capitalization domestic bonds. These bonds are generally thinly traded and domestic banking systems will likely have an even greater informational advantage in valuing these bonds relative to foreign investors. From the left panel in Figure 5, if anything domestic banking systems increase their exposure to the domestic large capitalization bonds. This panel focuses on the specification in Column 2 of Table 3, distinguishing between the effects on low capitalization and high capitalization bonds. Moreover, because systematic rather than idiosyncratic factors drive the performance of these large capitalization bonds, these bonds covary positively with the performance of the domestic banking system, making risk-shifting the more likely explanation. In fact, there is no evidence that domestic banks significantly exploit their information advantage in small capitalization bonds after an adverse solvency shock.

The right panel in Figure 5 provides further evidence in favor of the risk shifting hypothesis. This panel again focuses on the specification in Column 2 of Table 3, now distinguishing between the effects on bonds issued by banks and by non-banks. Clearly, the performance of domestic bank debt is most highly correlated with the performance of the domestic banking system. And some models note further that distressed banks can have an incentive to herd, collectively buying each other's debt, in order to increase the risk of failing together and precipitate a collective bailout (Acharya and Yorulmazer 2007). Consistent with this form of the risk-shifting hypothesis, the panel suggests that after a one percentage point decline in the Tier 1 to RWA ratio, the domestic banking system increases its net holdings of low-yielding and lower risk weight domestic bank debt by 0.2 percentage points. Measuring the information set of investors is generally difficult, but this evidence weighs against the information cum flight to safety hypothesis

Figure 5: Effect on private sector bond holdings of a decline in the Tier 1 ratio



A key objection to these results is that shocks to solvency might proxy for other balance sheet shocks, such as asset quality, that ultimately explain adjustment. For example, banking systems that experience an increase in funding costs because of creditor concerns about the system's asset quality, might rotate into sovereign debt to signal the quality of assets. At the same time, poor asset quality could eventually lead to losses and a depletion of equity, inducing a spurious association between contemporaneous equity shocks and the previously observed portfolio adjustments.

Our results are unchanged if we identify Tier 1 solvency shocks as the residual from a first order autoregressive process, suggesting that changes in Tier 1 capital do not mechanically proxy for other unobserved balance sheet outcomes.[13] But European banking regulations provide an important falsification test that can partially address the concern that changes in the Tier 1 ratio proxy for other relevant balance sheet characteristics that may not be directly related to risk-weighted capital regulation. The leverage ratio, the ratio of Tier 1 equity to total assets, supplements the risk based capital ratio in the US regulatory system, but was not introduced into European banking regulation until the very end of our sample–January 2018; prior to that banks had to merely report this ratio.

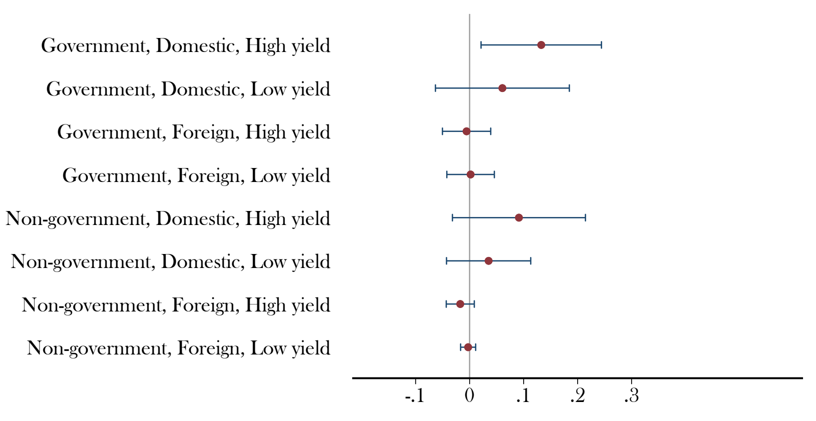
Since the numerator in the leverage ratio also captures shocks to equity, it also proxies for liquidity and other balance shocks that could ultimately explain the pattern of adjustment. In fact, since banks can to some extent manipulate risk weights, changes in the leverage ratio are likely more informative than changes in the Tier 1 ratio about shocks to a bank as a going concern (Mariathasan and Merrouche 2014). Hence, if the shocks to the Tier 1 ratio proxy for other balance sheet shocks rather than for risk-weighted capital constraints, replacing the change in the Tier 1 to risk weighted assets ratio with the change in the leverage ratio should yield approximately similar results. Similarly, if our results reflect unobserved factors that simultaneously drive bank equity shocks and the relative attractiveness of specific bonds, then using the leverage ratio instead of the regulatory solvency ratio should yield the same results.

However, if the results in Column 2 reflect the deliberate adjustment of banking systems to regulatory solvency shocks, then changes in the leverage ratio should yield insignificant results: regulators and banks did not target changes in leverage in the European context until the very end of the sample period. To examine this, Column 3 is based on the same specification as in Column 2, except that it uses the change in the leverage ratio as a proxy

[13] In particular, we estimate $Tier1_{jt} = \alpha_j + \beta Tier1_{jt-1} + v_{jt}$ using quarterly data, and replace $\Delta Tier1_{jt}$ with v_{jt} in Column 2 of Table 3. These results, available upon request, are little changed from that reported in Table 3.

for regulatory solvency shocks. The leverage ratio interactions are less precisely estimated and economically very small. As Figure 6 shows, in the one case where the effect of the leverage ratio shock is significant – the case of domestic government high yield debt – the implied effect is about 75 percent smaller than that obtained when using the ratio of Tier 1 equity to risk weighted assets.

Figure 6: Effect on bond holdings of a decline in the Leverage ratio



4.1.1 Bond holdings: robustness and extensions

A banking system's distance to regulatory insolvency can shape its incentives to engage in regulatory arbitrage and risk shifting after a solvency shock. For example, with a smaller equity cushion, an adverse solvency shock can make it even more attractive to shift into zero risk weighted assets like sovereign debt. Higher yielding sovereign debt assets can be especially attractive, as it can help rebuild a banking system's equity cushion faster. Systems that are closer to insolvency might also have greater incentives to gamble on domestic assets. Of course, if supervisory authorities want to maintain the bank as going concern, then they might limit the scope of the banking system to engage in regulatory arbitrage or search for yield behavior.

Table 4 examines these hypotheses. Columns 1 and 2 estimate the most basic specification separately for banking systems that have above median and below median regulatory

Table 4: Banking system sub-samples: low/high capitalization

Variables	High Tier 1 (1)	Low Tier 1 (2)	Difference (3)	High Tier 1 (4)	Low Tier 1 (5)	Difference (6)
ΔTier 1	0.0048	-0.0117	-0.0166	0.0005	0.0080	0.0074
	(0.0103)	(0.0175)	(0.0202)	(0.0128)	(0.0206)	(0.0241)
High yield#ΔTier 1	0.0245	0.0605**	0.0360	0.0210	-0.0015	-0.0225
	(0.0198)	(0.0274)	(0.0336)	(0.0191)	(0.0325)	(0.0376)
Government#ΔTier 1	-0.0430**	-0.0090	0.0340	-0.0755***	-0.0753*	0.0002
	(0.0204)	(0.0306)	(0.0366)	(0.0293)	(0.0454)	(0.0537)
Domestic#ΔTier 1	-0.0875**	-0.1680***	-0.0806	-0.0637	-0.2177***	-0.1540*
	(0.0404)	(0.0351)	(0.0537)	(0.0627)	(0.0490)	(0.0797)
High yield#Government#ΔTier 1				0.0601	0.1220*	0.0619
				(0.0418)	(0.0673)	(0.0790)
High yield#Domestic#ΔTier 1				0.0100	0.1779*	0.1679
				(0.0996)	(0.0931)	(0.1364)
Government#Domestic#ΔTier 1				0.2286*	0.2973***	0.0687
				(0.1209)	(0.0973)	(0.1563)
High yield#Government#Domestic#ΔTier 1				-0.7363***	-0.6109***	0.1254
				(0.1821)	(0.1660)	(0.2485)
Observations	291,420	291,420		289,786	289,786	
R-squared	0.4258	0.4258		0.4270	0.4270	
Bond x Banking system FE	Yes	Yes		Yes	Yes	
Bond x Time-period FE	Yes	Yes		Yes	Yes	

Note: *** p<0.01, ** p<0.05, * p<0.1. Columns 4 reports estimates from Equation (1) for bond holdings of banking systems with a low Tier 1 ratio, Column 5 reports estimates for bond holdings of banking systems with a high Tier 1 ratio, and Column 6 reports the differences between both samples. All estimates in Columns 4-6 are obtained from a single regression specification, which is equal to a version of Equation (1) where the regressors are interacted with a dummy variable for bond holdings of banking systems with a low/high Tier 1 ratio. The dependent variable is the quarter on quarter change in a banking system's holdings of an individual bond i as a percentage of the total amount outstanding of this bond. Standard errors are clustered at the bond level. The estimates in Columns 1-3 are obtained in a similar way.

solvency ratios respectively. Among the less-well capitalized systems, a one percentage point decline in the growth in regulatory solvency is associated with a 0.18 percentage point increase in the system's net position in domestic bonds; this effect is nearly twice that of the better capitalized systems in Column 1. There are also differences in the adjustment of these two systems towards government debt. At the same time, Column 3 shows that these differences are not statistically significant.

Columns 4 and 5 use the more granular regressions to understand better these differences in adjustment margins across banking systems. It shows that less-well capitalized banking systems shift disproportionately into private, low yielding domestic debt after an adverse solvency shock – the constrained risk-shifting hypothesis. A one percentage point negative solvency shock suggests a 0.21 percentage point increase in the holdings of private sector, low-yielding domestic bonds; among the better-capitalized systems, this adjustment margin is statistically insignificant. Within the category of domestic high-yielding government debt, both above and below median capitalization systems respond similarly. Taken together, the data suggest that risk-shifting occurs within the constraints of the capital requirements regulation. With limited balance sheet capacity to bear risk, distressed banking systems that are closer to insolvency increase their exposure to low-yielding domestic assets.

The incentives to engage in regulatory arbitrage by shifting into government debt likely depends on the riskiness of public sector debt and the capacity of the sovereign to bail-out creditors. In countries with high levels of government debt relative to GDP – like Portugal or Spain – government debt is likely to be riskier than countries with less government debt, such as Germany. And some versions of the risk-shifting hypothesis would then predict that banking systems in these more heavily indebted countries would be more likely to increase their exposure to higher yielding domestic government debt after an adverse equity shock. The moral suasion hypothesis could predict such an effect as well, as especially highly indebted governments may exert pressure on their banks to invest in domestic government debt.

However, in very highly indebted countries, bank creditors might correctly perceive the government as having little financial capacity to bail-out the banking system. And expecting large hair-cuts if domestic banks fail, creditors in these countries might exert greater discipline, and dissuade domestic banks from increasing their exposure to high-risk domestic governments. Table 5 considers this hypothesis that the indebtedness of the domestic government affects the adjustment of banking systems to solvency shocks. Columns 1 and 2 estimate separately the less granular specification for countries with below median government debt to GDP ratios (Column 1) and those above the median of this ratio (Column 2). There are suggestive differences in adjustment across these two subsamples. While a one percentage point drop in the solvency ratio is associated with a 0.05 percentage point increase in a banking systems' net position in government debt in

Table 5: Banking system sub-samples: low/high government debt

Variables	Low debt (1)	High debt (2)	Difference (3)	Low debt (4)	High debt (5)	Difference (6)
ΔTier 1	0.0088	-0.0050	-0.0138	0.0040	0.0165	0.0125
	(0.0103)	(0.0168)	(0.0193)	(0.0127)	(0.0199)	(0.0232)
High yield#ΔTier 1	0.0257	0.0568**	0.0311	0.0214	0.0007	-0.0207
	(0.0199)	(0.0265)	(0.0324)	(0.0190)	(0.0316)	(0.0363)
Government#ΔTier 1	-0.0535***	0.0077	0.0612*	-0.0883***	-0.0562	0.0321
	(0.0206)	(0.0290)	(0.0348)	(0.0291)	(0.0445)	(0.0524)
Domestic#ΔTier 1	-0.1145***	-0.1642***	-0.0497	-0.0741	-0.2433***	-0.1691**
	(0.0409)	(0.0347)	(0.0536)	(0.0583)	(0.0509)	(0.0775)
High yield#Government#ΔTier 1				0.0680	0.0915	0.0234
				(0.0418)	(0.0654)	(0.0769)
High yield#Domestic#ΔTier 1				0.0056	0.2078**	0.2021
				(0.0959)	(0.0952)	(0.1352)
Government#Domestic#ΔTier 1				0.3538**	0.2927***	-0.0611
				(0.1381)	(0.0935)	(0.1678)
High yield#Government#Domestic#ΔTier 1				-1.2017***	-0.5208***	0.6809**
				(0.2140)	(0.1552)	(0.2649)
Observations	291,420	291,420		289,786	289,786	
R-squared	0.4257	0.4257		0.4268	0.4268	
Bond x Banking system FE	Yes	Yes		Yes	Yes	
Bond x Time-period FE	Yes	Yes		Yes	Yes	

Note: *** p<0.01, ** p<0.05, * p<0.1. Columns 4 reports estimates from Equation (1) for bond holdings of banking systems in countries with a low government debt ratio, Column 5 reports estimates for bond holdings of banking systems in countries with a high government debt ratio, and Column 6 reports the differences between both samples. All estimates in Columns 4-6 are obtained from a single regression specification, which is equal to a version of Equation (1) where the regressors are interacted with a dummy variable for bond holdings of banking systems in countries with a low/high government debt ratio. The dependent variable is the quarter on quarter change in a banking system's holdings of an individual bond i as a percentage of the total amount outstanding of this bond. Standard errors are clustered at the bond level. The estimates in Columns 1-3 are obtained in a similar way.

systems located in less indebted countries, this effect is not significant in the more indebted subsample. Column 3, which computes the difference across the two specifications, suggests that these differences are weakly significant.

To understand better these effects, Columns 4 and 5 estimate the more granular specification separately for the two subsamples. The evidence suggests that adverse solvency shocks induce a larger shift into domestic higher yielding government debt in less indebted countries. A one percentage point decrease in regulatory solvency is associated with a 0.91 percentage point increase in a banking system's net position in higher yielding domestic government debt in the below median debt sample, but only a 0.21 percentage point increase in the more heavily indebted countries. Instead, these banking systems in more heavily indebted countries appear to increase their relative exposure to low-yielding, domestic, private sector debt.

While there are no formal or "Pillar 1" type regulations that limit a bank's exposure to the domestic sovereign, this result could reflect the fact that short-term creditors or ECB supervisors might exert some influence on these adjustment choices, limiting the ability of banks to concentrate risk in heavily indebted sovereigns. More likely is that banks, operating as fixed income investors, might have a target return on equity. And the required shift into domestic government debt in order to meet the target might be smaller in heavily indebted countries, as yields on those bonds would already be significantly higher than the yield on the equivalent maturity government bond in a low debt country (Gale and Yorulmazer 2010; Hanson et al. 2015).

The GIIPS countries — Greece, Ireland, Italy, Portugal and Spain -– were among the European countries most adversely affected by the 2008-2009 financial crisis and the ensuing sovereign debt crisis. They therefore provide an important setting to evaluate the risk-shifting hypothesis in the context of country risk. These five countries experienced simultaneous banking sector problems and government debt crises, with all except Italy losing access to private debt markets for a period of time. Table 6 replicates the same series of specifications as in Table 5, but splits the sample into GIIPS and non-GIIPs countries. The results are similar to those obtained using the more general government debt splits. After a one percentage point solvency shock, non-GIIPS banking systems increase their net position in domestic, government high-yielding assets by 0.76 percentage points; for GIIPS countries, this increase in exposure is only 0.17 percentage points. GIIPS banking systems tilt their adjustment relatively more towards private sector, low-yielding domestic bonds.

Table 6: Banking system sub-sample analysis: non-GIPS/GIPS countries

Variables	Non-GIPS (1)	GIPS (2)	Difference (3)	Non-GIPS (4)	GIPS (5)	Difference (6)
ΔTier 1	0.0078	-0.0072	-0.0150	0.0027	0.0308	0.0281
	(0.0099)	(0.0230)	(0.0255)	(0.0121)	(0.0270)	(0.0300)
High yield#ΔTier 1	0.0272	0.0581*	0.0309	0.0235	-0.0330	-0.0565
	(0.0190)	(0.0344)	(0.0400)	(0.0181)	(0.0436)	(0.0476)
Government#ΔTier 1	-0.0442**	-0.0043	0.0398	-0.0859***	-0.0528	0.0331
	(0.0198)	(0.0382)	(0.0439)	(0.0277)	(0.0597)	(0.0669)
Domestic#ΔTier 1	-0.1620***	-0.1211***	0.0410	-0.1319***	-0.2318***	-0.0999
	(0.0352)	(0.0407)	(0.0535)	(0.0502)	(0.0594)	(0.0774)
High yield#Government#ΔTier 1				0.0806**	0.0478	-0.0328
				(0.0395)	(0.0882)	(0.0977)
High yield#Domestic#ΔTier 1				-0.0007	0.3144***	0.3150**
				(0.0840)	(0.1143)	(0.1414)
Government#Domestic#ΔTier 1				0.2772**	0.2978***	0.0207
				(0.1122)	(0.1086)	(0.1556)
High yield#Government#Domestic#ΔTier 1				-0.9255***	-0.5452***	0.3804
				(0.1768)	(0.1820)	(0.2533)
Observations	291,420	291,420		289,786	289,786	
R-squared	0.4257	0.4257		0.4269	0.4269	
Bond x Banking system FE	Yes	Yes		Yes	Yes	
Bond x Time-period FE	Yes	Yes		Yes	Yes	

Note: *** p<0.01, ** p<0.05, * p<0.1. Columns 4 reports estimates from Equation (1) for bond holdings of banking systems in non-GIPS countries, Column 5 reports estimates for bond holdings of banking systems in GIPS countries, and Column 6 reports the differences between both samples. The list of GIPS countries includes Greece, Ireland, Portugal and Spain. All estimates in Columns 4-6 are obtained from a single regression specification, which is equal to a version of Equation (1) where the regressors are interacted with a dummy variable for bond holdings of banking systems in non-GIPS/GIPS countries. The dependent variable is the quarter on quarter change in a banking system's holdings of an individual bond i as a percentage of the total amount outstanding of this bond. Standard errors are clustered at the bond level. The estimates in Columns 1-3 are obtained in a similar way.

4.2 Price dynamics

We have seen evidence that banking systems adjust their bond portfolio in response to solvency shocks in ways that can potentially make the banking system riskier than its regulatory solvency ratio might suggest. These risks can in turn be transferred onto the banks' assets. Beginning with Grossman and Miller (1988), a large and influential theoretical literature has hypothesized that the capital position of intermediaries – market makers, broker-dealers and other large participants in a market – can influence market liquidity and pricing.[14]

A central idea in these models is that when markets are incomplete, financial institutions might be forced to sell assets in order to meet their regulatory solvency constraints or obtain liquidity.[15] In the interim, potential buyers of these assets must hold liquidity. But since holding liquidity is costly, the potential buyers of these assets will only do so if they can recoup the costs thereof by buying these assets at fire-sale prices. In our current setting, consider a bond that is mainly owned by an undercapitalized banking system. If the banking system does fail, then asset liquidations, including the sale of the bond, would be needed to payoff creditors. If the cash-in-the market to absorb these potential sales is limited, then these models predict that as the banking system approaches its regulatory solvency ratio and fire-sale risk increases, so should yields on these bonds. That is, bonds predominantly owned by less-well capitalized intermediaries should trade at a discount relative to otherwise similar bonds owned by intermediaries further away from regulatory insolvency.

A related set of arguments focus more specifically on the links between the health of the domestic financial system and the yields on government debt. These arguments note that banking-system distress that either precipitates a sovereign bailout, or increases expectations of such a bailout, could increase sovereign credit risk. These arguments also posit a feedback mechanism – a doom loop – whereby increased sovereign credit risk erodes the value of a banking-system's holdings of government debt, and thus the health of the banking system (Acharya, Drechsler, and Schnabl 2014).

To investigate these hypotheses, we construct the exposure to country-banking system solvency shocks for each bond in the sample. Specifically, let s_{ijt} denote the share of country banking system j in the holdings of bond i at time t. For example, if the German banking system owned 30 euro of a bond that has a total market capitalization of 100 euro, the German banking system's share of this bond i at time t would be 0.3. We then use

[14] See also Allen and Gale (2005); Brunnermeier and Pedersen (2009); He and Krishnamurthy (2013); Brunnermeier and Sannikov (2014).

[15] Rajan and Ramcharan (2016) and Ramcharan (2020) provide evidence of this fire-sale channel within the context of banking.

s_{ij} to compute the bond's exposure to solvency shocks: $\Delta\overline{Tier1}_{it} = \sum_j s_{ijt}\Delta Tier1_{jt}$. We next use this variable as a factor in pricing the bond:

$$\Delta Yield_{it} = \alpha_i + \alpha_{it}^{sector} + \alpha_{it}^{country} + \alpha_{it}^{maturity} + \beta\Delta\overline{Tier1}_{it} + e_{it}. \qquad (2)$$

Note that because a bond's exposure to banking system solvency shocks is weighted by the banking system's ownership share of the bond, reverse causality is unlikely to bias these estimates. In particular, each bond itself constitutes a very small share of the overall assets or even bond portfolio of a country-banking system. Hence, unobserved adverse shocks to an individual bond are unlikely to both increase the bond's yield and reduce country-banking system's risk based capital ratios.

Nevertheless, we saturate Equation (2) with issuing sector-by-year-quarter fixed effects to absorb time varying sector level shocks that could contaminate inference. For example, adverse economic news that increases all sovereign bond yields in a given quarter could also force banking systems to mark to market losses. Issuing sector-by-time fixed effects can non-parametrically control for these shocks. In addition, we include issuing country-by-year-quarter fixed effects to absorb common geographic shocks across bonds. At the bond-level, we control for residual maturity of the bond, which amongst others controls for the term structure of risk-free interest rates (Timmer 2018).

Table 7 reports the results from estimating Equation (2). The dependent variable is the change in the yield of an individual bond. Consistent with the prediction that bonds owned by distressed intermediaries might face greater fire-sale risk, Column 1 shows significant evidence that an increase in a bond's exposure to negative solvency shocks is associated with an increase in its yield. A one percentage point decline in the weighted average solvency is associated with a 0.19 percentage point increase in a bond's yield.

We next focus on whether these results vary depending on whether the bond is issued by a government. Column 2 interacts the weighted change in the Tier 1 ratio with an indicator variable that equals 1 if the bond is issued by a government and 0 otherwise. The evidence strongly suggests that yields on government bonds are significantly more

Table 7: Changes in solvency and bond yields

Variables	(1) ΔYield	(2) ΔYield	(3) ΔYield	(4) ΔYield
$\Delta\overline{\text{Tier1}}$	-0.1881***	-0.1407***	-0.1170**	-0.0784
	(0.0447)	(0.0473)	(0.0457)	(0.0500)
Government#$\Delta\overline{\text{Tier1}}$		-0.2159**		-0.1973**
		(0.0965)		(0.0917)
High yield#$\Delta\overline{\text{Tier1}}$			-0.1543**	-0.1454**
			(0.0729)	(0.0728)
Observations	177,864	177,864	176,841	176,841
R-squared	0.2587	0.2587	0.2685	0.2685
Bond FE	Yes	Yes	Yes	Yes
Residual maturity x Time FE	Yes	Yes	Yes	Yes
Issuing sector x Time FE	Yes	Yes	Yes	Yes
Issuing country x Time FE	Yes	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1. Column 1 estimates Equation (2). The dependent variable is the quarter on quarter change in the percentage yield on an individual bond i. Standard errors are clustered at the bond level.

sensitive to banking systems' solvency shocks. For private sector bonds, a one percentage point decline in the weighted solvency ratio is associated with a 0.14 percentage point increase in yields. But for a government bond, the same sized solvency shock suggests a 0.36 percentage point increase – more than double the private sector response. This result is consistent with both the fire-sale and sovereign risk hypotheses.

Columns 3 and 4 shows further that the greater sensitivity of government bonds to solvency shocks is not an artifact of the yield on the bond itself. Column 3 allows the effect of the solvency shock to depend on whether the bond is high-yielding. Solvency shocks among higher-yielding less liquid bonds have an effect more than two times bigger than the baseline magnitude. Column 4 combines the interaction terms, allowing the impact of weighted solvency shocks to vary depending on whether the bond is high-yielding, and whether the bond is government. The evidence in Column 4 shows that the effect of solvency shocks on bond yields are concentrated in these two types of bonds.

We have already seen that solvency shocks to banking systems induce portfolio adjust-

Table 8: Changes in solvency and bond yields while controlling for changes in holdings

Variables	(1) ΔYield	(2) ΔYield	(3) ΔYield	(4) ΔYield
$\Delta\overline{\text{Tier1}}$	-0.1677***	-0.1199**	-0.1018**	-0.0593
	(0.0444)	(0.0469)	(0.0457)	(0.0500)
ΔHoldings	-0.0217***	-0.0178***	-0.0049***	0.0011
	(0.0022)	(0.0019)	(0.0011)	(0.0019)
Government#$\Delta\overline{\text{Tier1}}$		-0.2425**		-0.2333**
		(0.0966)		(0.0914)
Government#ΔHoldings		-0.0402***		-0.0470***
		(0.0123)		(0.0123)
High yield#$\Delta\overline{\text{Tier1}}$			-0.1400*	-0.1352*
			(0.0724)	(0.0722)
High yield#ΔHoldings			-0.0298***	-0.0323***
			(0.0038)	(0.0042)
Observations	177,864	177,864	176,841	176,841
R-squared	0.2610	0.2618	0.2719	0.2730
Bond FE	Yes	Yes	Yes	Yes
Residual maturity x Time FE	Yes	Yes	Yes	Yes
Issuing sector x Time FE	Yes	Yes	Yes	Yes
Issuing country x Time FE	Yes	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the quarter on quarter change in the percentage yield on an individual bond *i*. The change in holdings is calculated as the percentage point change in the holdings of bond *i* by the sum of all banking systems in the sample. Standard errors are clustered at the bond level.

ments at these systems, and a key concern is that these changes in yields reflect changes in relative demand among banking systems rather than the fire-sale hypothesis. That is, an adverse solvency shock to a country's banking system could decrease that banking system's relative demand for certain kinds of bonds, thereby increasing the yield on the bond. To address this possibly mechanical form of bias, Table 8 replicates Table 7, but includes the change in the holdings of each bond among all banking systems. The change in holdings is clearly jointly determined along with yields, but the impact of a bond's weighted exposure to solvency shocks is unchanged. From Column 1 of Table 8 for example, the coefficient on the Tier 1 variable is -0.17, while the corresponding coefficient in Table 7 is -0.19.

Disaggregating the data by domestic and foreign bond holdings can help us tell apart more easily whether the fire-sales or the sovereign risk hypothesis explain the larger impact of solvency shocks on government bond yields. Under the sovereign risk hypothesis, it is the domestic governments that would be expected to bail out its own banking system. And thus, when the nationality of the banking system and the government is the same, shocks to the solvency of the banking system should have the largest effect on domestic government yields. In contrast, distress at banking systems does not increase the contingent liabilities of the foreign government. As such, any negative relationship between solvency shocks and foreign government debt likely reflect the fire-sale hypothesis rather than the cost of any sovereign bail-out.

Table 9: Changes in solvency and domestic and foreign bonds yields

Variables	(1) ΔYield	(2) ΔYield	(3) ΔYield	(4) ΔYield
Domestic#$\Delta\overline{\text{Tier1}}$	-0.1499***	-0.0532	-0.0616	0.0268
	(0.0577)	(0.0665)	(0.0683)	(0.0764)
Foreign#$\Delta\overline{\text{Tier1}}$	-0.2310***	-0.2608***	-0.1758***	-0.1882***
	(0.0684)	(0.0661)	(0.0558)	(0.0618)
Government#Domestic#$\Delta\overline{\text{Tier1}}$		-0.4049***		-0.3596***
		(0.0837)		(0.0789)
Government#Foreign#$\Delta\overline{\text{Tier1}}$		0.1567		0.1225
		(0.2405)		(0.2312)
High yield#Domestic#$\Delta\overline{\text{Tier1}}$			-0.1744**	-0.1784**
			(0.0844)	(0.0844)
High yield#Foreign#$\Delta\overline{\text{Tier1}}$			-0.1354	-0.1579
			(0.1371)	(0.1331)
Observations	177,864	177,864	176,841	176,841
R-squared	0.2587	0.2587	0.2685	0.2685
Bond FE	Yes	Yes	Yes	Yes
Residual maturity x Time FE	Yes	Yes	Yes	Yes
Issuing sector x Time FE	Yes	Yes	Yes	Yes
Issuing country x Time FE	Yes	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the quarter on quarter change in the percentage yield on an individual bond i. Standard errors are clustered at the bond level.

Column 1 of Table 9 thus again uses the weighted exposure of a bond to changes in solvency of the banking system, where as before the weight is that banking system's share of the bond. However, the specification now computes this weighted exposure separately for whether the banking system is from the same country as the bond issuer. Adverse solvency shocks to bank owners of foreign bonds, as well as shocks to bank owners of domestic bonds both increase yields. But we have already seen that banks sell foreign bonds when solvency declines, and the point estimate on the weighted change in solvency shocks is about 50 percent larger for foreign bonds than for domestic bonds.

Column 2 allows the effect of a weighted solvency change to depend on whether the bond is issued by a domestic or a foreign government. There are striking differences across the effect of solvency changes. A one percentage point decrease in the weighted solvency is associated with about a 0.1 percentage point increase in the yields on foreign government bonds, but this effect is not significant. This result is consistent with the idea that shocks to banking systems do not increase the contingent liabilities of foreign governments. At the same time, yields on foreign private sector bonds increase by 0.26 percentage points after a 1 percentage point decline in solvency, which suggests that foreign private sector bonds are more sensitive to fire sales.

But the impact of solvency shocks on bond yields is especially large for domestic government bonds. In this case, a one percentage point decline in the solvency of the banking system suggests a 0.47 percentage point increase in the yield of domestic government debt that is owned by the banking system. This large effect suggests that sovereign risk is of considerable importance in explaining the impact of bank solvency shocks on domestic government bond yields. Columns 3 and 4 of Table 9 check whether these results are driven by illiquid higher yielding assets. The differential effects between domestic and foreign banking systems on government bonds persist. Moreover, especially higher yielding bonds decline in price after a negative solvency shock, which is consistent with the idea that riskier bonds are more sensitive to fire sales.

5 Conclusion

This paper uses granular bond portfolio data across the European Union to study how banking systems adjust their asset holdings in response to regulatory solvency shocks in the period after the EU harmonized banking regulation across its member states and centralized supervision within the ECB. We find evidence that banks risk-shift within the constraints of risk-weighted capital regulation. Adverse solvency shocks for example induce banking systems to increase their exposure at the intensive margin to domestic higher yielding but zero risk-weight government bonds. Banking systems also increase their exposure to domestic low-yielding bonds after adverse shocks. And these effects are especially strong for less well capitalized banking systems. Domestic assets are highly correlated with the survival of the domestic banking system, and their lower risk weights allow these banking systems to increase their exposure within the constraints of capital regulation.

We also study the effects of these bank solvency shocks on bond prices. We find significant evidence that a bond's weighted average exposure to negative solvency shocks is associated with an increase in its yield. This is consistent with the hypothesis that the potential for future disorderly asset liquidations by distressed sellers can affect current yields. These effects are largest for high yielding illiquid bonds and for government bonds. Disaggregating by the nationality of the banking system, we find that a government bond's weighted average exposure to negative solvency shocks emanating from the domestic banking system has very large effects on yields. By contrast, the yields of foreign government bonds do not increase in response to negative solvency shocks of the holding banks. This contrast is consistent with the fact that shocks to the regulatory solvency of the banking system increases both the liquidation risk of domestic government bonds held by this banking system as well as the contingent liabilities of the domestic government.

Taken together, these results suggest that capital regulation, and the use of risk weights, interact with the risk shifting hypothesis to explain banking systems' portfolio adjustments after an adverse regulatory solvency shock. The shift into more illiquid assets, and the decline in asset diversification suggest that banking systems might be even riskier than their distance to regulatory insolvency might suggest. Sovereign debt is important for the functioning of credit markets and financial regulation, and the impact of solvency shocks on bond yields also shows how distress in banking systems might feedback onto asset prices in the economy, and create an "overhang", impeding recovery after a banking crisis. Moreover, while we cannot measure the extent of bank-risk taking incentives in the absence of the SSM, this evidence suggests that the SSM in its current version might only imperfectly represent the interests of member states when banking systems suffer solvency shocks. The empirical estimates in this paper could be useful for general equilibrium modelling exercises that aim to quantify the effectiveness of regulation and of solvency shocks on bank-risk taking behavior and asset prices.

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