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The (unobservable) value of central bank's refinancing operations

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Abstract

We quantify the impact that central bank refinancing operations and funding facilities had at reducing the banking sector's intrinsic fragility in the euro area in 2014-2019. We do so by constructing, estimating and calibrating a micro-structural model of imperfect competition in the banking sector that allows for runs in the form of multiple equilibria, in the spirit of Diamond & Dybvig (1983), banks' default and contagion, and central bank funding. Our framework incorporates demand and supply for insured and uninsured deposits, and for loans to firms and households, as well as borrowers' default. The estimation and the calibration are based on confidential granular data for the euro area banking sector, including information on the amount of deposits covered by the deposit guarantee scheme and the borrowing from the European Central Bank (ECB). We document that the quantitative relevance of non-fundamental risk is potentially large in the euro area banking sector, as witnessed by the presence of alternative equilibria with run-type features, but also that central bank interventions exerted a crucial role in containing fundamental as well as non-fundamental risk. Our counterfactuals show that 1 percentage point reduction (increase) in the ECB lending rate of its refinancing operations reduces (increases) the median of banks' default risk across equilibria by around 50%, with substantial heterogeneity of this pass-through across time, banks and countries.

JEL-classification: E44, E52, E58, G01, G21, L13.

Keywords: Central bank policies, Bank runs, Multiple equilibria, Imperfect competition, Structural estimation.

Non-technical summary

Economic theory clearly explains that banks are intrinsically fragile institutions, as they are subject to a host of strategic complementarities such as expectations over the performance of their exposures, the evolution of their funding costs, or the behaviour of competitors in lending and deposit markets. In this context, it is recognized that one of the main effects and purposes of central bank liquidity injections and refinancing operations is to prevent the materialization of adverse equilibria with runs on retail or wholesale bank funding, eventually resulting in disorderly deleveraging with potentially very large welfare losses.

Surprisingly, despite the widely acknowledged relevance of this source of tail risk and of the role played by central banks in this context, the empirical evidence of these mechanisms is, at best, still scant. The main reason for that is the severity of the identification challenge that needs to be tackled: the endogenous timing of central bank interventions, or even just the expectation about these measures, is sufficient to eradicate the risk of the materialisation of runs. This also explains why runs are relatively rare events and why such rarity cannot be taken as sign of a limited role of central banks in addressing this source of systemic risk.

Our paper addresses this challenge by developing and estimating a micro-structural model of bank competition, also including a central bank that can inject potentially unlimited amount of liquidity at pre-determined conditions. The model is partly estimated and partly calibrated based on proprietary individual data for the euro area. The model also takes into account of the presence of other relevant institutional features that can mitigate the intrinsic fragility of the banking sector, namely the presence of a deposit insurance scheme. With this tool at hand it becomes possible to check to what extent the economy admitted alternative equilibria other than the realised one, and what are their features. Moreover, it is possible to construct counterfactual scenarios of what we would have observed had the central bank not (endogenously) intervened, which is what is needed to effectively assess the effects of its interventions.

Our main findings relate to the documentation and characterisation of multiple equilibria. For any bank in any given period, we define as fundamental risk its average default probability across the different existing equilibria and as non-fundamental risk its dispersion. First, we show that the presence of non-fundamental risk is highly relevant for the euro area banking sector, as witnessed by the pervasiveness of the multiplicity of equilibria and the very adverse outcome these entail. Second, even under the observed and accommodative monetary policy the economy admitted multiple equilibria, on top of the observed equilibrium. Compared to the latter, the alternative equilibria tend to be characterized by worse aggregate outcomes. Some intrinsic fragility (the possibility that the economy shifts to an inefficient equilibrium) has therefore been present and was not fully eradicated by the accommodative policies actually implemented. Interestingly, in isolated but meaningful cases the economy also admitted some equilibria that were more efficient than the realized. This can be interpreted as suggesting that more confidence could have moved the economy into a more efficient region. Non-fundamental risk is on average positively related to fundamental risk, meaning that banks with higher default probability tend to be more exposed to the risk of run-type equilibria. The simulations of counterfactual scenarios where central bank funds are artificially provided at more or less accommodative conditions indicate that monetary policy has a strong impact in mitigating both fundamental and non-fundamental risk.

1 Introduction

Since the seminal contribution by Diamond & Dybvig (1983) and Goldstein & Pauzner (2005), it is well understood that banks are intrinsically fragile institutions, as they are subject to a host of strategic complementarities such as expectations over the performance of their exposures, the evolution of their funding costs, or the behaviour of competitors in lending and deposit markets. In this context, it is recognized that one of the main effects and purposes of central bank liquidity injections and refinancing operations is to prevent the materialization of adverse equilibria with runs on retail or wholesale bank funding, eventually resulting in disorderly deleveraging with potentially very large welfare losses. Largely motivated by this purpose, in the last ten years the European Central Bank launched a series of massive short and long term refinancing operations, with peak take up of €1.5 trillions, corresponding to around 15% of the euro area GDP.

While other institutional features exist to temper the risk of bank runs, notably the presence of deposit insurance schemes, monetary policy can be considered to maintain a crucial role in dealing with banks' intrinsic fragility due to several factors. First, moral hazard considerations explain why deposit insurance schemes universally envisage only a partial coverage (I.A.D.I. 2013). Second, deposit insurance could be ineffective at preventing systemic runs because it is often not financed upfront, but instead based on ex post contributions provided on a mutualistic basis by other intermediaries within the same banking sectors. Third, deposit insurance could also fail to work when the solvability of the domestic government, often considered the ultimate explicit or implicit guarantor of bank liabilities, is doubtful to begin with or is put at stake by the bank run itself, through the so-called sovereign bank nexus (Dell'Ariccia, Ferreira, Jenkinson, Laeven, Martin, Minoiu & Popov 2018). Finally, as clearly shown by the experience of the global financial crisis, runs can concern not only retail deposits but also, if not primarily, wholesale ones (Gorton 2010).

Surprisingly, despite the presence of this source of tail risk and the widely acknowledged role played by central banks in this context, the empirical evidence of the relevance of these prevention mechanisms is, at best, still scant. In principle, in order to be able to quantify the effectiveness of central banks' interventions in this context, one should identify and compare episodes where central banks exogenously did not intervene with comparable episodes where they intervened. This is clearly a daunting task because of the endogenous timing of these measures, which are adopted by central banks whenever the risk of a systemic run emerges. If such endogeneity issue is not adequately dealt with, both the risk of a run and the stabilization impact of monetary policy interventions will be largely underestimated. In other words, it could be argued that it is essentially impossible to grasp the role of monetary policy in taming the risk of runs when, in equilibrium, runs are actually hardly ever observed. Moreover, run equilibria can be averted even in the absence of an explicit central bank intervention, because the very fact that agents expect the central bank to step in can be sufficient at inducing them to coordinate on a non-run equilibrium. These considerations suggest that, in order to tackle this crucial and thorny identification challenge, the empirical strategy should be based on a framework that allows constructing simulated counterfactual scenarios which can quantify what would have happened in the absence of the central bank's interventions.

Our paper addresses this challenge developing and estimating such framework, and simulating those counterfactual scenarios, to quantify the effectiveness of central bank's refinancing operations at preventing bank runs in the form of multiple equilibria. Specifically, we build and estimate a structural equilibrium framework of the euro area banking sector, modeling demand and supply in imperfectly competitive deposit and loan markets, as well as borrowers' and banks' default risk, and the central bank's funding interventions. We generalize the approach of Egan, Hortaçsu & Matvos (2017), which quantifies multiple equilibria with bank run features for the US banking sector, and

we analyze the effects of banking regulation on the multiplicity of equilibria and welfare. In order to quantify the value of the central bank's interventions, we extend their framework along two crucial dimensions.

First, we allow for the presence of a central bank which is willing to inject liquidity in the banking sector at pre-determined conditions. This is in line with the central bank's function of lender of last resort, through which it can alter the competition for deposits in the banking sectors, and potentially eradicate run equilibria. This role allows the central bank to lower the severity of feedback loops between high deposit rates, low profitability, and higher banks' default probabilities, reducing the multiplicity of equilibria and increasing the resilience of the system. Second, we introduce into the model a market for bank loans to the real sector under asymmetric information, following Crawford, Pavanini & Schivardi (2018). Modelling simultaneously loan granting and deposit taking is not only done for the sake of realism, but also because it is a crucial ingredient to be able to assess the implications of banks' intrinsic fragility on banks' lending capacity and ultimately on the real economy, as captured by developments in borrowing firms' default rates.

The structural model provides a characterization of banks' activity with high degree of detail, and allows for various dimensions of heterogeneity across banks. In particular, our framework models banks' behavior at the individual intermediary-level for what concerns both lending and liabilities, following the empirical industrial organization literature on demand for differentiated products (Berry 1994, Berry, Levinsohn & Pakes 1995). On the deposit demand side, we distinguish between insured and uninsured depositors and estimate their preferences for bank characteristics, including interest rates and banks' default risk, while on the supply side banks compete on interest rates and have heterogeneous and time-varying marginal costs of providing deposit services. Banks are allowed to raise capital not only through deposits, but also through bonds and via borrowing from the central bank. On the lending side, we distinguish between loan demand for households and non-financial corporations (NFCs) and estimate their preferences for bank characteristics, including interest rates, while on the lending supply side banks compete on interest rates, have heterogeneous marginal costs, but also form expectations over borrowers' default risk that affect their pricing. Last, banks have limited liability and may default if a shortfall in profits exceeds their franchise value next period. The ability of the model to identify and characterize all possible multiple equilibria that would be admissible, with the same fundamentals and monetary policy that determined the observed data, allows to evaluate the resilience of the banking system to run-like episodes during its recent historical experience. The possibility to do the same under counterfactual scenarios for the monetary policy allows gauging the unobserved beneficial effects of such policy interventions.

The model is estimated with mostly two proprietary ECB datasets on euro-area banks, and allows to analyze the various liquidity operations adopted by the ECB since 2009. In our setting, we focus on the latest rounds of the Targeted Longer-Term Refinancing Operations (TLTROs) during the period 2014-2019, which covered almost all of the ECB funding to banks with a peak take up at €780 billions. Our estimation is based on the Individual Balance Sheet Indicators (IBSI) database, which reports at the unconsolidated level the main asset and liability items of over 260 banks resident in the euro area from August 2007 to November 2019. This dataset provides information on the amount of outstanding deposits, loans, and other relevant bank balance sheet information. We complement IBSI with the Individual Monetary and Financial Institutions Interest Rates (IMIR) database, which contains information on deposits and lending rates. Information on the breakdown between insured and uninsured deposits is obtained from confidential supervisory statistical reports. The merge of our rich data yields a representative sample of the euro area banking sector, consisting of an unbalanced panel of 86 banks for 148 months from August 2007 to November 2019, covering 12 euro area countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Portugal,

Slovakia, Spain, and the Netherlands). The banks in our sample represent around 60% of their domestic loan and deposit markets on average across countries.

The demand schedules included in our structural model are estimated with instrumental variables. The main results can be summarized as follows. We find that insured and uninsured depositors are almost equally price sensitive, with rather low demand elasticity of around 0.15. As expected, our estimates show that uninsured deposits' market shares are decreasing with banks' default probabilities, but we also find a similar result for insured deposits' market shares, with a smaller elasticity corresponding to around one third of that of uninsured deposits. This latter result can be explained by the doubtful solvability of some of the euro area domestic governments, especially during the sovereign debt crisis. The stronger relationship between banks' share of uninsured deposits and their default risk is what generates a potential mechanism of financial contagion across banks, which can be summarized as follows. Distressed banks, finding it hard to attract depositors in the uninsured sector, will be forced to offer more attractive rates in the insured deposit market to make up for the loss of capital. This however will push solvent banks to raise their rates too, in order not to lose insured deposits, increasing their cost of capital and negatively affecting their solvency. As expected, we find a negative demand elasticity for loans, with NFCs being more sensitive than households, and find that borrowers' expected default rates are increasing in loan interest rates, consistent with evidence of either adverse selection or moral hazard. In line with recent work (Ippolito, Peydró, Polo & Sette 2016, Altavilla, Boucinha, Holton & Ongena 2019, Albertazzi & Esposito 2017), we find that loan demand is decreasing in bank's default risk, even though to a lesser extent than uninsured deposits' demand.

In terms of documenting multiple equilibria and counterfactuals, our main findings can be summarized as follows. We define as fundamental risk the average default probability of a bank-time combination across all admissible equilibria, and as non-fundamental risk its dispersion. First, we show that the presence of non-fundamental risk is highly relevant for the euro area banking sector, as witnessed by the pervasiveness of the multiplicity of equilibria. We consider this an important result, hinting towards a framework for economic fluctuations that is different from the one embedded in many macro-economic models. Second, even under the observed and accommodative monetary policy the economy admitted multiple equilibria, on top of the observed equilibrium. Compared to the latter, the alternative equilibria tend to be characterized by worse aggregate outcomes. Some intrinsic fragility (the possibility that the economy shifts to an inefficient equilibrium) has therefore been present and was not fully eradicated by the accommodative policies actually implemented. Interestingly, in isolated but meaningful cases the economy also admitted some equilibria more efficient than the realized. Non-fundamental risk is on average positively related to fundamental risk, meaning that banks with higher default probability tend to be more exposed to the risk of run-type equilibria. The simulations of counterfactual scenarios where central bank funds are artificially provided at more or less accommodative conditions indicate that monetary policy has a strong impact in mitigating both fundamental and non-fundamental risk .

Related Literature. A number of empirical studies of central bank liquidity injections, based on granular datasets and on a diff-in-diff approach, look at their impact on credit supply.¹ These studies capture the stimulative effect of the accommodative conditions at which these funds were provided, that is at cheaper conditions compared to what otherwise available in funding markets. However, these papers cannot capture the role of liquidity injections in averting the materialization

¹For the euro area see, for example, Carpinelli & Crosignani (2018), Jasova, Mendicino & Supera (2018), Andrade, Cahn, Fraisse & Mésonnier (2019), and Garcia-Posada & Marchetti (2016). Similar analysis for the US and focusing on money-market mutual funds, instead of banks, is presented in Duygan-Bump, Parkinson, Rosengren, Suarez & Willen (2013).

of runs, which might have huge but yet unobservable consequences if the central bank intervention itself is successful. To better clarify the difference between the two channels, it can be pointed out that the cheap funding channel is by definition not active if central bank funds are provided at market conditions. The channel that we are instead looking at, that is the impact of central bank interventions in avoiding the realization of inefficient run equilibria, could in principle be active even if the rates applied were above prevailing market conditions.

As mentioned before, the closest article in terms of methodology is Egan et al. (2017), placing our work among a growing recent strand of papers applying structural equilibrium models from the empirical industrial organization literature to financial markets. This includes applications to insurance (Kojen & Yogo 2016), asset demand (Kojen & Yogo 2019), deposits (Ho & Ishii 2011, Xiao 2020), commercial loans (Crawford et al. 2018, Ioannidou, Pavanini & Peng 2019, Darmouni 2020), and mortgages (Benetton 2019, Robles-Garcia 2019). A recent paper by Wang, Whited, Wu & Xiao (2020) also estimates a micro-structural model of the banking sector to explore the transmission of monetary policy. Their objective is to document the high importance of the banking sector's market structure in affecting the monetary policy transmission mechanism. The paper does not envisage multiplicity of equilibria and therefore does not explore the relevance of what we define as non-fundamental risk nor the role played by monetary policy in abating it. In this respect, closer to our paper is also the analysis by Robatto (2019), who develops and calibrates a macro model of the banking sector with multiple equilibria, and shows how large enough liquidity injections may eradicate bad equilibria. The most relevant difference with our approach is that, by constructing, estimating and calibrating a structural micro-level banking model, we can better capture the role of heterogeneity in the banking sector, and assess the possibility of contagion of both fundamental and non-fundamental risk (bank-specific) shocks.

Last, we also contribute to the empirical work on runs both in the banking sector and in other financial markets (Iyer & Puri 2012, Iyer, Puri & Ryan 2016, Calomiris & Mason 2003). Pèrignon, Thesmar & Vuillemeys (2018), by focusing on wholesale markets, can identify and explore some episodes of funding dry-ups. However, as they point out, they do not observe market freeze, possibly reflecting the presence of stabilizing factors and, in particular, of lender of last resort facilities. Moreover, the episodes they consider largely refer to intermediaries in deep distress, which hardly provides overall evidence of the systemic relevance of banks' intrinsic fragility. More recently, Artavanis, Paravisini, Robles-Garcia, Seru & Tsoutsoura (2019) provide interesting and convincing empirical evidence of run-like deposit withdrawals by examining the variation in the cost of withdrawal induced by the maturity expiration of time-deposits in Greece, but do not assess the stabilizing role of monetary policy. While their identification strategy forces them to focus on the panic-driven withdrawals triggered by a fundamental shock on bank funding, our framework can instead assess the relevance of intrinsic fragility also if totally unrelated to a deterioration of the fundamentals.

The rest of the paper is organized as follows. Section 2 introduces the institutional background and the data, Section 3 describes the model, Section 4 presents the estimation strategy and results, Section 5 displays and discusses multiple equilibria under the actual policy, Section 6 simulates alternative scenarios with different policies, and Section 7 concludes.

2 Institutional Background and Data

Since the outbreak of global financial crisis, the euro area banking sector has been exposed to a number of systemic shocks that led to significant impairment in its funding and lending capacity,

leading to the adoption of unprecedented monetary policy measures.² The freeze in international money markets experienced in 2007 was followed soon after by the so called global financial crisis, ignited by the collapse of Lehman Brothers in September 2008. This immediately reverberated outside the US economy via a dry-up in some funding segments, such as wholesale deposits placed by non-residents, and the euro banking sector was heavily affected. In the following years Greece, Ireland, Italy, Portugal, and Spain (hereafter, the “stressed” countries) were involved in sovereign debt crises that strongly impaired wholesale funding conditions of the domestic banking sector. These tensions strained financial conditions due to banks’ sovereign exposures, rising non-performing loan levels and, in particular, due to the fact that the domestic sovereign was perceived by market participants as the explicit or implicit guarantor of bank liabilities.

In a bank-based economy such as the euro area, the fear that a material impairment in funding conditions could lead to a credit crunch, or at least prevent the transmission to the real sector of the stimulus provided by the accommodative monetary policy, motivated the adoption of a number of operations providing credit intermediaries with short term liquidity and longer term funding.³

First, starting in October 2008 the ECB allowed banks to obtain unlimited short-term liquidity at a fixed rate as long as they pledged sufficient collateral, through the so-called Fixed-Rate Full-Allotment (FRFA) policy. For every amount of eligible collateral, the banks could access an equal amount of liquidity minus a haircut that depended on the characteristics of the pledged collateral (asset class, residual maturity, rating, coupon structure).⁴ The rate was the same as that on the Main Refinancing Operations (MRO).

Second, the ECB promoted a series of Longer-Term Refinancing Operations (LTROs). Differently from standard operations with a maturity of up to three months, these new operations extended liquidity with maturities of one year (in July 2009) and three years (in December 2011 -vLTRO I- and February 2012 -vLTRO II-), with the aim of reducing roll-over risks and favoring longer-term investment. Funds available to banks were still constrained only by the collateral requirements.⁵ While the central bank balance sheet was protected by the adoption of haircuts, which depended on the degree of liquidity of the assets pledged, this revision of the collateral policy substantially relaxed the collateral constraints existing for banks in accessing those funding facilities.⁶ The interest rate applied was equal to the rate applied on regular short term operations, on average over the time span of each operation, so to reflect the accommodative monetary policy stance. All these factors contributed to a high take up by banks in these operations, especially in stressed countries, and to the massive increase in the liquidity in the system (by more than a trillion euros, approximately 8% of GDP).

Third, even larger amounts of liquidity were injected via the subsequent operations adopted by the ECB. These not only supported the funding conditions and the stability of the banking sector, but

²See Rostagno, Altavilla, Carboni, Lemke, Motto, Saint Guilhem & Yiangou (2019) for a detailed and comprehensive review of the conduct of monetary policy in the euro area.

³The sovereign crisis had opposite effects for banks in non-stressed countries, which experienced positive revaluations of their domestic government bond holdings and stable macroeconomic conditions.

⁴Eligible assets included government and regional bonds, covered bonds, corporate bonds, asset-backed securities, and other uncovered credit debt instruments. The large majority of the collateral was provided by government bond holdings.

⁵Pledgeable ABSs started to include securities with a lower rating and with underlying assets comprising residential mortgages and loans to small and medium enterprises (excluding mixed-class ABSs and ABSs with non-performing, structured, syndicated, or leveraged loans). Crucially, the list of pledgeable assets was extended and included an increasing number of assets, also relatively less liquid, such as individual bank loans (so-called Additional Credit Claims -ACCs-).

⁶It is also worth noting that the risk of losses on these assets remained with the corresponding national central banks instead of with the entire Eurosystem.

also were conceived so as to avoid some of the side effects experienced with the previous operations.⁷ These Targeted Longer-Term Refinancing Operations (TLTROs) were announced in June 2014 (TLTRO I, with eight quarterly auctions from September 2014 to June 2016) and in March 2016 (TLTRO II, with four quarterly operations from June 2016). In between the two waves of TLTROs, the ECB also updated the rules on borrowing limits, maturities, and early repayment options. Eligibility criteria and haircut schedules for the collateral were the same as the previous operations. Borrowing limits (for TLTRO I) and interest rates (for TLTRO II) differed. TLTRO I's borrowing limits were direct functions of the amount of loans that banks extended over the period of the operations, while the interest rates were fixed over the time span of each operation at the MRO level prevailing at the time of take-up (plus an additional fixed spread of 10 basis points for the first two TLTRO I auctions). TLTRO II's borrowing limits and interest rates were instead both functions of the loans extended over the period of the operations, with interest rates decreasing with the volume of loans from the MRO rate (which was in parallel reduced to 0%) down to the Deposit Facility Rate (DFR, the rate at which excess reserves are remunerated, which stood at -0.4%).⁸

Figure 1 reports the time series evolution of the total amount of ECB funding since 2010, with a breakdown across each of the operations described above, as well as the policy rate that was applied. While for the estimation of the structural model we rely on a sample of banks from 2007 until 2019, the red vertical line corresponding to January 2015 marks the starting point of the sample that we use for our simulations and counterfactuals. We decided to focus on this latest part of the sample for the policy experiments as during those years the TLTRO operations were covering almost the entire amount of ECB funding, as the Figure clearly shows. This guarantees that our exercise is focussed on a single type of operation, as opposed to modeling several simultaneous operations, which would have instead required additional layers of modeling complexity.

As mentioned, despite the large size of the operations, the estimated quantitative impact on loan supply is rather modest, and in any case apparently incompatible with the gravity of the perceived risks that these operations have supposedly been taming, envisaging the possibility of a systemic crisis, with broad based runs on bank liabilities and disordered deleveraging. One plausible reason for this is that for this assessment one needs to consider a scenario where the run actually materializes. This is difficult to do because of the endogenous response of the central bank that, by de facto acting as lender of last resort, systematically manages to avoid systemic runs. Below we present a model that allows doing so.

2.1 Data

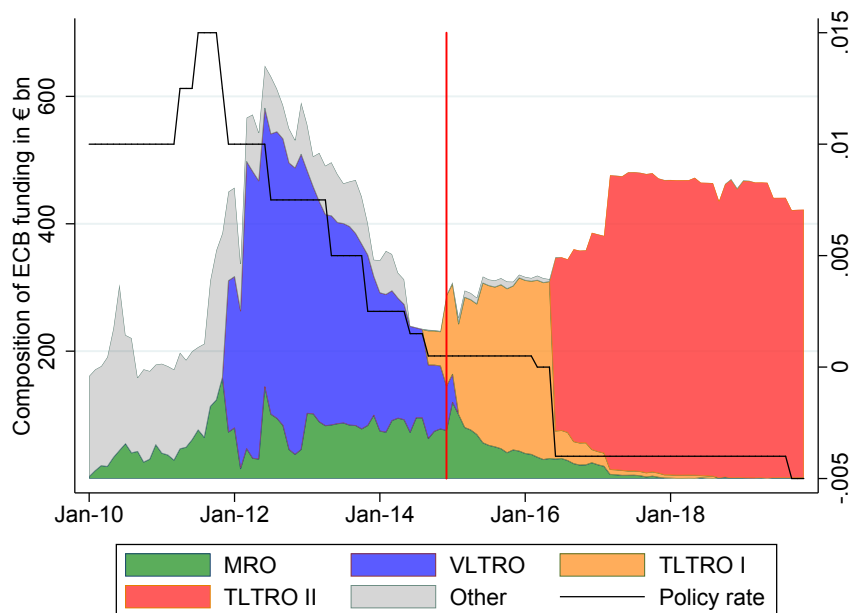
Our empirical analysis relies on bank level information from various proprietary databases maintained by the ECB. First, we use the Individual Balance Sheet Indicators (IBSI) database, which reports at the unconsolidated level the main asset and liability items of over 260 banks resident in the euro area from August 2007 to November 2019. This dataset provides information on the amount of outstanding deposits, loans, and other relevant bank balance sheet information. Second, we complement IBSI with the Individual Monetary and Financial Institutions Interest Rates (IMIR) database, which contains information on deposits and lending rates.

The merge of our rich data yields a representative sample of the euro area banking sector, consisting

⁷See Albertazzi, Barbiero, Marqués-Ibañez, Popov, Rodriguez D'Acri & Vlassopoulos (2020) for a comparative review of the papers assessing the financial stability spillover of these and other unconventional monetary policy measures.

⁸An additional feature of TLTROs was that banks could participate to the operations both individually and in groups, with no reference to the banking group that the single banks were part of.

Figure 1: ECB FUNDING AND POLICY RATE WITHIN OUR SAMPLE



Note: MRO corresponds to Main Refinancing Operations. VLTRO corresponds to the three Longer-Term Refinancing Operations launched respectively in July 2009, December 2011, and February 2012. TLTRO I and II correspond to the Targeted Longer-Term Refinancing Operations announced respectively in June 2014 and March 2016. Policy rate is the borrowing rate applied to each of these operations over time. This figure is based on our sample of banks, which corresponds to roughly 60% of overall loan and deposit volumes, and this proportion is also reflected in the amount of ECB funding that our sample covers.

of an unbalanced panel of 86 banks for 148 months from August 2007 to November 2019, covering 12 euro area countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Portugal, Slovakia, Spain, and the Netherlands). The banks in our sample represent around 60% of their domestic loan and deposit markets on average across countries. We express all shares vis-à-vis domestic markets because in the euro area both deposit and loan markets are segmented along country lines. Although some cross-border lending does exist, it is negligible compared to the aggregate. We report the summary statistics of our sample in Table 1.

For the deposit demand model we use each bank’s market share of the domestic market of deposits, at the month-country level. For the uninsured deposits, we use the overnight deposits of domestic corporate clients, and the bank’s interest rate on overnight NFCs’ deposits. For the insured deposits, we use the overnight deposits of domestic household clients, and the bank’s interest rate on overnight households’ deposits. Corporate deposits are typically larger than the €100,000 threshold of the Deposit Guarantee Scheme (DGS), while household deposits are typically smaller, which makes them a good proxy for insured deposits. To validate our assumption, we obtain confidential information about the share of insured and uninsured deposits from the Supervisory Reports of the Single Supervisory Mechanism (SSM). This allows us to confirm, for the subset of entities supervised by the ECB, that the share of corporate to total (household and corporate) overnight deposits is indeed highly correlated with the share of uninsured over total (insured and uninsured) deposits.

Deposit shares range from almost nil to over 40 percent in some jurisdictions, with an average value of 9 percent in the case of uninsured deposits and 10 percent in the case of insured deposits. Deposit rates are close to zero in most countries, reaching at maximum less than 4 percent. Some deposit rates are negative, with some reaching the level of the DFR at -0.4 percent. The average interest rate on insured deposits is 0.2 percent while the average interest rate on uninsured deposits is less

than 0.4 percent. This difference can be attributed to both the slightly higher market power in the uninsured deposit market and the mark-down applied to insured deposits because of the government guarantee.

Table 1: SUMMARY STATISTICS

| | Obs. | Mean | St.Dev. | Min | p25 | p50 | p75 | Max |
|----------------------------|-------|-------|---------|--------|-------|-------|-------|--------|
| Uninsured Deposits | | | | | | | | |
| Deposit Volume (€bn) | 9,025 | 9.43 | 10.98 | 0.52 | 2.22 | 4.72 | 12.53 | 49.91 |
| Deposit Rate (%) | 9,025 | 0.36 | 0.58 | -0.42 | 0.03 | 0.13 | 0.43 | 3.73 |
| Market Share (%) | 9,025 | 10.16 | 9.44 | 0.23 | 1.82 | 7.84 | 15.20 | 45.40 |
| Insured Deposits | | | | | | | | |
| Deposit Volume (€bn) | 9,025 | 16.10 | 19.22 | 0.69 | 4.16 | 9.48 | 19.52 | 97.90 |
| Deposit Rate (%) | 9,025 | 0.24 | 0.38 | -0.01 | 0.02 | 0.10 | 0.28 | 3.52 |
| Market Share (%) | 9,025 | 9.00 | 9.14 | 0.05 | 1.67 | 5.42 | 14.02 | 37.06 |
| Loans to NFCs | | | | | | | | |
| Loan Volume (€bn) | 9,025 | 25.93 | 25.97 | 2.00 | 7.07 | 16.22 | 34.61 | 124.86 |
| Lending Rate (%) | 9,025 | 3.18 | 1.19 | 1.20 | 2.27 | 3.02 | 3.79 | 6.37 |
| Market Share (%) | 9,025 | 9.14 | 8.76 | 0.34 | 1.58 | 6.08 | 14.35 | 36.39 |
| Loans to Households | | | | | | | | |
| Loan Volume (€bn) | 9,025 | 30.67 | 41.21 | 1.00 | 8.35 | 16.24 | 32.20 | 323.72 |
| Lending Rate (%) | 9,025 | 3.63 | 1.41 | 1.24 | 2.50 | 3.50 | 4.58 | 7.55 |
| Market Share (%) | 9,025 | 8.16 | 8.28 | 0.15 | 1.30 | 5.10 | 12.89 | 36.88 |
| CDS Spread (%) | 9,025 | 2.09 | 2.75 | 0.25 | 0.74 | 1.20 | 1.98 | 17.29 |
| Default Probability (%) | 9,025 | 3.28 | 4.08 | 0.41 | 1.21 | 1.95 | 3.20 | 24.91 |
| NPL Ratio (%) | 9,025 | 7.27 | 8.22 | 0.48 | 2.67 | 4.82 | 7.98 | 45.18 |
| Lending Rate Default (%) | 9,025 | 3.40 | 1.23 | 1.41 | 2.41 | 3.27 | 4.15 | 6.47 |
| Bank Size (€bn) | 9,025 | 58.47 | 65.22 | 3.32 | 17.62 | 35.66 | 63.36 | 445.37 |
| EONIA (%) | 9,025 | 0.30 | 1.04 | -0.46 | -0.35 | 0.04 | 0.36 | 4.30 |
| Sovereign Rate Spread (%) | 9,025 | 2.55 | 3.09 | -0.35 | 0.93 | 1.81 | 3.22 | 45.96 |
| ECB Borrowing (€bn) | 9,025 | 5.35 | 8.62 | 0.00 | 0.00 | 1.50 | 6.85 | 62.00 |
| ECB Policy Rate (%) | 9,025 | 0.51 | 1.08 | -0.50 | -0.40 | 0.15 | 1.00 | 4.25 |
| Other Net Balance (€bn) | 9,025 | 25.72 | 43.80 | -71.73 | 5.65 | 13.09 | 26.95 | 283.49 |
| Other Borrowing Rate (%) | 9,025 | 2.84 | 3.23 | -0.71 | 0.81 | 2.12 | 4.05 | 46.32 |

Note: Unbalanced panel of 86 banks for 148 months from August 2007 to November 2019, covering 12 EA countries (AT, BE, DE, ES, FI, FR, GR, IE, IT, NL, PT, SK). Lending Rate Default refers to the weighted average of lending rates to NFCs and Households that is used to estimate the loan default model later on.

For the loan demand model we use bank's market share of the domestic market of loans, at the month-country level. For loans to NFCs, we use the outstanding amounts of loans to domestic corporate clients, and the bank's average interest rate on these outstanding amounts. For loans to households, we use the outstanding amounts of loans to domestic households, and the bank's interest rate is defined accordingly. The market of loans to NFCs is slightly more concentrated than the market of loans to households, with average shares around 9 and 8 percent, respectively. Shares in some smaller countries can reach up to 37 percent, similarly to the deposit markets. Loan rates

hover around 3 to 4 percent on average, and can reach 7 percent for some banks.

Similarly to Egan et al. (2017), we measure the financial solvency of each bank with the CDS spreads. We derive five-year CDS spreads from Datastream, and calculate the probability of default of each bank under the same risk neutral model with a constant hazard rate and under the same assumptions as in Egan et al. (2017).⁹ The average CDS spread in our dataset is 209 basis points, but can reach peaks of over 1,700 basis points during the sovereign debt crisis. Under our assumptions, these peaks correspond to a sizable risk-neutral probability of bank default of 25 percent.

We proxy borrowers' default with the ratio of gross non-performing loans to gross total loans, as reported in the proprietary data SNL Financial. In our sample, this ratio is on average 7 percent and can reach over 45 percent in the aftermath of the sovereign debt crisis. Consistently, we proxy the aggregate loan interest rate that affects borrowers' default with the average interest rate on outstanding amounts of loans to the non-financial private sector. The control for bank size in all specifications is represented by the outstanding amounts of loans to the non-financial private sector. We also summarize the EONIA rate and the sovereign rate spread that we use as instruments for our demand models. Last, at the bottom of Table 1 we report descriptive statistics for the volume of banks' borrowing from the ECB as well as the policy rate that they were required to pay. To complete the summary of banks' balance sheets, we include the net balance of the other components of banks' assets and liabilities, and the borrowing rate for the liabilities side.

3 The Model

Our framework models the behavior of four agents: depositors, borrowers, banks, and the central bank. We distinguish between insured and uninsured depositors, corresponding respectively to households and non-financial corporations, and let them have preferences for banks' characteristics that determine their demand for deposit services. Depositors will consider in their deposit demand not only the interest rate offered, but also a measure of financial fragility of each financial institution. Similarly, we consider borrowers as either households or non-financial corporations, and let them have preferences for banks' characteristics that determine both their demand for loans and likelihood to default. Borrowers will choose their preferred bank based on the offered loan interest rate, which will also have an effect on their default probability, capturing any potential extent of moral hazard and/or adverse selection.

We model banks' supply of deposits and loans as Bertrand-Nash competition on interest rates, following the standard empirical industrial organization literature on demand for differentiated products (Berry 1994, Berry et al. 1995). In the spirit of Hortacısu, Matvos, Shin, Syverson & Venkataraman (2011) and Egan et al. (2017) we also let banks default if, when running a loss, their expected franchise value next period is expected to be lower in absolute value than such loss. The combination of endogenous banks' default, of banks' limited liability, and of depositors' preferences for banks' stability is what allows the model to produce multiple equilibria, a key ingredient for our policy evaluations.

The degree to which the model will allow for multiple equilibria depends directly on the size of the sensitivity to price and risk conditions of the different schedules, representing the behavior banks, depositors and firms. For instance, if depositors expect a bank to default, then demand of mostly uninsured deposits for that bank will diminish, which can be offset by offering higher deposit rates for both insured and uninsured deposits. In equilibrium this may not only validate the expectations of a bank's default, but also contribute to a contagion effect, as solvent banks are

⁹We use a 5% risk free rate and bank-month specific recover rates.

now forced to increase their deposit rates as well in order not to lose market shares, which will eventually negatively affect their solvency. Alternatively, the distressed bank may also react by charging higher lending rates, raising the riskiness of the loan book and, in turn, of the bank itself. Again, if the deterioration of the asset quality is large enough, the initial expectations of a bank's default get validated.

Last, but crucially, we introduce a central bank, that is the ECB in our empirical application, that is willing to provide liquidity to banks at predetermined rates. No arbitrage considerations imply that the potentially unlimited availability of central bank funds determines the cost at which banks are marginally willing to borrow from comparable alternative funding sources, such as international wholesale markets, as well as the return of comparable assets. In what follows we outline the specifics of the deposit demand models, the loan demand and default models, lenders' supply through deposit and loan pricing, and banks' default decisions.

3.1 Deposit Demand

We model demand for deposits by specifying the indirect utilities that determine uninsured \mathcal{N} (i.e. non-financial corporations) and insured \mathcal{I} (i.e. households) depositors' choice of bank, where banks are allowed to provide differentiated services. More specifically, depositor i of type $d = \{\mathcal{N}, \mathcal{I}\}$ has the following indirect utility from depositing at bank j in country m at month t :

$$U_{ijmt}^d = \alpha^d P_{jmt}^d + \gamma^d F_{jmt} + \delta_j^d + \zeta_{mt}^d + \xi_{jmt}^d + \varepsilon_{ijmt}^d, \quad (1)$$

where P_{jmt}^d is the interest rate on deposits, F_{jmt} is a measure of bank's fragility, δ_j^d are bank fixed effects controlling for differences in depositors' mean utilities due to observed and unobserved (by the econometrician) bank characteristics, ζ_{mt}^d are country-month fixed effects absorbing any macroeconomic factor, ξ_{jmt}^d are bank-country-month unobserved characteristics (by the econometrician), and ε_{ijmt}^d are IID shocks that follow a Type 1 Extreme Value distribution. We normalize to zero the utility from choosing the outside option, that is a set of small fringe banks.¹⁰ From these indirect utilities we can derive each bank's market share in country m at month t , both for uninsured and insured deposits, as follows:

$$S_{jmt}^d = \frac{\exp\left(\alpha^d P_{jmt}^d + \gamma^d F_{jmt} + \delta_j^d + \zeta_{mt}^d + \xi_{jmt}^d\right)}{1 + \sum_k \exp\left(\alpha^d P_{kmt}^d + \gamma^d F_{kmt} + \delta_k^d + \zeta_{mt}^d + \xi_{kmt}^d\right)}. \quad (2)$$

As reported in the descriptive statistics in Table 1, a small but increasing over time fraction of deposit interest rates are actually below the Zero Lower Bound (ZLB), only for uninsured depositors. Based on a recent strand of literature looking at deposit markets with rates below the ZLB (Heider, Saidi & Schepens 2019, Altavilla, Burlon, Giannetti & Holton 2019), we investigated in the context of our deposit demand model whether depositors had non-linear preferences for deposit rates, which would justify a stronger demand response to deposit rates below zero, hence limiting banks' incentives to set negative deposit rates. We experimented with a quadratic term for deposit rates in the indirect utility function for both insured and uninsured depositors, as well as with an interaction of deposit rates with a dummy for negative rates for the case of uninsured depositors only, for which we

¹⁰Our choice of inside vs outside option banks is mostly driven by data availability. We focus on banks for which we can observe the CDS spreads, our measure of banks' fragility, the borrowers' default probability, and the loss given default. Our final sample of (inside) banks corresponds to the largest institutions representing on average 40% of both aggregate deposits' and loans' volumes.

have observations with negative rates. We found that none of these nonlinearities are statistically significant, therefore rejected any difference in depositors' response to interest rates above or below the ZLB, and maintained the current specification with a linear relationship.

3.2 Loan Demand and Borrowers' Default

We model demand for loans in a very similar way. In particular, we define borrowers as either firms \mathcal{F} (i.e. non-financial corporations) or households \mathcal{H} , and let each borrower $b = 1, \dots, B$ of type $\ell = \{\mathcal{F}, \mathcal{H}\}$ have the following indirect utilities from taking a loan from bank j in country m in month t :

$$U_{bjmt}^\ell = \alpha^\ell P_{jmt}^\ell + \gamma^\ell F_{jmt} + \delta_j^\ell + \zeta_{mt}^\ell + \xi_{jmt}^\ell + \varepsilon_{bjmt}^\ell, \quad (3)$$

where $P_{jmt}^\mathcal{F}, P_{jmt}^\mathcal{H}$ are respectively the average loan interest rates for firms and households, δ_j^ℓ are bank fixed effects, ζ_{mt}^ℓ are country-month fixed effects, ξ_{jmt}^ℓ are unobserved bank-country-month attributes, and ε_{bjmt}^ℓ are IID shocks that follow a Type 1 Extreme Value distribution. We let borrowers choose an outside option, that is any small fringe bank, and normalize to zero the utility from that option. Hence, these indirect utilities allow us to derive each bank's market share for firm and household borrowers in country m at month t as:

$$S_{jmt}^\ell = \frac{\exp\left(\alpha^\ell P_{jmt}^\ell + \gamma^\ell F_{jmt} + \delta_j^\ell + \zeta_{mt}^\ell + \xi_{jmt}^\ell\right)}{1 + \sum_k \exp\left(\alpha^\ell P_{kmt}^\ell + \gamma^\ell F_{kmt} + \delta_k^\ell + \zeta_{mt}^\ell + \xi_{kmt}^\ell\right)}, \quad (4)$$

Finally, we let borrowers default on their loans based on the following indirect utility function:

$$U_{bjmt}^\mathcal{D} = \beta P_{jmt}^\mathcal{L} + \delta_j^\mathcal{D} + \zeta_{mt}^\mathcal{D} + \xi_{jmt}^\mathcal{D} + \varepsilon_{bjmt}^\mathcal{D}, \quad (5)$$

where $P_{jmt}^\mathcal{L} = \frac{S_{jmt}^\mathcal{F}}{S_{jmt}^\mathcal{F} + S_{jmt}^\mathcal{H}} P_{jmt}^\mathcal{F} + \frac{S_{jmt}^\mathcal{H}}{S_{jmt}^\mathcal{F} + S_{jmt}^\mathcal{H}} P_{jmt}^\mathcal{H} = (1 - w_{jmt}^\mathcal{H}) P_{jmt}^\mathcal{F} + w_{jmt}^\mathcal{H} P_{jmt}^\mathcal{H}$ is the weighted average of the loan interest rates for firms and households,¹¹ and the other controls and fixed effects follow the same logic as the loan demand models. Hence, the share of defaulting borrowers across firms and households that bank j expects to have is defined as:

$$\mathcal{D}_{jmt} = \frac{\exp\left(\beta P_{jmt}^\mathcal{L} + \delta_j^\mathcal{D} + \zeta_{mt}^\mathcal{D} + \xi_{jmt}^\mathcal{D}\right)}{1 + \exp\left(\beta P_{jmt}^\mathcal{L} + \delta_j^\mathcal{D} + \zeta_{mt}^\mathcal{D} + \xi_{jmt}^\mathcal{D}\right)}. \quad (6)$$

Finally, we assume that once default occurs, only a fraction \mathcal{X}_{jt} of the loan principle and promised interest payment is lost, with $1 - \mathcal{X}_{jt}$ measuring bank-month specific recovery rates. This aims at capturing the effect of most loans being collateralized and amortized over time, which means that the default in general does not wipe out the whole principle and accrued interest. As a result, each bank's expected revenue from its loan portfolio can be expressed as:

$$(1 - \mathcal{D}_{jmt})(1 + P_{jmt}^\mathcal{L}) + \mathcal{D}_{jmt}(1 - \mathcal{X}_{jt})(1 + P_{jmt}^\mathcal{L}) = (1 - \mathcal{X}_{jt}\mathcal{D}_{jmt})(1 + P_{jmt}^\mathcal{L}). \quad (7)$$

¹¹We use this weighted average as we only observe non-performing loans accurately enough at the bank-country-month level, not with breakdown by households and firms.

It is important to discuss a restrictive assumption that we are making in this context, which has to do with the total size of the market, both in terms of deposits and loans. We are in fact assuming that banks can attract depositors and borrowers, by increasing their market shares, from a fixed pool of potential deposits' volume $M_{mt}^{\mathcal{I}}, M_{mt}^{\mathcal{N}}$ (insured and uninsured), as well as potential loans' volume $M_{mt}^{\mathcal{F}}, M_{mt}^{\mathcal{H}}$ (for firms and households). These quantities are defined respectively as the total amount of insured and uninsured deposits in country m at time t , and the total amount of loans granted to firms and households in country m at time t . This assumption, in line with Egan et al (2017), means that the model allows for substitution of quantities of deposits and loans across banks, but does not allow the aggregate volume of deposits and loans to change endogenously. Relaxing this assumption is however challenging, as it requires making an assumption over the potential market size for deposits and loans that goes beyond the observed aggregate volumes.

3.3 Deposit and Loan Pricing, Bank Default, and ECB Funding

On the supply side, we let banks compete Bertrand-Nash on interest rates in deposit and loan markets, but also decide on their survival depending on whether equity holders, who are subject to limited liability, find it profitable to finance a shortfall of the bank or not. We allow banks to raise capital from three different sources. First, from insured and uninsured depositors, whose interest rates are set by banks to maximize their expected equity value. Second, from the central bank, which sets a borrowing rate, that is also equivalent to a deposit interest rate if banks decide to deposit funds instead of borrowing. Last, from any source other than deposits and central bank funding, namely equity, debt security issuances, borrowing from other MFIs, and financial liabilities. We set the amount and interest rate on this latter source as fixed across our counterfactuals.

Accordingly, we define the total expected net profits of bank j in country m at month t as:

$$\begin{aligned} \Pi_{jmt} = & \sum_{\ell \in \mathcal{F}, \mathcal{H}} M_{mt}^{\ell} S_{jmt}^{\ell} \left[\left(1 + P_{jmt}^{\ell}\right) [1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}] - w_{jmt}^{\ell} C_{jmt} \right] - M_{mt}^{\mathcal{F}} S_{jmt}^{\mathcal{F}} C_{jmt}^{\mathcal{F}} \\ & - \sum_{d \in \mathcal{I}, \mathcal{N}} M_{mt}^d S_{jmt}^d \left(1 + P_{jmt}^d + (1 - w_{jmt}^{\ell}) C_{jmt}\right) - M_{mt}^{\mathcal{I}} S_{jmt}^{\mathcal{I}} C_{jmt}^{\mathcal{I}} \\ & - M_{jmt}^{\mathcal{C}} (1 + P_t^{\mathcal{C}} + C_{jmt}^{\mathcal{C}}) - M_{jmt}^{\mathcal{B}} (1 + P_{jmt}^{\mathcal{B}}), \end{aligned} \quad (8)$$

where $M_{mt}^{\mathcal{I}}, M_{mt}^{\mathcal{N}}$ are respectively the total amount of insured and uninsured deposits in country m in month t , $M_{mt}^{\mathcal{F}}, M_{mt}^{\mathcal{H}}$ are the total amount of loans for firms and households, $C_{jmt}^{\mathcal{F}}$ are extra costs of providing loans to firms relative to households, and $C_{jmt}^{\mathcal{I}}$ are extra costs of providing insured deposits relative to uninsured ones. We let $M_{jmt}^{\mathcal{B}}$ be any source of capital for banks other than deposits and central bank liquidity injections, and $P_{jmt}^{\mathcal{B}}$ be its price. We take this cost of funding as exogenous, and define as $M_{jmt}^{\mathcal{C}}$ the amount that bank j borrows from the central bank, which decides on a common rate $P_t^{\mathcal{C}}$.¹² $C_{jmt}^{\mathcal{C}}$ captures any extra cost that bank j faces when borrowing from the central bank, such like hitting the target of maximum amount that can be borrowed as a function of its pleadable assets. Last, C_{jmt} represents any lending or deposit related costs, including administrative costs, marketing, screening and monitoring costs, and borrowers' default costs not predicted by \mathcal{D}_{jmt} or other cost variables. We assume that $C_{jmt} \sim N(\mu_{jmt}, \sigma_{jmt}^2)$ and that these costs are shared across loans and deposits with normalized weights w_{jmt}^{ℓ} and $1 - w_{jmt}^{\ell}$.¹³ We let

¹²Note that in some cases we can have $M_{jmt}^{\mathcal{B}} = M_{mt}^{\mathcal{F}} S_{jmt}^{\mathcal{F}} + M_{mt}^{\mathcal{H}} S_{jmt}^{\mathcal{H}} - M_{mt}^{\mathcal{I}} S_{jmt}^{\mathcal{I}} - M_{mt}^{\mathcal{N}} S_{jmt}^{\mathcal{N}} - M_{jmt}^{\mathcal{C}} < 0$, which means that the bank borrows more than what it lends through loans. This will then become a source of revenue with the same price/cost structure.

¹³In our current estimation and counterfactual exercises we are setting $w_{jmt}^{\ell} = 0.5$.

banks' returns to be defined as:

$$R_{jmt} = \sum_{\ell \in \mathcal{F}, \mathcal{H}} M_{mt}^{\ell} S_{jmt}^{\ell} \left[\left(1 + P_{jmt}^{\ell}\right) [1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}] - 1 - P_t^{\mathcal{C}} - C_{jmt}^{\mathcal{C}} \right] - M_{mt}^* S_{jmt}^* C_{jmt}, \quad (9)$$

where $M_{mt}^* S_{jmt}^* = w_{jmt}^{\mathcal{L}} (M_{mt}^{\mathcal{F}} S_{jmt}^{\mathcal{F}} + M_{mt}^{\mathcal{H}} S_{jmt}^{\mathcal{H}}) + (1 - w_{jmt}^{\mathcal{L}}) (M_{mt}^{\mathcal{I}} S_{jmt}^{\mathcal{I}} + M_{mt}^{\mathcal{N}} S_{jmt}^{\mathcal{N}})$. Banks' risk neutral equity holders will decide to finance a shortfall if the equity value of the bank next period E_{jmt} exceeds the shortfall, based on the following condition:

$$\Pi_{jmt} + \frac{1}{1+r} E_{jmt} > 0. \quad (10)$$

There will be a threshold level of C_{jmt} such that equity holders are indifferent between financing the bank in country m and month t and letting it default, defined as \bar{C}_{jmt} . We can then solve for the optimal cutoff rule as follows:

$$\begin{aligned} -\Pi_{jmt}(\bar{C}_{jmt}) &= \frac{1}{1+r} \overbrace{\Phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right)}^{\text{Survival Prob}} \left[\overbrace{\mathbb{E}\left(R_{jmt}(C_{jmt}) - R_{jmt}(\bar{C}_{jmt}) \mid R_{jmt}(C_{jmt}) - R_{jmt}(\bar{C}_{jmt}) \geq 0\right)}^{\text{Expected Return conditional on survival}} \right] \\ &= \frac{1}{1+r} \Phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right) \left[M_{mt}^* S_{jmt}^* \left(\bar{C}_{jmt} - \mu_{jmt} + \sigma_{jmt} \lambda\left(-\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right) \right) \right], \end{aligned} \quad (11)$$

where we let $M_{mt}^{\mathcal{L}} S_{jmt}^{\mathcal{L}} = M_{mt}^{\mathcal{F}} S_{jmt}^{\mathcal{F}} + M_{mt}^{\mathcal{H}} S_{jmt}^{\mathcal{H}}$ and $\lambda(\cdot)$ is the inverse Mills ratio.¹⁴ Similarly to Egan et al. (2017), a crucial feature of the first order condition in equation (11) is that it can be satisfied by multiple values of bank's default probability, which gives rise to multiplicity of equilibria for the same model primitives (preferences and costs). The feedback loop between depositors' demand depending on bank's risk, and bank's risk depending on depositors' demand, implies that banks' default probabilities perceived by depositors can be self fulfilling, generating panic-based runs as in Diamond & Dybvig (1983) and Goldstein & Pauzner (2005).

Banks will set deposit and loan interest rates $P_{jmt}^{\mathcal{I}}, P_{jmt}^{\mathcal{N}}, P_{jmt}^{\mathcal{F}}, P_{jmt}^{\mathcal{H}}$ maximizing their equity value, solving the following optimization problem under limited liability and risk neutrality:

$$\begin{aligned} E_{jmt} &= \max_{P_{jmt}^{\mathcal{I}}, P_{jmt}^{\mathcal{N}}, P_{jmt}^{\mathcal{F}}, P_{jmt}^{\mathcal{H}}} \int_{-\infty}^{\bar{C}_{jmt}} \left[\Pi_{jmt} + \frac{1}{1+r} E_{jmt} \right] dF(C_{jmt}) \\ &\equiv \max_{P_{jmt}^{\mathcal{I}}, P_{jmt}^{\mathcal{N}}, P_{jmt}^{\mathcal{F}}, P_{jmt}^{\mathcal{H}}} \left[R_{jmt} - M_{mt}^{\mathcal{F}} S_{jmt}^{\mathcal{F}} C_{jmt}^{\mathcal{F}} - M_{mt}^{\mathcal{I}} S_{jmt}^{\mathcal{I}} (P_{jmt}^{\mathcal{I}} + C_{jmt}^{\mathcal{I}} - P_t^{\mathcal{C}} - C_{jmt}^{\mathcal{C}}) \right. \\ &\quad \left. - M_{mt}^{\mathcal{N}} S_{jmt}^{\mathcal{N}} (P_{jmt}^{\mathcal{N}} - P_t^{\mathcal{C}} - C_{jmt}^{\mathcal{C}}) - M_{jmt}^{\mathcal{B}} (P_{jmt}^{\mathcal{B}} - P_{jmt}^{\mathcal{C}} - C_{jmt}^{\mathcal{C}}) \right] \Phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right), \end{aligned} \quad (12)$$

¹⁴The formula for the inverse Mills ratio is $\lambda\left(-\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right) = \frac{\phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right)}{\Phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right)}$.

where:

$$C_{jmt} = \mu_{jmt} - \sigma_{jmt} \lambda \left(-\frac{\overline{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}} \right). \quad (13)$$

We use the four first order conditions of this optimization problem to back out the unobserved cost components of the bank's objective function, as described in detail in the Appendix B. Those equilibrium conditions, together with the optimal cutoff rule of equation (11), allows us to derive $C_{jmt}^I, C_{jmt}^F, C_{jmt}^C, \mu_{jmt}, \sigma_{jmt}$.

4 Estimation

We estimate four separate but rather similar demand systems, respectively demand for uninsured and insured deposits, as well as households' and firms' demand for loans. Moreover, we estimate a similar model to determine borrowers' default probabilities. We follow an instrumental variables approach in the spirit of Berry (1994), based on aggregate market shares at the bank-country-month level for each type of depositors and borrowers.

The estimation for deposit demand is based on the following regression equation:

$$\ln S_{jmt}^d - \ln S_{0mt}^d = \alpha^d P_{jmt}^d + \gamma^d F_{jmt} + \delta_j^d + \zeta_{mt}^d + \xi_{jmt}^d, \quad (14)$$

where S_{0mt}^d is the market share of the outside option, that is the fringe of small banks. Note that the country-month fixed effects ζ_{mt}^d absorb the variation of the outside good, therefore we do not need to normalize the explanatory variables as difference between the value corresponding to bank j and the value corresponding to the outside good.

We address the identification concerns for both α^d and γ^d using instrumental variables. Our instrument for deposit rates is the bank-specific pass-through of the Euro Overnight Index Average (EONIA), constructed in the spirit of Villas-Boas (2007) as interactions of the EONIA with bank dummies. Our instrument for banks' CDS spreads instead is a measure of bank-specific pass-through of sovereign risk, constructed again as interactions of bank dummies with the spread between each country's sovereign yield and the EONIA. The basic idea is to identify the slope of households demand of deposits by exploiting the variation in deposit rates which reflects shifts in banks' willingness to rely on this source of funding. Changes in the monetary policy rate are transmitted to deposit rates differently across banks, largely reflecting banks' specific characteristics, such as in particular their pricing power in the deposit market. For example, after a monetary policy tightening, some bankers will be less eager or less quick to increase deposit rates because they can rely on higher market power. Analogous considerations hold for the slope of household' demand with respect to the level of bank risk. We find these instruments to be strongly relevant in the first stage across all four models. The economic interpretation of the instruments adopted in the regressions below mimics that of the deposit demand equation.

Similarly, the estimation for the loan demand will result in the following regression equation:

$$\ln S_{jmt}^\ell - \ln S_{0mt}^\ell = \alpha^\ell P_{jmt}^\ell + \gamma^\ell F_{jmt} + \delta_j^\ell + \zeta_{mt}^\ell + \xi_{jmt}^\ell. \quad (15)$$

We use here as instrument for household loan interest rates once again the bank specific pass-through of the EONIA and for corporate loan interest rates the NPL ratio of the bank. Last, the estimation for borrowers' default is based on the following regression equation:

$$\ln \mathcal{D}_{jmt} - \ln(1 - \mathcal{D}_{jmt}) = \beta P_{jmt}^{\mathcal{L}} + \delta_j^{\mathcal{D}} + \zeta_{mt}^{\mathcal{D}} + \xi_{jmt}^{\mathcal{D}}, \quad (16)$$

where we instrument the aggregate loan interest rate $P_{jmt}^{\mathcal{L}}$ with the bank-specific pass-through of sovereign risk.

4.1 Results

We report the main estimates of the five models in Table 2, while a more detailed summary of the results can be found in the Appendix in Tables 8, 9, and 10. We first look at the demand for uninsured deposits. The results in column 1 of Table 2 highlight a positive effect of the remuneration of deposits on the demand for such contracts. However, they also highlight the sensitivity of deposited funds to the risk profile of the bank. A higher default probability prompts a lower demand for uninsured deposits in that bank, and this emerges even after controlling for unobserved heterogeneity related to bank-specific characteristics (i.e. bank fixed effects) or aggregate developments in the country of residence (i.e. country-month fixed effects).

We then turn to the demand for insured deposits. In principle, this demand should be as price-elastic as the demand for uninsured deposits, but should not react to banks' default probability, as the government guarantee should separate deposit safety from banks' creditworthiness for these types of contracts. However, in the euro area the sovereign debt crisis has decreased substantially the credibility of governments to offer the necessary fiscal backing, were the solvency of banks on their insured deposit obligations to come under scrutiny. Thus, differently from what happens in the US, the lack of a credible deposit insurance makes insured depositors be sensitive to banks' financial solvency, as reported in column 2 of Table 2.

Price elasticities between the two deposit types are similar and are not statistically different. In terms of magnitudes, the price elasticity is around 14 percent for uninsured deposits and above 12 percent for insured deposits at the level of a 5 percent market share of the domestic market and a 1 percent interest rate. Insured deposits respond to banks' default probability but remain less sensitive to it than uninsured deposits, with a 5 percent share in the domestic market of uninsured deposits declining by 2.1 percentage points and that of insured deposits declining only 0.4 percent for a 1 percent increase in the default probability.

We report the estimates for the loan demand in columns 3 and 4 of Table 2. The results show that the demand functions yield the expected sign for their slope, and as expected the price elasticity of the demand for loans to NFC (20 percent) is larger than that of the demand for loans to households (12 percent). As retail deposits are sensitive to banks' default probability, we check whether borrowers also factor in banks' financial solvency when demanding loans. Indeed, we find that both NFCs and households decrease their demand for loans for higher levels of banks' default probability. This is consistent with the findings of Ippolito et al. (2016) for the case of credit line draw-downs during the financial crisis. This may either point to a substantial level of sophistication on the side of borrowers, that anticipate higher costs for future draw-downs of the granted amounts of credit, or reflect the association of credit and deposit contracts with the same intermediary, which makes foregone clients appear both as lower borrowed funds and lower deposited funds.

Table 2: DEPOSIT AND LOAN DEMAND, BORROWERS' DEFAULT

| | DEPOSITS | | NFCs | LOANS | |
|--------------------------|--------------------|--------------------|---------------------|---------------------|-----------------|
| | Uninsured | Insured | | Households | Default |
| Interest Rate | 14.63*** (1.46) | 13.13*** (2.32) | -21.51*** (5.11) | -12.98*** (0.96) | 6.43* (3.45) |
| Bank Default Probability | -2.16*** (0.33) | -0.47* (0.27) | -0.70** (0.28) | -0.94*** (0.26) | |
| Bank Control | Yes | Yes | Yes | Yes | Yes |
| Bank FE | Yes | Yes | Yes | Yes | Yes |
| Country-Month FE | Yes | Yes | Yes | Yes | Yes |
| Observations | 9,025 | 9,025 | 9,025 | 9,025 | 9,025 |
| R-squared | 0.334 | 0.263 | 0.436 | 0.581 | -0.004 |

Note: Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Bank control includes a measure of bank size given by its total loan volume.

The sensitivity of loan demand to bank's default probability (normalized to a 5 percent share and a 1 percent default probability) stands at -0.7 percent for NFCs and -0.9 percent for households. Loan shares react less strongly than uninsured deposit shares, so this mechanism is less likely to provide the feedback loops necessary to originate alone very heterogeneous multiple equilibria. However, it does exacerbate extreme scenarios of banks' default probabilities, as the elasticity at a default probability around 25 percent (as those observed in Greece during the sovereign debt crisis) is -17.5 percent for NFC loans and -22.3 percent for household loans. The consequent compression in profit margins, as intermediaries are pushed to keep lending rates low so as not to lose market shares, may further increase bank defaults. Our model encompasses this feedback loop when looking for alternative equilibria, allowing for a more correct identification and characterization of the alternative equilibria.

The last piece of the model is the equation describing borrowers' default. We report the estimates of its parameters in column 5 of Table 2. We find that indeed increases in aggregate interest rate lead to a riskier borrowers' pool. A 1 percent increase in the aggregate lending rate, which roughly corresponds to 1 standard deviation in our sample, leads to a 0.5 percent increase in borrowers' default. Considering that the standard deviation of the latter is 8 percent, the default equation describes a mechanism that explains over 6 percent of the unconditional variation in borrowers' default (gross of bank and country-time fixed effects).

4.2 Model-Implied Unobservable Costs

In this Section we display model-based quantifications of a set of parameters not directly observable, with the aim to check if the time series and cross sectional patterns obtained are consistent with the financial instability episodes, as well as with the monetary policy and regulatory initiatives observed over the same period. By doing so we conduct an additional qualitative check about the overall plausibility of our modeling framework, providing an overall analysis of the fit of the model. In particular, we focus on the mean μ_{jmt} and variance σ_{jmt} of banks' unobserved costs C_{jmt} , as well as on the incremental cost C_{jmt}^I of providing insured deposits relative to uninsured, the incremental

cost $C_{jmt}^{\mathcal{F}}$ of granting loans to NFCs relative to households, and the extra cost $C_{jmt}^{\mathcal{C}}$ of borrowing from the central bank.

The model-implied accounting of assets (loans) and liabilities (deposits and central bank funding) leaves a net balance sheet position for each bank in our sample. The evolution of this residual variable reflects three main developments (Figure 5). First, in the aftermath of the crisis, euro area intermediaries have started a deleveraging process that is still ongoing. Second, the deposit base expanded across euro area countries, but especially among non-vulnerable countries. Third, deleveraging in vulnerable countries was made possible only after the adoption of the Unconventional Monetary Policies (UMPs), presumably reflecting a re-capitalization process that has been going on in parallel with the adoption of unconventional monetary policy measures.

The expected cost of borrowers' default μ_{jmt} which, based on the model, is implicit in the pricing of loans, seems to be strongly countercyclical (Figure 6). Banks perceive borrowers' defaults as more expensive in crisis times, and the distribution normalizes again only after the adoption of UMPs. A possible and interesting interpretation of this is that in the context of a systemic crisis banks anticipate the possibility of fire sales depressing asset values, including loan collateral, thereby increasing the losses incurred from defaulted loans. The average but also the dispersion in this measure is particularly pronounced in vulnerable countries, with higher tails on both ends of the distribution (Figure 7).

The variance of costs of borrowers' default σ_{jmt} follows a long-term downward trend (Figure 8). This implies, together with Figure 6, that μ_{jmt} and σ_{jmt} were negatively correlated, at least until the adoption of UMPs, which is coherent with the notion that fire sales, by depressing collateral values in the entire economy, increase default costs across the board, diminishing cross sectional heterogeneity in default costs. The adoption of UMPs is instead associated with a decline in both parameters. In the comparison across countries, σ_{jmt} is evenly spread across intermediaries between vulnerable and non-vulnerable countries, with a lower average variance in vulnerable countries.

Distribution of mark-ups does not change over time because it is a transformation of market power. As may be expected, banks' market power is lower in lending markets than in deposit markets, in line with the different size of the average customer in the two markets. Indeed, when looking at lending markets, market power is smaller for firms than for households. The lower margins applicable to insured deposits reflect the easier substitutability for consumers among these products (Figure 10). The risk profile of insured deposits is by definition largely independent of the bank issuing those products.

The opportunity cost of holding insured deposits as opposed to uninsured ones $C_{jmt}^{\mathcal{I}}$ became permanently lower after the crisis (Figure 11). The distribution became also more asymmetric, with a thicker left tail. The adoption of UMP measures did not materially affect such distribution, possibly reflecting the parallel tightening in regulation that increased the "bail-in-ability" of uninsured deposits. The opportunity cost of lending to NFCs as opposed to households $C_{jmt}^{\mathcal{F}}$ did not change significantly over time (Figure 12). Instead, costs of central bank funding $C_{jmt}^{\mathcal{C}}$ became increasingly higher, relative to other funding sources, despite the decrease in policy rates (Figure 13). This does not imply ineffectiveness of these liquidity injections. Quite the opposite, this result is consistent with a strong stabilization role of the availability of central bank funding that eradicated runs on bank liabilities and compressed funding costs, even irrespectively of the policy rate (lender of last resort). This strengthens the case for analyzing the impact of this monetary policy instrument through the lens of a micro-structural model, like the present one, which can properly account for these effects.

5 Multiple Equilibria Under the Actual Policy

In this Section we review the findings obtained by simulating the model under the actual policy, with the main objective to assess whether equilibria other than the realized one are admissible and, if so, how these are characterized. Equilibria are defined as an alternative set of prices (deposit and lending rates for each bank) and banks' default probabilities that satisfy all first-order conditions in a given country and year, given the estimated coefficients of elasticity of the demand schedules and given the policy rate prevailing in any given year. The counterfactual scenarios for the policy rate in Section 6 will instead consider exogenously defined higher or lower policy rates in the different years. Any equilibrium will also be characterized by different levels of welfare and default probabilities for borrowers, although the focus will be almost exclusively on banks' default probabilities, the most direct measure of financial stability. For any given bank in any given year, the dispersion of its default probability across alternative equilibria is defined as non-fundamental risk. This captures the possibility that, even for given "fundamentals", the default probability is high or low only depending on which equilibrium occurs. We define instead fundamental risk as the average default probability of a bank, in a given year, across alternative equilibria.

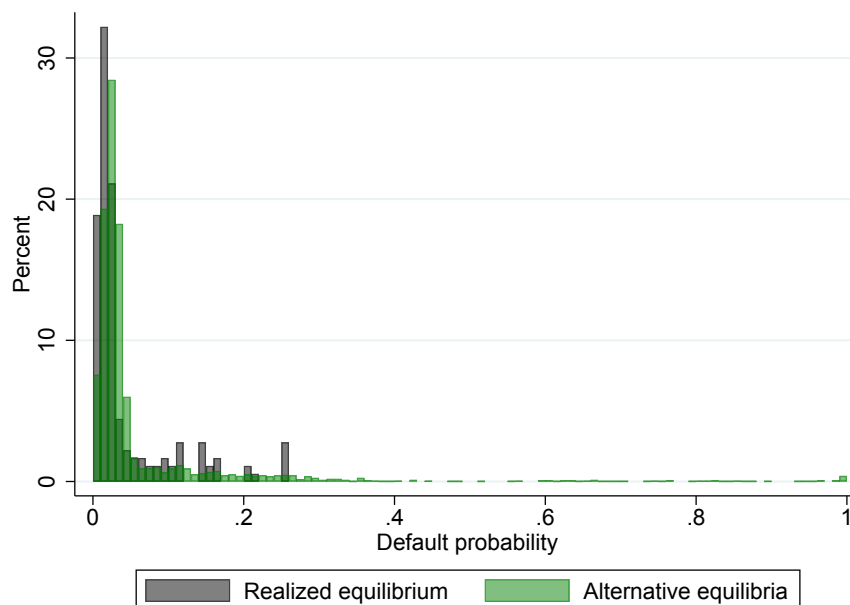
We consider a subsample of the data, relative to the estimation sample, for the analysis of multiple equilibria and of alternative policy scenarios, mostly for computational reasons. We focus on six yearly snapshots of the 9 largest countries, covering the main 30 banks. Two preliminary remarks can be done before discussing the properties of the set of equilibria. One important consistency check performed consisted in verifying that the realized outcome of the economy (the equilibrium observed in the data) is included in the set of equilibria identified, which turns out to be the case. The analysis below will however de-emphasize the number of equilibria identified. One reason for this is that such number is to some extent arbitrary, as it depends on various numerical thresholds used for convergence. Relatedly, in line with Egan et al. (2017), equilibria that are considered very similar are grouped and treated as one, which introduces another factor of arbitrariness in the number of equilibria. What is instead not arbitrary, and will be an important part of our analysis, is the location of such equilibria, defined in terms of the outcome variable analyzed (banks' default probabilities). A large number of equilibria will be at hand, as it will allow representing smoother distribution functions.

The distribution of banks' default probabilities across bank-year-equilibrium is shown in Figure 2, together with the distribution of realized values across bank-year.¹⁵ An important finding of this paper is that the former is characterized by a visibly thicker right tail. In the years considered, and at actual policy rates, the market structure of the euro area banking sector has been consistent with the existence of equilibria other than the realized ones, and characterized by significantly higher default rates. The quantitative relevance of the non-fundamental risk at 2.0%, expressed by the median default probability in the bank-time distribution of the realized equilibrium, is smaller than the corresponding quantity in the bank-time-equilibrium distribution at 2.8%. In a Diamond-Dybvig framework, the realization of run-type alternative equilibria represents a source of tail risk, which is the risk of low probability but high loss events. The relevance of this non-linearity can be expressed comparing the deterioration of the median values with that of more extreme percentiles. For example, the 95th percentile of the two distributions rises from 16.1% to 26.0%; the 99th, from 29.3% up to 82.2%. At the same time, it is interesting that the set of alternative equilibria also includes some lower default rates, which can be labelled as high-confidence equilibria. This is visible, for example, by comprising the left tail of the two distributions: the 5th percentile, in the

¹⁵We focus on banks' default probabilities because they are intimately connected with the welfare costs or gains of alternative equilibria: equilibria characterized by higher average default probabilities compared to the actual ones are also equilibria where total welfare is generally lower (Figure 14).

bank-time-equilibria distribution is 0.5%, slightly smaller than the corresponding quantity for the distribution in the realized equilibrium at 0.6%.

Figure 2: DISTRIBUTION OF REALIZED AND ALTERNATIVE DEFAULT PROBABILITIES



Notes: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2018 plus April 2019 for the balanced panel of 30 intermediaries). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters.

The interpretation of the findings above is that over the sample period scrutinized, the banking sector has endured some non-negligible levels of non-fundamental risk. Even if the accommodative monetary policy stance adopted has played a stabilizing role for the euro area banking sector, which we will discuss below when comparing alternative policy scenarios, it was not able to completely eradicate the presence of non-fundamental risk, in the form of alternative equilibria with different levels of default rates. Among the possible equilibria, moreover, the realized one was close but not coinciding with the most efficient ones, where a high level a self-fulfilling confidence would have reduced further the risk in the banking sector.

An alternative way to assess the quantitative relevance of non-fundamental risk in the economy is to decompose the total variance in the bank-time-equilibrium distribution in the two components related to fundamental and non-fundamental risk. By exploiting the three-dimensional panel feature and considering that all fundamental risk is captured by bank-specific time varying characteristics, such decomposition can be done by computing the fit of a regression saturated with bank-time specific fixed effects.¹⁶ The results are presented in Table 3, showing the fit of regressions only including gradually finer and finer sets of fixed effects. The main result is visible in column (6), indicating that the set of bank-time fixed effects explain about 60% of the total variance in the bank-time-equilibrium distribution. Conversely, 40% of the total variance is not explained by individual bank characteristics and is instead due to non-fundamental risk.¹⁷ Another interesting result in

¹⁶No finer control for fundamental characteristics can be considered. These fixed effects, indeed, control for all characteristics specific to a bank, time invariant and time varying, irrespectively of whether they are observable or not. In other words, any control one may think about, would just be redundant in such specification.

¹⁷Based on this metric the role of non-fundamental risk seems to be more material than what implied by the

Table 3 is that the fit of the specification with country-time fixed effects, 33%, is more than half of that with bank-time fixed effects, which is indicative of the large role played by macro-economic conditions in determining the stability of the banking system.

Table 3: VARIABILITY EXPLAINED BY FUNDAMENTALS

| | (1) | (2) | (3) | (4) | (5) | (6) |
|----------------------|-------|-------|-------|-------|-------|-------|
| Fixed Effects | | | | | | |
| Time | Yes | No | Yes | No | No | No |
| Country | No | Yes | Yes | No | No | No |
| Country-Time | No | No | No | Yes | Yes | No |
| Bank | No | No | No | No | Yes | No |
| Bank-Time | No | No | No | No | No | Yes |
| Observations | 3,071 | 3,071 | 3,071 | 3,071 | 3,071 | 3,044 |
| R-squared | 0.032 | 0.319 | 0.329 | 0.347 | 0.507 | 0.569 |

Note: Regressions of default probability across equilibria on fixed effects.

The alternative equilibria located on the right tail of the distribution can be interpreted as equilibria with runs, as suggested by the strong association between the higher default probabilities in “tail equilibria” and higher funding costs (Figure 15). The distribution with alternative equilibria shown in Figure 2 conflates the time series and cross-sectional heterogeneity in default rates (i.e. fundamental risk) and, for any given bank-period, the heterogeneity across alternative equilibria (i.e. non-fundamental risk). A cleaner picture of the role of the latter can be derived by depicting the distribution of default probability across alternative equilibria, in deviation from the corresponding realized one, which is specific to each bank-time pair. Deviations from realized values highlight the more pronounced right tail, but also the existence of some equilibria more efficient than the realized one, that means with lower banks’ default probabilities, as shown in Figure 16 for individual banks and in Figure 17 for country averages. Interestingly, the tail emerges for stressed countries, but for these there are also equilibria with lower defaults. Note however that this does not reflect differences in fundamentals, as these are deviations from realized values. Non-vulnerable countries were not exposed to large tail risks in the aftermath of the UMPs. The evolution of default probabilities in vulnerable countries instead highlights the normalization of deposit and lending markets, with a distribution of default probabilities, net of fundamental factors, similar to the non-vulnerable countries in the latest years.

Figure 18 shows that banks with low NPL ratios face multiple equilibria that only yield lower ROAs and marginally lower NPLs, as the associated lower lending rates do not have a material effect on debtor creditworthiness which is already good enough. Banks with high NPL face multiple equilibria distributed on both sides, with NPL ratios being more steeply associated across equilibria to ROA levels (as described by our default equation). The non-linear nature of non-fundamental risk and its relation with fundamental is displayed in Figure 19, showing that alternative equilibria characterized by high bank default probabilities are common for banks with weak fundamentals,

discussion above. This can be reconciled by considering our measure of fit, the coefficient of determination R-squared. Outliers tend to disproportionately deteriorate such an indicator of the goodness of fit of the linear regression. At the same time, the difference in the two distributions displayed in Figure 2 is more significant at the two tails, suggesting that run equilibria are relatively far from what would be predicted by a regression line.

here captured by the observed level of NPL ratio. Moreover, the chart also clearly shows that the default probability in alternative equilibria for such banks is disproportionate compared to what is implied for the other banks by the relation between NPL ratio and default probability.

The relation between fundamental and non-fundamental risk can be more formally tested in a regression framework as in Table 4. The regressions in this table consider as measure of fundamental risk the bank-time specific average of bank default probability across the different existing equilibria. The non-fundamental risk is instead defined as the difference between the bank default probability in any given bank-time-equilibrium and the minimum default probability across equilibria observed for the same bank-time. In column 1 of Table 4 the measure of non-fundamental risk is regressed on the measure of fundamental risk, leading to a statistically significant and positive coefficient, corroborating the conclusion suggested by Figure 19 of a positive relation between fundamental and non-fundamental risk.

The theory foresees a possible non-linear relation between fundamental with non-fundamental risk, which also depends on the regions for the fundamentals considered. In particular, following the arguments adopted in standard currency crises models (Obstfeld 1986, Morris & Shin 1998), for bad enough fundamentals only bad equilibria are admitted, while for good enough fundamentals only good equilibria are possible. In between, there may be a region where both equilibria are possible. In order to capture such possible non linearity, column 2 in Table 4 enhances the specification presented in column 1 by adding the quadratic term of the unique regressor considered. While also this term turns out to be statistically significant, the shape of the estimated polynomial envisages a very mild curvature in the (0,1) interval, the range of possible values to the default probability. This can be more easily seen in column 3, where a non parametric specification is estimated substituting the linear and quadratic terms with dummies denoting low, median and high values of fundamentals. In our sample, therefore, multiple equilibria remain a prerogative of weaker institutions. Figure 20 visually confirms a monotonic relation between fundamental risk (i.e. bank-year average default probability) and non-fundamental risk (i.e. bank-year dispersion in default probability across equilibria).

Column 4-6 in Table 4 present similar exercises but conducted on a smaller sample, with only one observation for each bank-time pair. The measure of fundamental risk is defined as in columns 1-3, while the non-fundamental risk here is, for each bank-time pair, the max-min difference of the default probabilities across the different existing equilibria. The findings confirm the presence of a monotonic and positive relation between fundamental and non-fundamental risk.

Table 4: NON MONOTONIC EFFECTS OF FUNDAMENTAL RISK ON NON-FUNDAMENTAL RISK

| | All Equilibria | | | Observed Equilibria | | |
|-----------------------------|-------------------|-------------------|-------------------|---------------------|-------------------|-------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Avg Default Prob | 0.91*** (0.06) | 0.33*** (0.12) | | 1.65*** (0.21) | 0.28 (0.29) | |
| Avg Default Prob Squared | | 1.41*** (0.39) | | | 3.66*** (0.72) | |
| 0.1 to 0.2 Avg Default Prob | | | 0.07*** (0.01) | | | 0.09*** (0.03) |
| Over 0.2 Avg Default Prob | | | 0.30*** (0.02) | | | 0.58*** (0.16) |
| Observations | 3,071 | 3,071 | 3,071 | 180 | 180 | 180 |
| R-squared | 0.491 | 0.509 | 0.405 | 0.768 | 0.858 | 0.613 |

Note: Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All models include a constant.

The interpretation as bank runs equilibria of the mass of alternative equilibria in the right tail of the distribution is further corroborated by the higher reliance on ECB funding that they exhibit, as shown in Figure 21. Despite the run on deposits, the availability of central bank funds at an exogenously fixed policy rate keeps the economy from shifting towards a disordered deleveraging state. This is clearly visible in Figure 22, which shows that the higher reliance on central bank funding in the alternative equilibria is associated with a strong pass through on lending rates, that is a negative correlation between share of central bank funding and lending rates, across alternative equilibria. The reduction in the heterogeneity of funding conditions embedded in these equilibria leads to an increase in the competitive pressure in the lending market.

Focusing only on the realized equilibrium, the relation between central bank funding and lending rates in the bank-time cross section (instead of the equilibria cross section) turns out to be flatter, as shown by the black line in Figure 22. In the absence of runs, only stronger banks keep funding themselves from cheaper market sources. With lending rates fixed by market conditions, hence relatively stable across banks, the intermediaries accessing inexpensive capital in funding markets can avoid a recourse to central bank facilities, obtaining higher levels of profitability.¹⁸

Possible heterogeneity in the relation between fundamental and non-fundamental risk is explored in Table 11. Column 1 presents an extension of the specification of column 1 in Table 4, where the unique regressor, the average default probability across equilibria, is interacted with time dummies. Column 2 instead considers its interaction with a dummy for stressed economies. The results suggest a somewhat weaker relation in the second part of the sample and in stressed economies.

Last, Table 5 summarizes some descriptive statistics on the distribution of alternative equilibria, which includes the realized ones, across vulnerable and non-vulnerable countries. Those summary

¹⁸These results are instructive about the possible distortions in individual banks' incentives under the actual policy. While some marginal institutions may be implicitly subsidized by the existence of these central bank facilities, which can be seen as a distortion of normal market functioning, their important stabilizing role is documented by the strong reliance on this funding source shown in run-type equilibria. At the same time, the existence of these funding facilities does not seem to have been inducing over-reliance, as suggested by the result that stronger banks maintained an incentive to keep their access to market funding.

statistics capture the variation across equilibria in the main outcomes of the model, including banks' default probabilities, deposit and loan volumes and rates, share of non performing loans, total ECB funding, and changes in depositors' and borrowers' surplus, banks' profits, and total welfare between the realized equilibrium and each alternative one. Last, Table 5 reports the average number of equilibria per country-year combinations.

Table 5: DESCRIPTIVE STATISTICS ACROSS COUNTRIES, YEARS, ALTERNATIVE EQUILIBRIA

| | Vulnerable Countries | | | Non-Vulnerable Countries | | |
|------------------------------------|----------------------|--------|---------|--------------------------|--------|---------|
| | Mean | Median | Std Dev | Mean | Median | Std Dev |
| Bank Default Probability (%) | 7.52 | 2.95 | 14.15 | 2.02 | 1.72 | 1.48 |
| Total Deposit Volume (€bn) | 244.58 | 259.26 | 158.65 | 187.41 | 188.24 | 48.09 |
| Deposit Rates (%) | 0.12 | 0.08 | 0.22 | 0.01 | 0.00 | 0.11 |
| Total Loan Volume (€bn) | 472.92 | 591.13 | 255.46 | 323.79 | 282.65 | 141.73 |
| Loan Rates (%) | 1.21 | 1.00 | 2.51 | 1.00 | 1.45 | 2.09 |
| Share NPL (%) | 14.57 | 6.27 | 14.61 | 2.92 | 1.88 | 2.34 |
| Δ Depositors' Surplus (€bn) | -0.42 | -0.45 | 0.53 | -1.35 | -1.05 | 1.42 |
| Δ Borrowers' Surplus (€bn) | -17.69 | -13.04 | 18.37 | -45.25 | -40.81 | 33.27 |
| Δ Banks' Profits (€bn) | 1.03 | 1.03 | 2.41 | 3.17 | 3.02 | 4.63 |
| Δ Total Welfare (€bn) | -17.08 | -12.18 | 17.84 | -43.42 | -39.76 | 30.87 |
| Total ECB Funding (€bn) | 114.76 | 99.50 | 81.18 | 74.24 | 65.25 | 55.73 |
| N of Country-Year Equilibria | | 19.23 | | | 5.88 | |

Note: Descriptive statistics are calculated across 9 countries, 6 years, and all equilibria, with breakdown by 5 vulnerable countries (IT, ES, GR, IE, PT) and 4 non-vulnerable countries (AT, DE, FR, NL). An equilibrium is counted as a country-year combination. This means that uniqueness (N of country-year equilibria equal to 1) would imply 30 equilibria in vulnerable countries and 24 equilibria in non-vulnerable countries.

6 Counterfactuals

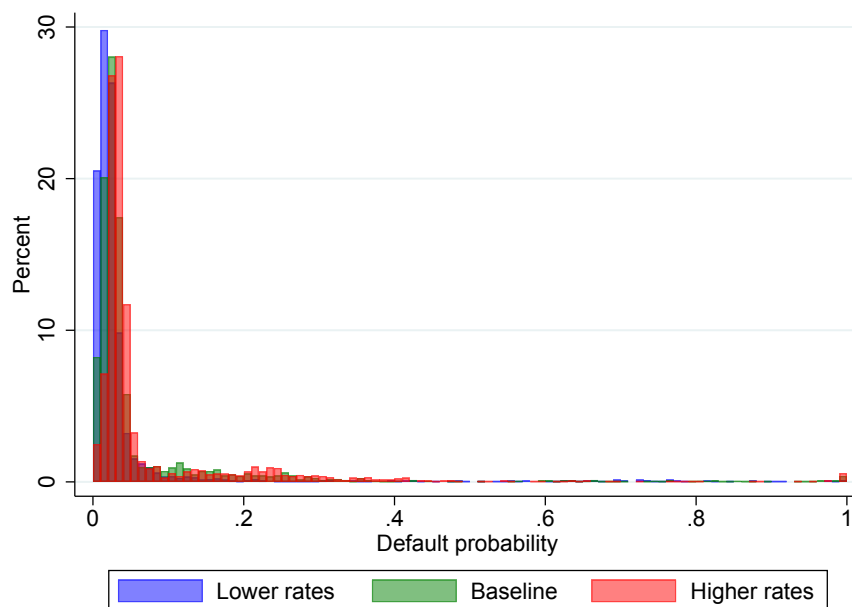
In what follows we look at the response of key bank-level variables across equilibria in counterfactual scenarios, in which the policy rates at which intermediaries can borrow from the central bank are either higher (one percentage point higher every year from 2014 to 2019) or lower (one percentage point lower every year from 2014 to 2019).¹⁹ First, as shown in Figures 3 and 4, we find that banks' default rates are higher with higher rates and lower with lower rates, compared to the possible equilibria resulting from the actual level of policy rates. As we increase the policy rates, the whole distribution of banks' default probabilities shifts to the right, with an increase in the fatness of the right tail. The opposite occurs as we decrease the policy rates.

We find that default rates of banks are materially affected by the price of central bank funds. An increase (decrease) of 1 percentage point in the policy rate induces around a 1 percentage point increase (decrease) in the median probability of default, from 2.4 percent to 3.4 (1.5) percent. The impact changes from year to year, from a maximum of almost 10 percentage points in 2016-2017 to a minimum of 0.5 percentage points in 2015. More importantly, the effect is unevenly spread along the cross-sectional distribution of default probabilities and is asymmetric between policy rate

¹⁹We have conducted robustness checks with different alternative policy rates like plus or minus 1 basis point, and plus or minus 2 percentage points. All qualitative results hold across calibrations.

scenarios. Riskier banks, e.g. banks belonging to the 90th percentile of the distribution of default risk, pass from a 23 percent probability of default to a marginally higher 28 percent probability in the scenario of policy rate increase, but to a substantially lower 3 percent probability in the scenario of policy rate decrease. This is particularly pronounced in years where fundamental risk is intense in certain jurisdictions, like 2015-2017.

Figure 3: DISTRIBUTION OF DEFAULT PROBABILITY ACROSS POLICY RATE SCENARIOS



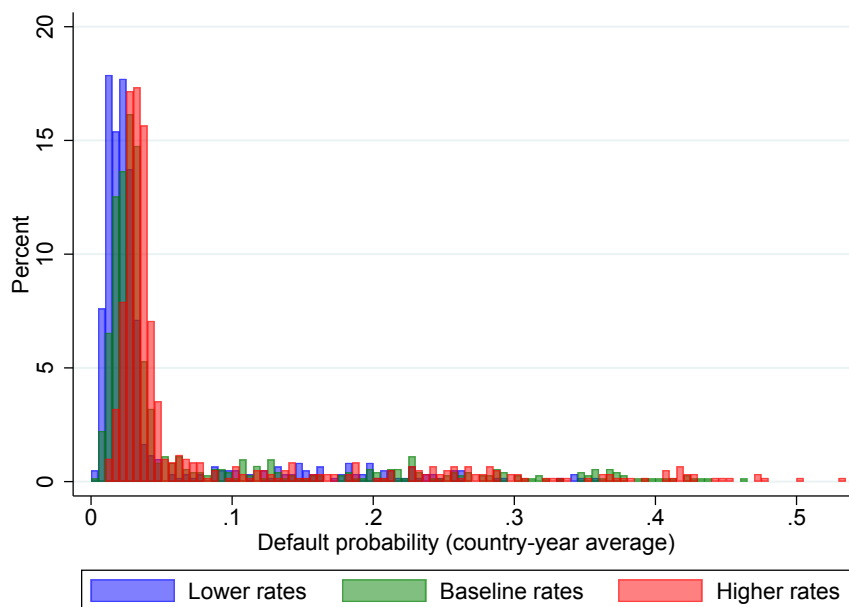
Notes: Pooled bank-year observations. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones.

The price of central bank funding impacts default probabilities mainly via funding costs, bringing them from around 0.05 percent to 1 percent in the case of rate increase and to -0.9 percent in the case of rate decrease.²⁰ This compresses profit margins in the tightening case and widens them in the accommodative case. The unit margin between the interest rate on loans, measured as the weighted average between NFCs and households, and funding costs, measured as the weighted average between insured and uninsured deposits and central bank funds, passes from 2.5 percent to 1 percent in case of an increase in the cost of central bank funding, and from 2.5 percent to 2.9 percent in case of a decrease.

Monetary policy can have an impact on bank default rates, as well as on other variables, by reducing the fundamental risk but also by reducing non-fundamental risk, that is by eliminating inefficient run-type equilibria. Figures 3 and 4 above show the overall effect of different policy scenarios on the distribution of banks’ default probability, and as such conflate the impact of monetary policy on both fundamental and non-fundamental risk. In order to isolate the role played in taming the intrinsic fragility related to non-fundamental risk, we isolate for each bank the equilibrium with the lowest default probability given a level of policy rates, and take deviations from that level to see how monetary policy alters the distribution of “bad” equilibria. In Figure 23 we compare the

²⁰If the lower bound on deposit rates was stricter, the effectiveness of further accommodation would not come via price effects but arguably via a higher reliance on central bank funding at the lower price. We abstract from this channel in our application.

Figure 4: COUNTRY-YEAR AVERAGES OF DISTRIBUTION OF DEFAULT PROBABILITY



Notes: Pooled country-year observations (average default rates in each country and year). “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones.

scenario with higher policy rates to the scenario with lower policy rates. Since these are deviations from “good” equilibria, these distributions express how far the economies are from their financial stability potential. As rates increase, there is a larger mass of adverse equilibria, and this is even more evident if we consider country averages, as shown in Figure 24. Going from the high policy rate scenario to the low rate one, the median default probability, in deviation from the minimum observed across equilibria, reduces by about half of its value, to 0.4%.

There is an almost perfect pass-through of rate cuts and hikes to deposit rates (Figure 25). At the same time, the higher attractiveness of central bank funding allows intermediaries to tap more into the facility (Figure 26). Most importantly, this higher reliance on central bank funding is concentrated in adverse equilibria (Figure 27). In other words, with a more competitive price vis-à-vis market-based alternatives, the central bank is able to convey the stimulus in the situations where it is needed the most. This implies that lending rates that normally would increase as the situation worsens do not do so thanks to the preservation of margins via lower funding costs. This can be seen from Figure 28, where lower rates correspond to a lower elasticity of lending rates to the adversity of non-fundamental shocks, and from Figure 29, where lower rates lead to higher average net returns (ROA) from lending activities. Despite this higher average ROA, when the policy rate is lower the sensitivity of ROA to the severity of the shock is also lower, as can be seen from the flatter line in Figure 29. This is due to the fact that the lower need to reach for yield by intermediaries leads to lower average riskiness of borrowers, thus making in equilibrium the NPL ratio be less responsive to the realization of the adverse shocks (Figure 30). Besides, consider that the actual policy rates generate a wide set of equilibria that is closer to the scenario with higher rates than the scenario with lower rates, at least in terms of the reliance of intermediaries on central bank funding in case of need (Figure 27), and consequently in terms of the transmission of adverse shocks to lending rates (Figure 28). This may be a signal that, for the stability of the deposit and lending markets in the

euro area, the pricing of ECB funds may be excessively high for the facility to act effectively as a backstop against large non-fundamental shocks.

Table 6 reports the average change in key variables for an increase of 10 basis points in the policy rate. We report the change for each country-year to focus on aggregate effects, and we do so with respect to the actual data (“Actual”) and all equilibria (“All”, that is, both actual and alternative equilibria with baseline policy rates). Most of the differences between the two columns stem from the fact that banks resort more to ECB funding in alternative equilibria compared to actual equilibria, and higher pressure on profitability coming from higher funding costs is compensated by higher recourse to the facility. As a result default probabilities remain broadly unchanged. Welfare measures instead show substantial changes. Depositors’ welfare slightly increases in light of the higher remuneration of deposits. On the other hand, borrowers’ surplus sharply decreases, especially in non-vulnerable countries. Banks’ profits slightly decrease in vulnerable countries due to the funding cost pressures while they increase in non-vulnerable countries as margins expand. Total welfare is thus balanced between savers and borrowers in vulnerable countries, while it is tilted to the downside by the larger decrease for borrowers that more than compensates the increase in savers’ welfare and banks’ profits. ECB funding plays a crucial role in avoiding a sizable deleveraging of euro area banks when interest rates increase. In the column labelled “Low uptake” we report the responses for the subset of banks that do not increase substantially their uptake in response to the change in the policy rate. These banks decrease substantially their loan volume, especially in vulnerable countries where funding pressures are higher.

Table 6: DEVIATION RELATIVE TO BASELINE

| | Vulnerable Countries | | | Non-Vulnerable Countries | | |
|-----------------------------------|----------------------|-------|------------|--------------------------|--------|------------|
| | Actual | All | Low uptake | Actual | All | Low uptake |
| Avg. Bank Default Prob. (%) | 2.01 | -0.03 | 0.07 | 0.16 | 0.70 | 0.00 |
| Total Deposit Volume (%) | 0.01 | 0.39 | -1.15 | 0.74 | -0.03 | 0.43 |
| Total Loan Volume (%) | 9.39 | 0.23 | -7.18 | 2.03 | 18.49 | -0.62 |
| Depositors’ Surplus (€bn) | 0.00 | 0.41 | | 1.14 | 0.02 | |
| Borrowers’ Surplus (€bn) | -17.37 | -0.13 | | -4.78 | -35.79 | |
| Banks’ Profits (€bn) | 0.76 | -0.23 | | -0.04 | 2.43 | |
| Total Welfare (€bn) | -16.61 | 0.05 | | -3.69 | -34.40 | |
| Total ECB Funding (%) | 53.55 | -0.61 | -36.90 | 59.17 | 5.85 | -1.58 |
| Number of Country-Year Equilibria | | 18.57 | | | 4.92 | |

Note: Descriptive statistics are calculated across 9 countries, 6 years, and all equilibria with a central bank policy rate that is 1 pp higher than the benchmark in each year, with breakdown by 5 vulnerable countries (IT, ES, GR, IE, PT) and 4 non-vulnerable countries (AT, DE, FR, NL). An equilibrium is counted as a country-year combination. This means that uniqueness (N of country-year equilibria equal to 1) would imply 30 equilibria in vulnerable countries and 24 equilibria in non-vulnerable countries. We report the mean deviations across country-year equilibria. Deviations for the columns labelled “Actual” are computed with respect to the country-year average in the actual data. Deviations for the columns labelled “All” are computed with respect to the country-year average across all equilibria (actual and alternative) that could be sustained with the actual policy rate. Deviations for the columns labelled “Low uptake” are computed with respect to the country-year average in the actual data for the subsample of banks that increase uptake by less than 50% of the actual outstanding amounts.

Table 7 illustrates how non-fundamental risk is highest for intermediate scenarios. We regress the

default probability of banks across equilibria of a given scenario on the bank-time fixed effects. The ability of the bank-time fixed effects to absorb the variation across equilibria for a given monetary policy scenario is our measure of the prevalence of fundamental rather than non-fundamental risk. Columns 1 through 7 report the various scenarios of the rate at which intermediaries can access central bank funding, from -200 basis points below actual values (column 1) to the actual values (column 4), to 200 basis points above actual values (column 7). The R-squared is the minimum for the actual policy rates, and it increases for both higher and lower policy rates. As policy rates are decreased (increased) below (above) actual ones, equilibria concentrate around focal points characterized by lower (higher) default probability of banks and, more generally, a higher (lower) level of welfare. At the same time, this concentration of equilibria means that the non-fundamental risk surrounding these ‘good’ or ‘bad’ equilibria is compressed.

Table 7: VARIABILITY EXPLAINED BY FUNDAMENTAL RISK (BANK-TIME FIXED EFFECTS)

| Policy Rate Change (in Basis Points) | -200 | -100 | -10 | 0 | 10 | 100 | 200 |
|---|-------------|-------------|------------|----------|-----------|------------|------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Observations | 2,103 | 2,654 | 2,863 | 3,044 | 2,932 | 2,598 | 2,171 |
| R-squared | 0.821 | 0.705 | 0.617 | 0.569 | 0.520 | 0.641 | 0.831 |

Note: Regressions of default probability across equilibria on bank-time fixed effects.

7 Conclusion

We provide quantitative evidence of the impact that central bank liquidity and funding facilities have exerted on the reduction of the banking sector’s intrinsic fragility. We define fragility as the presence of run-type equilibria, where lack of coordination among bank financiers leads to equilibria with higher default rates, irrespectively of the level of fundamental risk. We do so by constructing, estimating and calibrating a micro-structural model of competition in the banking sector for the euro area, that allows for both runs in the form of multiple equilibria, in the spirit of Diamond & Dybvig (1983), and for central bank liquidity injections. Crucially, our model allows for imperfect competition among banks in both deposit and loan markets. The estimation and the calibration are based on confidential granular data for the euro area banking sector, including information on the amount of deposits covered by the deposit guarantee scheme and the borrowing from the European Central Bank, over the period 2014-2019.

Our main findings can be summarized as follows. First, we document that the presence of non-fundamental risk is highly relevant in the euro area banking sector, as witnessed by the pervasiveness of the multiplicity of equilibria. Second, even under the observed and accommodative monetary policy the economy admitted multiple equilibria, on top of the observed equilibrium. Compared to the latter, the alternative equilibria tend to be characterized by worst aggregate outcomes. Some intrinsic fragility, defined as the possibility that the economy shifts to an inefficient equilibrium, has therefore been present and was not fully eradicated by the accommodative policies actually implemented. Interestingly, in isolated but meaningful cases, the economy also admitted some equilibria that were more efficient than the realized ones. This can be interpreted as suggestive that more confidence could have moved the economy into a more efficient region. We find that on average non-fundamental risk is positively related to fundamental risk, meaning that banks with higher default probability tend to be more exposed to the risk of run-type of equilibria. The simulations of counterfactual scenarios where central bank funds are artificially provided at more

or less accommodative conditions indicate that monetary policy has a strong impact in mitigating both fundamental and non-fundamental risk.

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Appendix A - Additional Tables and Figures

Table 8: DEPOSIT DEMAND

| | Uninsured | | Insured | |
|----------------------|--------------------|--------------------|--------------------|--------------------|
| | OLS | IV | OLS | IV |
| Interest Rate | 24.18*** (1.17) | 14.63*** (1.46) | 7.42*** (2.02) | 13.13*** (2.32) |
| Bank Default Prob | -3.06*** (0.21) | -2.16*** (0.33) | -0.97*** (0.19) | -0.47* (0.27) |
| Bank Control | Yes | Yes | Yes | Yes |
| Bank FE | Yes | Yes | Yes | Yes |
| Country-Month FE | Yes | Yes | Yes | Yes |
| IV - Monetary Policy | No | Yes | No | Yes |
| IV - Sovereign Risk | No | Yes | No | Yes |
| Observations | 9,025 | 9,025 | 9,025 | 9,025 |
| R-squared | 0.988 | 0.334 | 0.992 | 0.263 |

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Bank control includes a measure of bank size given by its total loan volume.

Table 9: LOAN DEMAND

| | NFCs | | Households | |
|----------------------|--------------------|---------------------|---------------------|---------------------|
| | OLS | IV | OLS | IV |
| Interest Rate | 4.15*** (0.79) | -21.51*** (5.11) | -12.21*** (0.66) | -12.98*** (0.96) |
| Bank Default Prob | -0.63*** (0.13) | -0.70** (0.28) | -0.34** (0.14) | -0.94*** (0.26) |
| Bank Control | Yes | Yes | Yes | Yes |
| Bank FE | Yes | Yes | Yes | Yes |
| Country-Month FE | Yes | Yes | Yes | Yes |
| IV - NPL ratio | No | Yes | No | No |
| IV - Monetary Policy | No | No | No | Yes |
| IV - Sovereign Risk | No | Yes | No | Yes |
| Observations | 9,025 | 9,025 | 9,025 | 9,025 |
| R-squared | 0.543 | 0.436 | 0.582 | 0.581 |

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Bank control includes a measure of bank size given by its total loan volume.

Table 10: DEFAULT EQUATION

| | OLS | IV |
|---------------------|-----------------|-----------------|
| Interest rate | -2.60 (1.92) | 6.43* (3.45) |
| Bank Control | Yes | Yes |
| Bank FE | Yes | Yes |
| Country-Month FE | Yes | Yes |
| IV - Sovereign Risk | No | Yes |
| Observations | 9.025 | 9.025 |
| R-squared | 0.001 | -0.004 |

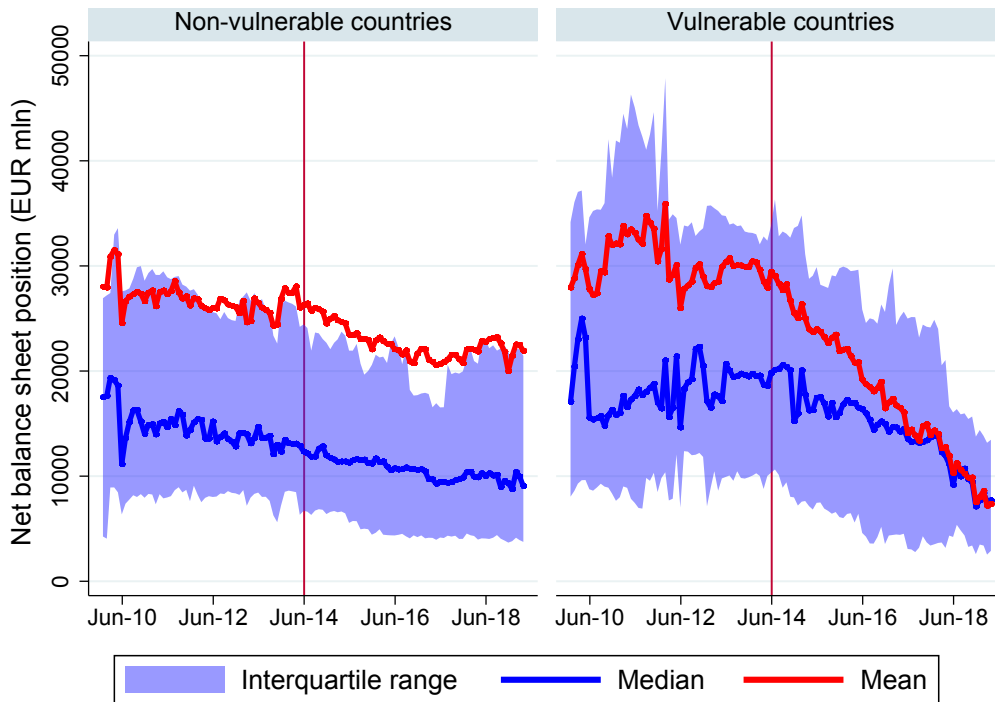
Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Bank control includes a measure of bank size given by its total loan volume.

Table 11: HETEROGENEOUS RELATION BETWEEN FUNDAMENTAL AND NON-FUNDAMENTAL RISK

| | Over Time (1) | Stressed vs. Non-Stressed (2) |
|--------------------|--------------------|----------------------------------|
| Avg Default Prob. | 1.03*** (0.09) | 1.28*** (0.12) |
| Year Interactions: | | |
| 2015 | -0.16 (0.11) | |
| 2016 | -0.53*** (0.07) | |
| 2017 | -0.13 (0.16) | |
| 2018 | -0.57*** (0.09) | |
| 2019 | -0.43*** (0.10) | |
| Other Interaction: | | |
| Stressed | | -0.36*** (0.07) |
| Observations | 3,071 | 3,071 |
| R-squared | 0.508 | 0.492 |

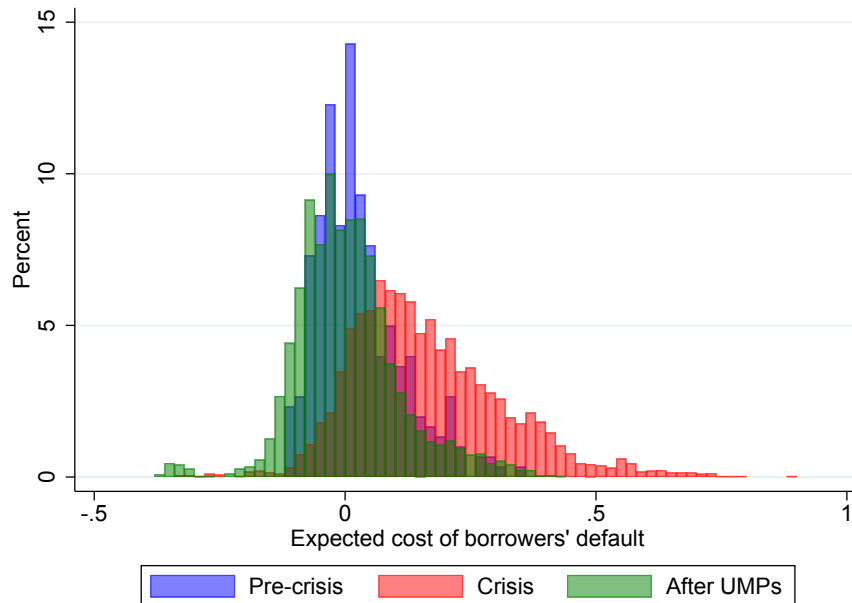
Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All models include a constant.

Figure 5: MODEL-IMPLIED VARIABLES: EVOLUTION OF NET BALANCE SHEET POSITION



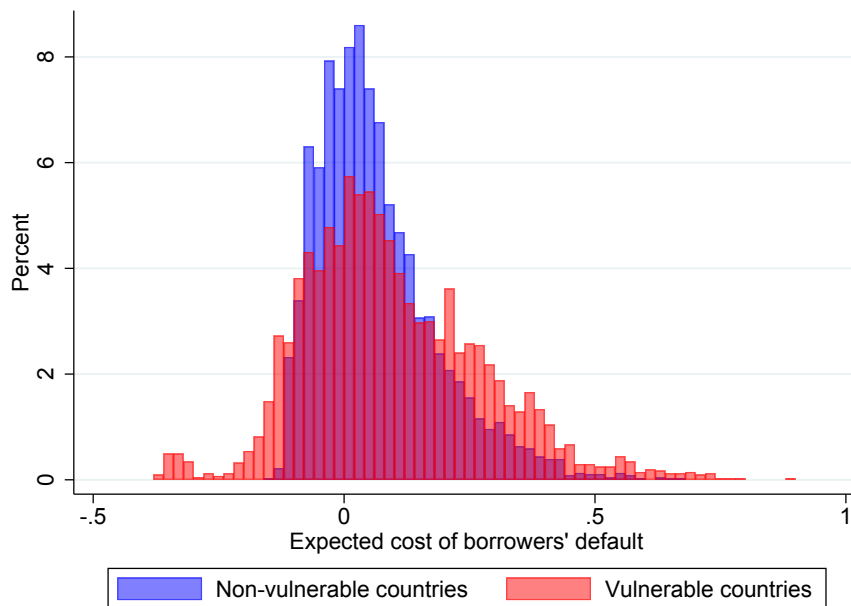
Notes: Pooled bank-month observations. “Non-vulnerable countries” include AT, BE, DE, FI, FR, NL, SK. “Vulnerable countries” include IT, ES, GR, IE, PT.

Figure 6: MODEL-IMPLIED VARIABLES: EXPECTED COST OF BORROWERS’ DEFAULT



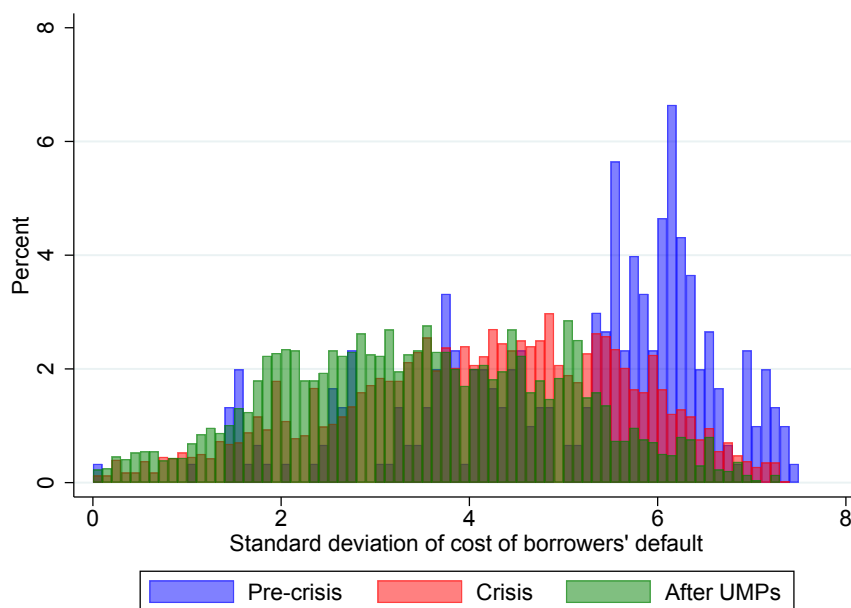
Notes: Pooled bank-month observations. “Pre-crisis” is between August 2007 and May 2008. “Crisis” is between June 2008 and May 2014. “After UMPs” is between June 2014 and April 2019.

Figure 7: MODEL-IMPLIED VARIABLES: EXPECTED COST OF BORROWERS' DEFAULT ACROSS COUNTRIES



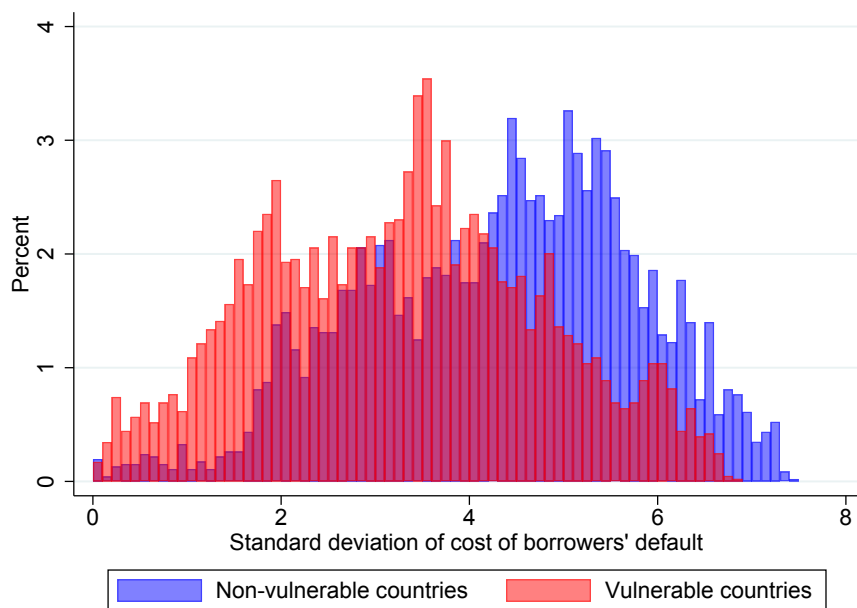
Notes: Pooled bank-month observations. “Non-vulnerable countries” include AT, BE, DE, FI, FR, NL, SK. “Vulnerable countries” include IT, ES, GR, IE, PT.

Figure 8: MODEL-IMPLIED VARIABLES: STANDARD DEVIATION OF COST OF BORROWERS' DEFAULT



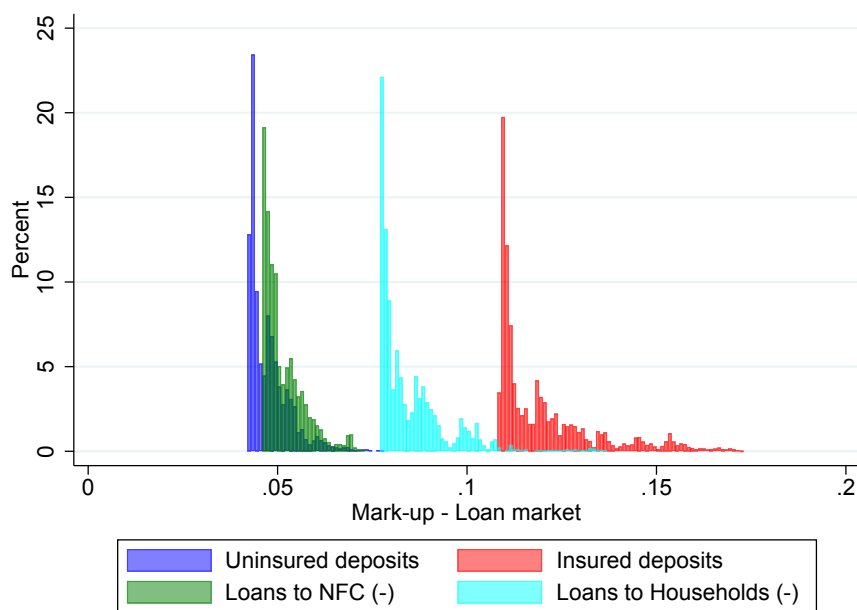
Notes: Pooled bank-month observations. “Pre-crisis” is between August 2007 and May 2008. “Crisis” is between June 2008 and May 2014. “After UMPs” is between June 2014 and April 2019.

Figure 9: MODEL-IMPLIED VARIABLES: STANDARD DEVIATION OF COST OF BORROWERS' DEFAULT ACROSS COUNTRIES



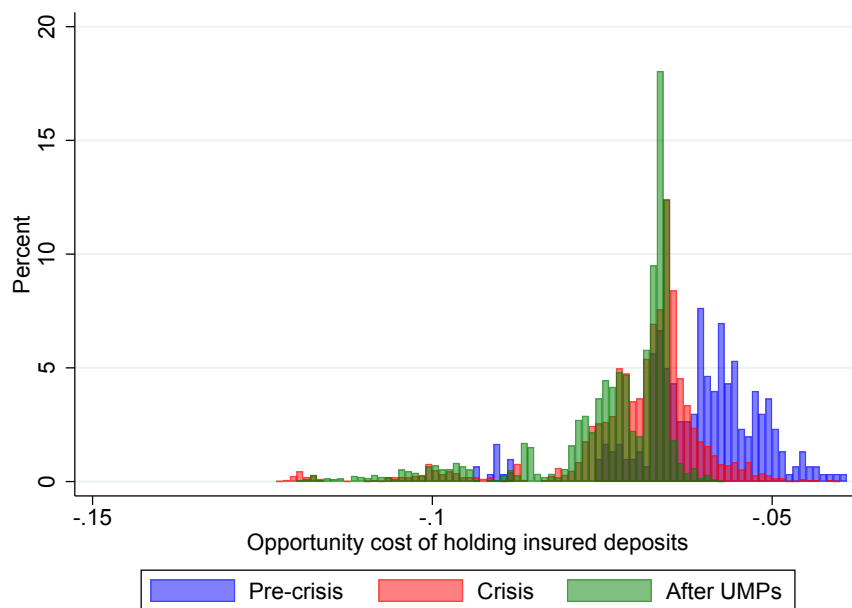
Notes: Pooled bank-month observations. “Non-vulnerable countries” include AT, BE, DE, FI, FR, NL, SK. “Vulnerable countries” include IT, ES, GR, IE, PT.

Figure 10: MODEL-IMPLIED VARIABLES: MARKUPS



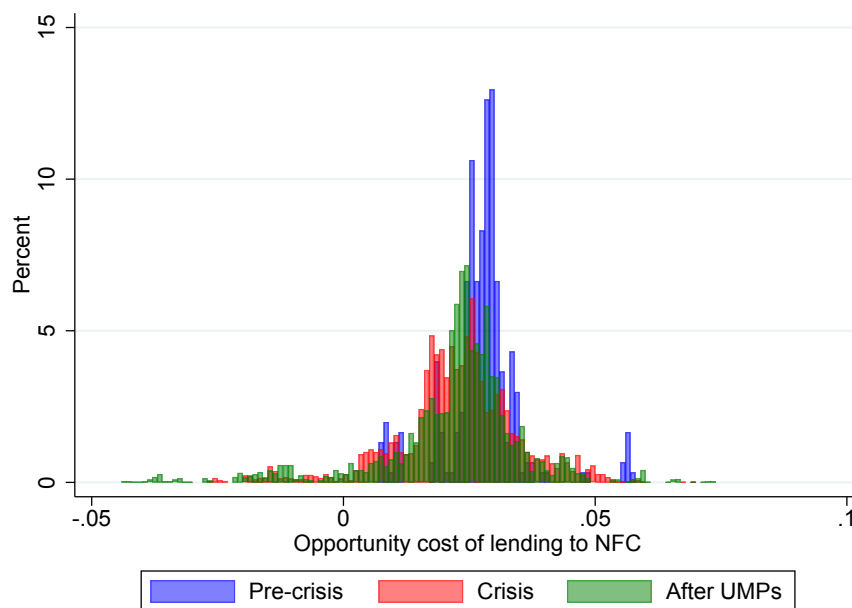
Notes: Pooled bank-month observations. “Pre-crisis” is between August 2007 and May 2008. “Crisis” is between June 2008 and May 2014. “After UMPs” is between June 2014 and April 2019.

Figure 11: MODEL-IMPLIED VARIABLES: OPPORTUNITY COST OF INSURED DEPOSITS



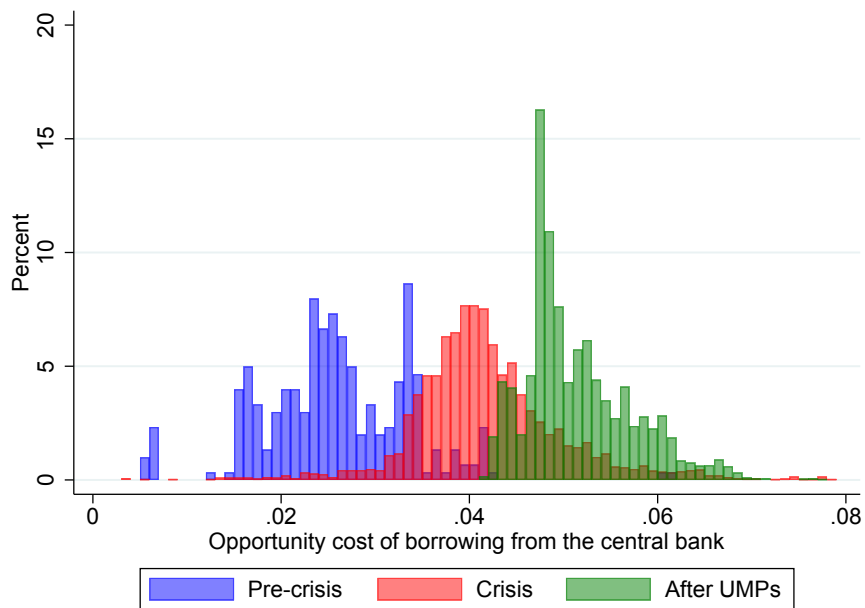
Notes: Pooled bank-month observations. “Pre-crisis” is between August 2007 and May 2008. “Crisis” is between June 2008 and May 2014. “After UMPs” is between June 2014 and April 2019.

Figure 12: MODEL-IMPLIED VARIABLES: OPPORTUNITY COST OF LOANS TO NFCs



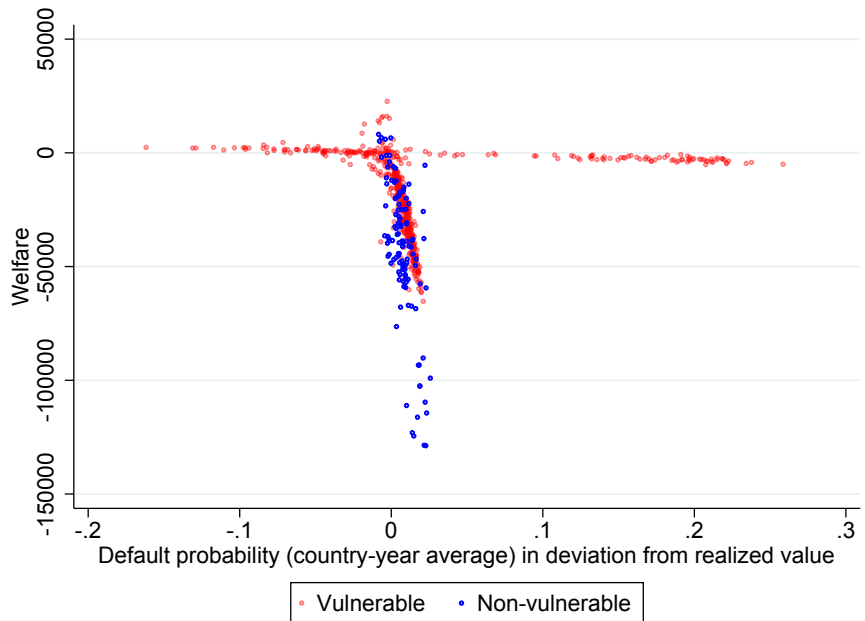
Notes: Pooled bank-month observations. “Pre-crisis” is between August 2007 and May 2008. “Crisis” is between June 2008 and May 2014. “After UMPs” is between June 2014 and April 2019.

Figure 13: MODEL-IMPLIED VARIABLES: OPPORTUNITY COST OF CENTRAL BANK FUNDING



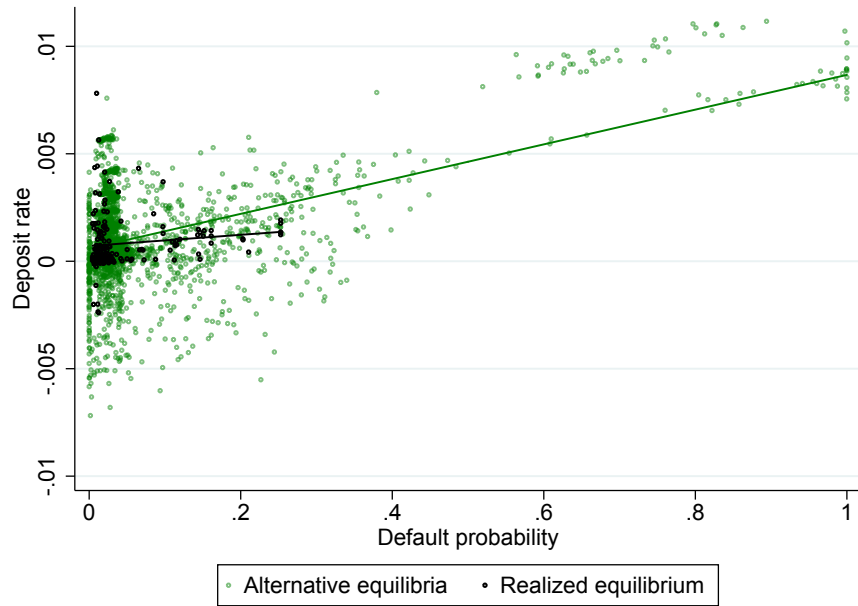
Notes: Pooled bank-month observations. “Pre-crisis” is between August 2007 and May 2008. “Crisis” is between June 2008 and May 2014. “After UMPs” is between June 2014 and April 2019.

Figure 14: MULTIPLE EQUILIBRIA: CORRELATION BETWEEN DEFAULT PROBABILITY IN DEVIATION FROM ACTUAL VALUES AND TOTAL WELFARE



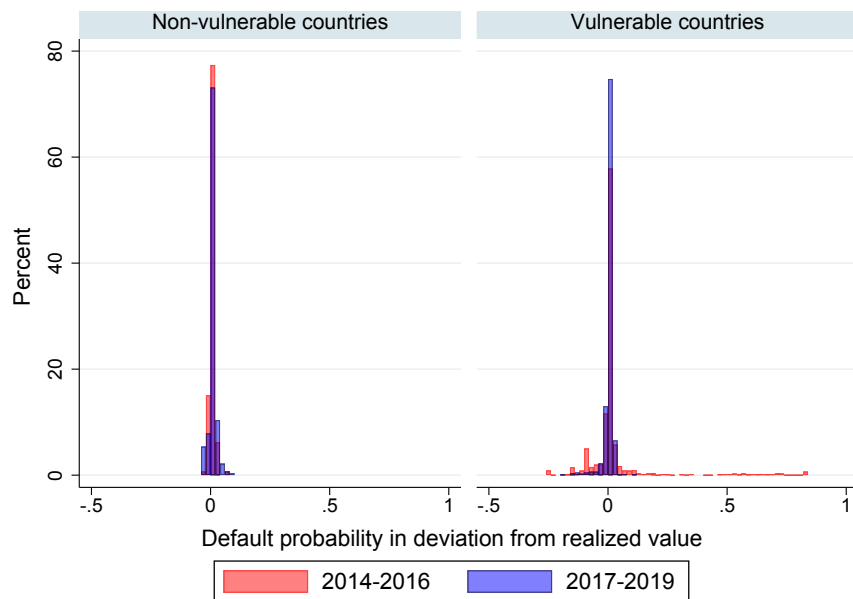
Notes: Pooled country-year observations. Default rates of alternative equilibria are reported as country-year averages in deviation from realized values.

Figure 15: MULTIPLE EQUILIBRIA: CORRELATION BETWEEN DEFAULT PROBABILITY AND DEPOSIT RATE



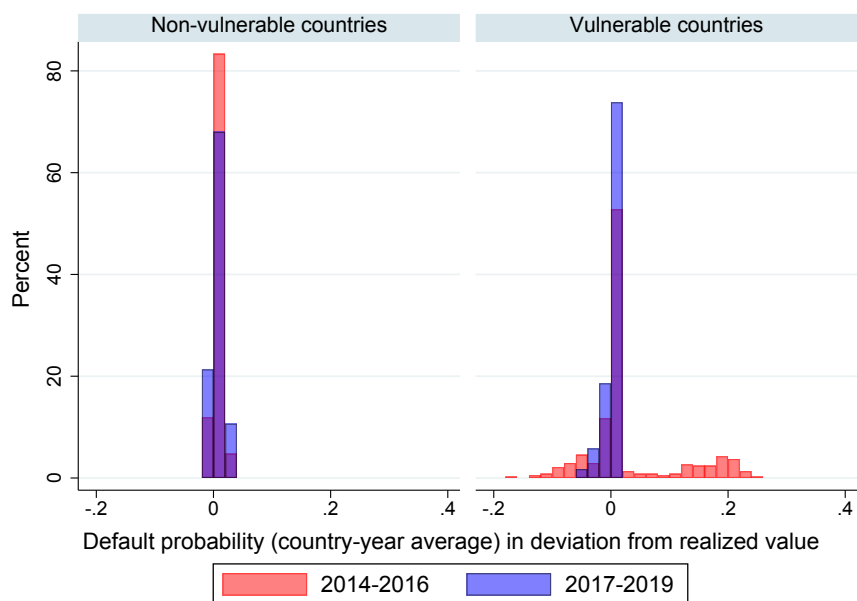
Notes: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2018 plus April 2019 for the balanced panel of 30 intermediaries). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 16: MULTIPLE EQUILIBRIA: DISTRIBUTION OF DEFAULT PROBABILITY IN DEVIATION FROM REALIZED VALUES



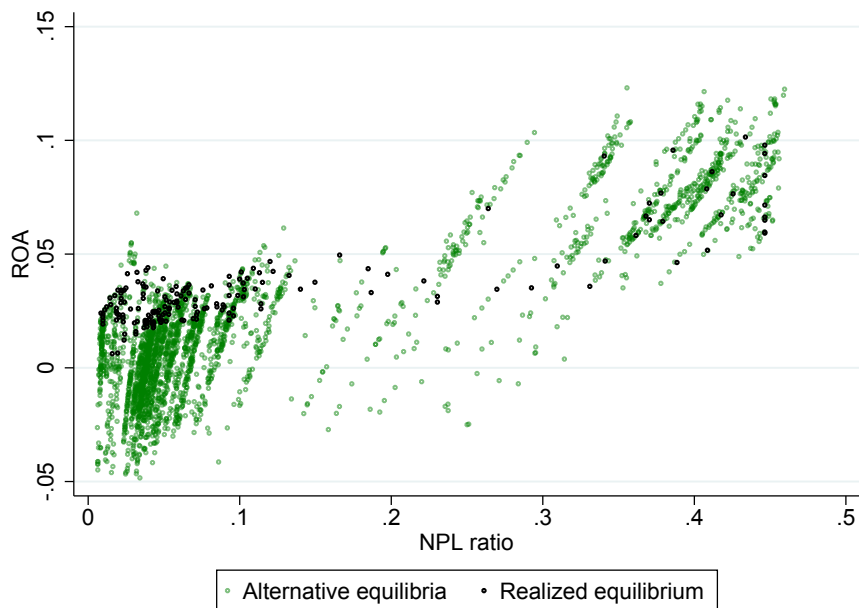
Notes: Pooled bank-year observations. Default rates of alternative equilibria are reported as deviations from realized values.

Figure 17: MULTIPLE EQUILIBRIA: DISTRIBUTION OF DEFAULT PROBABILITY IN DEVIATION FROM REALIZED VALUES (COUNTRY-YEAR AVERAGES)



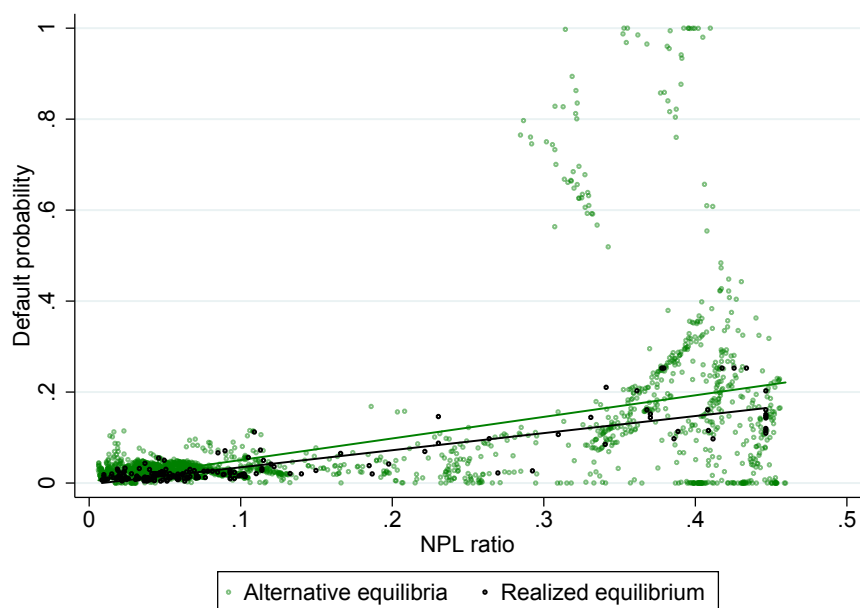
Notes: Pooled country-year observations. Default rates of alternative equilibria are reported as country-year averages in deviation from realized values.

Figure 18: MULTIPLE EQUILIBRIA: CORRELATION BETWEEN BANK PERFORMANCE AND BORROWERS' DEFAULT



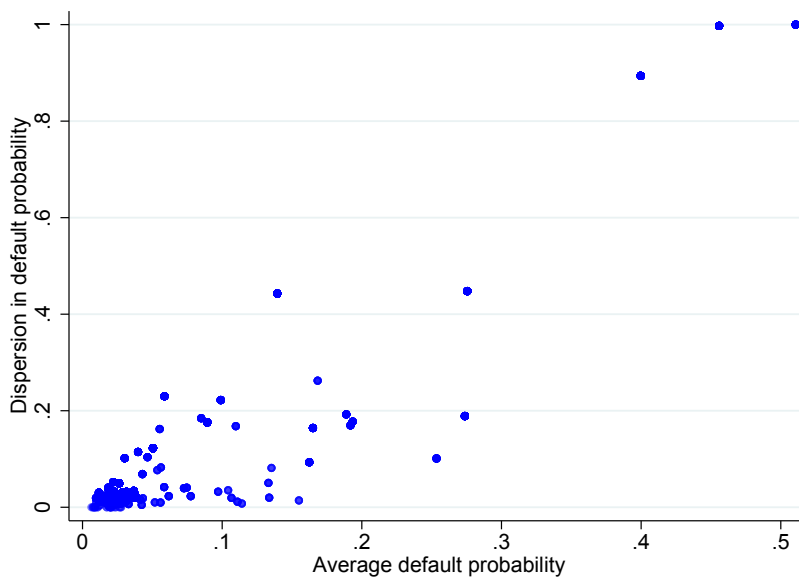
Notes: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2018 plus April 2019 for the balanced panel of 30 intermediaries). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters.

Figure 19: MULTIPLE EQUILIBRIA: CORRELATION BETWEEN BORROWERS' DEFAULT AND BANK DEFAULT PROBABILITY



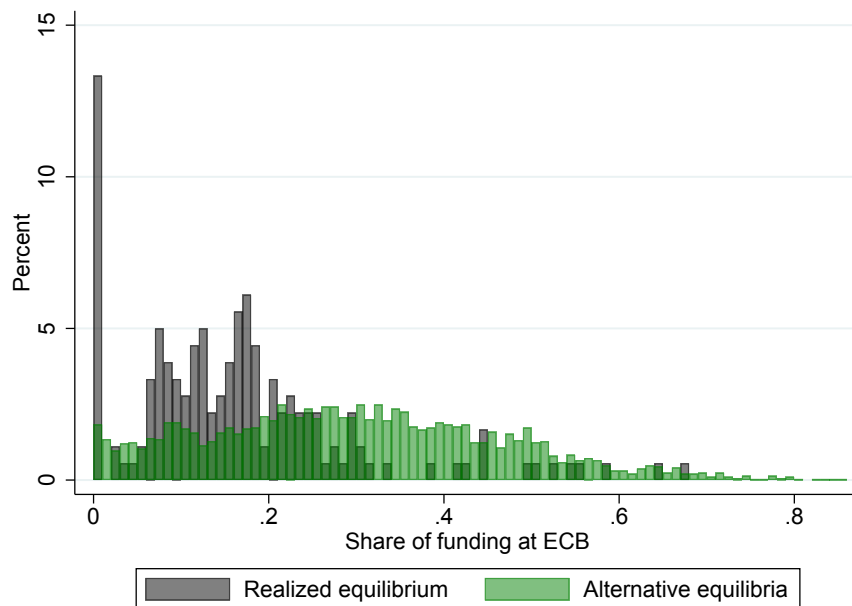
Notes: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2018 plus April 2019 for the balanced panel of 30 intermediaries). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 20: MULTIPLE EQUILIBRIA: DISPERSION OF BANKS' DEFAULT PROBABILITY



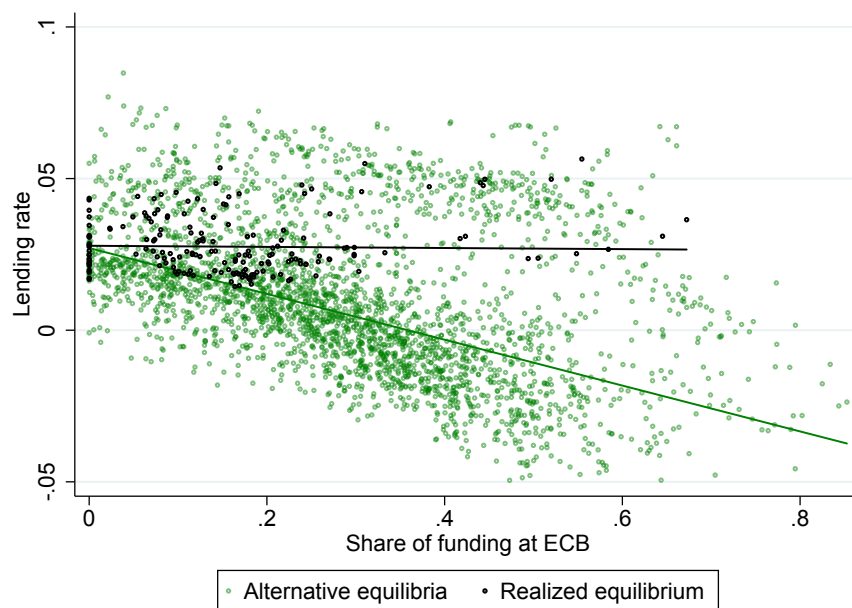
Notes: Pooled bank-year observations.

Figure 21: MULTIPLE EQUILIBRIA: RELIANCE ON CENTRAL BANK FUNDING IN REALIZED AND ALTERNATIVE EQUILIBRIA



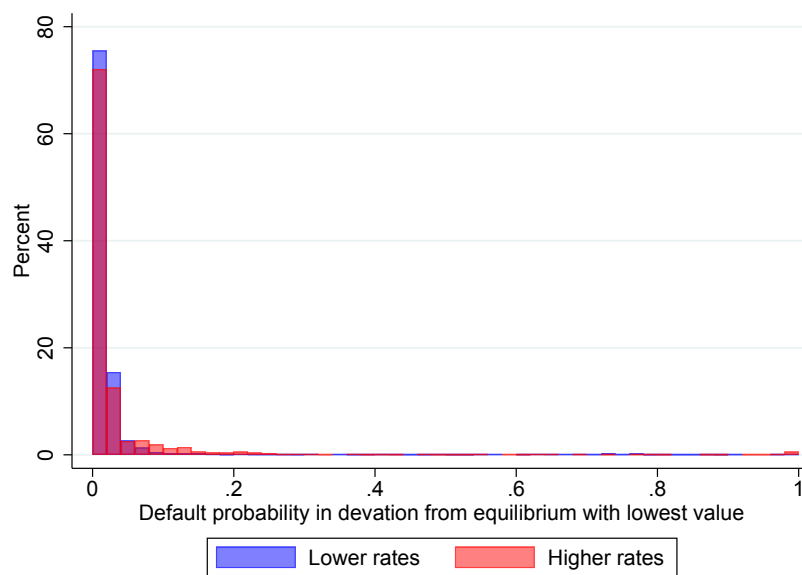
Notes: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2018 plus April 2019 for the balanced panel of 30 intermediaries). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters.

Figure 22: MULTIPLE EQUILIBRIA: LENDING RATES AND RELIANCE ON CENTRAL BANK FUNDING



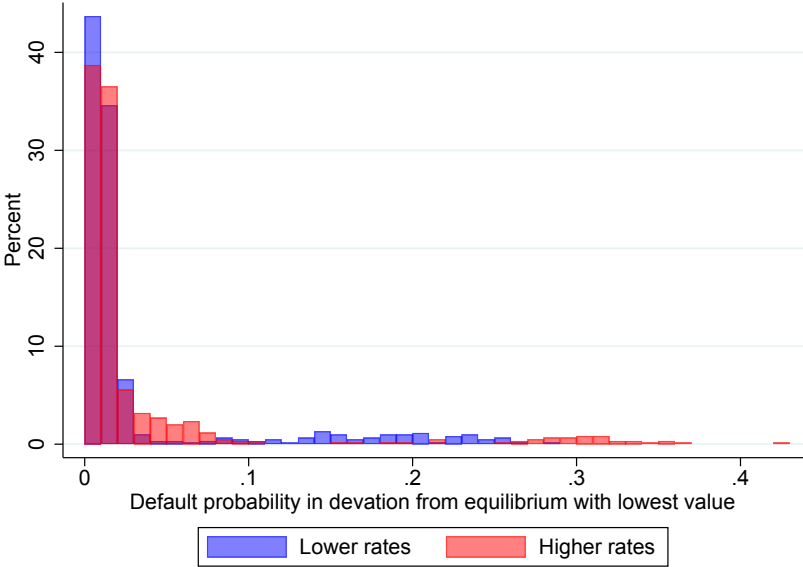
Notes: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2018 plus April 2019 for the balanced panel of 30 intermediaries). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 23: POLICY RATE SCENARIOS: DISTRIBUTION OF DEFAULT PROBABILITY (IN DEVIATION FROM EQUILIBRIUM WITH LOWEST DEFAULT PROBABILITY)



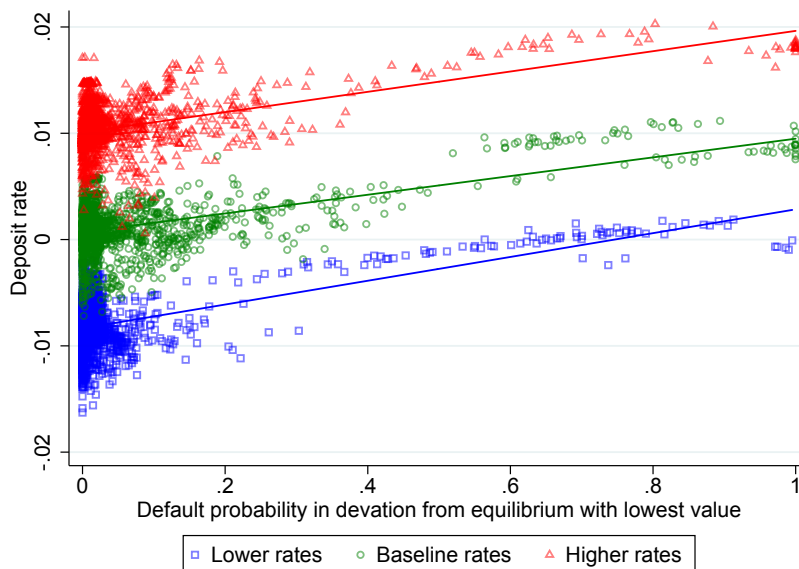
Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. “Lower rates” (“Higher rates”) correspond to the equilibria with policy rates that are 1 percentage point lower (higher) than actual ones.

Figure 24: POLICY RATE SCENARIOS: DISTRIBUTION OF DEFAULT PROBABILITY (COUNTRY AVERAGES, IN DEVIATION FROM EQUILIBRIUM WITH LOWEST DEFAULT PROBABILITY)



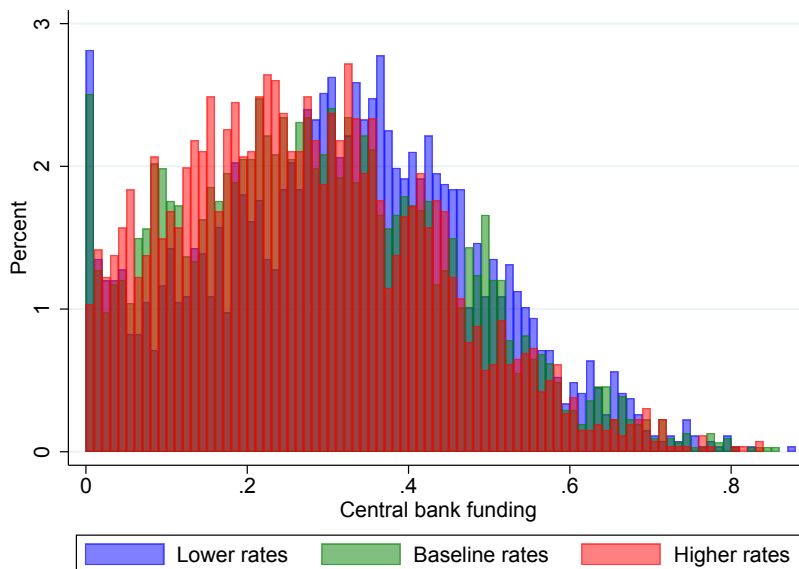
Notes: Pooled country-year observations (average default rates in each country and year). Average default rates are expressed as deviations from the equilibria with the lowest average default probability. “Lower rates” (“Higher rates”) correspond to the equilibria with policy rates that are 1 percentage point lower (higher) than actual ones.

Figure 25: POLICY RATE SCENARIOS: DEPOSIT RATE IN EQUILIBRIA WITH HIGHER DEFAULT PROBABILITY



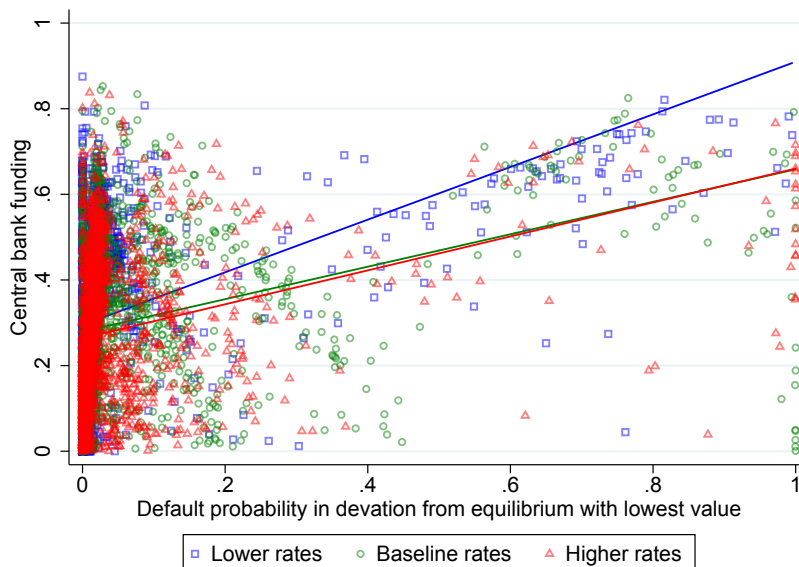
Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 26: POLICY RATE SCENARIOS: DISTRIBUTION OF RELIANCE ON CENTRAL BANK FUNDING



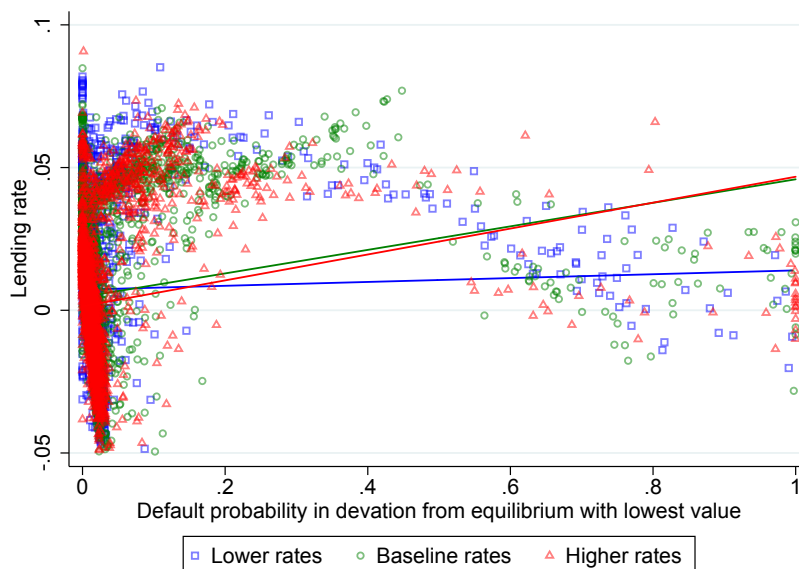
Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. Central bank funding is defined as the share of central bank funding over total funding. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones.

Figure 27: POLICY RATE SCENARIOS: CENTRAL BANK FUNDING IN EQUILIBRIA WITH HIGHER DEFAULT PROBABILITY



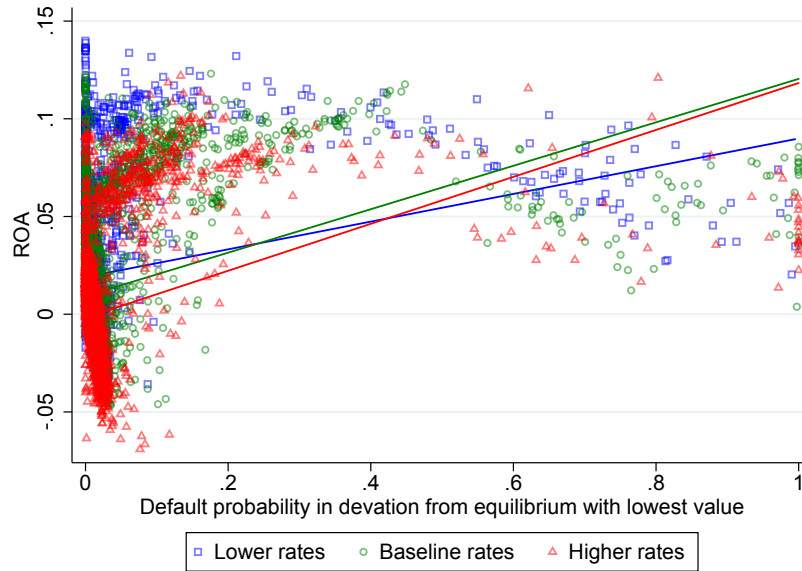
Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. Central bank funding is defined as the share of central bank funding over total funding. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 28: POLICY RATE SCENARIOS: LENDING RATE IN EQUILIBRIA WITH HIGHER DEFAULT PROBABILITY



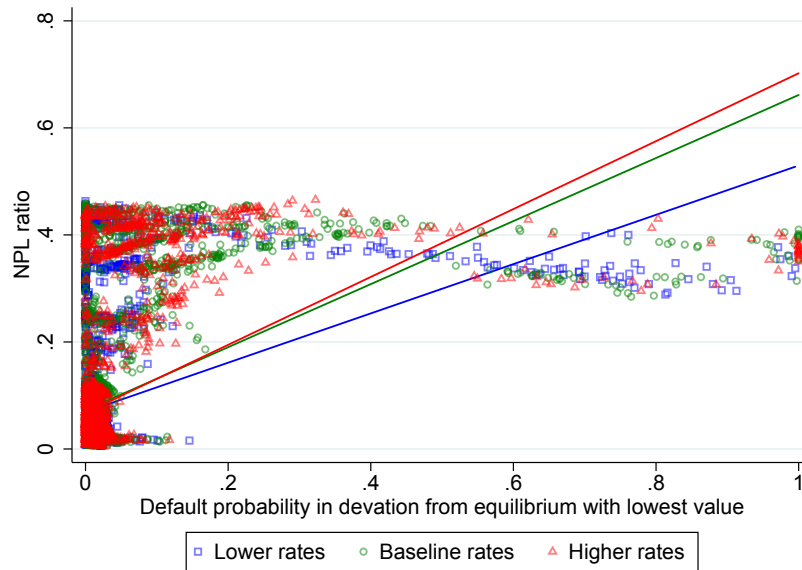
Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 29: POLICY RATE SCENARIOS: ROA IN EQUILIBRIA WITH HIGHER DEFAULT PROBABILITY



Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. ROA is defined as the net interest income from lending activity over total lending. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones. Solid lines are linear predictions weighted by loans to the NFPS.

Figure 30: POLICY RATE SCENARIOS: NPL RATIO IN EQUILIBRIA WITH HIGHER DEFAULT PROBABILITY



Notes: Pooled bank-year observations. Default rates are expressed as deviations from the equilibria with the lowest default probability. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 percentage point lower (higher) policy rates than actual ones. Solid lines are linear predictions weighted by loans to the NFPS.

Appendix B - First Order Conditions

Note that, as in Egan et al. (2017), we assume that each bank's current decision variables do not affect the continuation value of the bank. This will result in the following two first order conditions for insured and uninsured deposit rates:

$$P_t^C + C_{jmt}^C - (P_{jmt}^I + C_{jmt}^I + (1 - w_{jmt}^L)C_{jmt}) = \frac{1}{(1 - S_{jmt}^I)\alpha^I}, \quad (17)$$

$$P_t^C + C_{jmt}^C - (P_{jmt}^N + (1 - w_{jmt}^L)C_{jmt}) = \frac{1}{(1 - S_{jmt}^N)\alpha^N}. \quad (18)$$

From these two equations we can back out C_{jmt}^I as:

$$C_{jmt}^I = \left(P_{jmt}^N + \frac{1}{(1 - S_{jmt}^N)\alpha^N} \right) - \left(P_{jmt}^I + \frac{1}{(1 - S_{jmt}^I)\alpha^I} \right). \quad (19)$$

We can then invert the survival probability using our measure of bank fragility as follows:

$$F_{jmt} = 1 - \Phi \left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}} \right) \Rightarrow \frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}} = \Phi^{-1}(1 - F_{jmt}). \quad (20)$$

The first order conditions for loan interest rates will be the following:

$$w_{jmt}^L C_{jmt} = (1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}) [1 + P_{jmt}^H] - 1 + \frac{1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{H}*}}{(1 - S_{jmt}^H)\alpha^H} - P_t^C - C_{jmt}^C, \quad (21)$$

where:

$$\mathcal{D}_{jmt}^{\mathcal{H}*} = \mathcal{D}_{jmt} \left(1 + \underbrace{(1 - \mathcal{D}_{jmt}) \beta (1 + P_{jmt}^H) w_{jmt}^H}_{\text{due to changes in defaults}} \left(1 + \underbrace{(1 - w_{jmt}^H) (1 - S_{jmt}^H) \alpha^H (P_{jmt}^H - P_{jmt}^F)}_{\text{due to compositional changes}} \right) \right), \quad (22)$$

with \mathcal{H} referring to households, and $\mathcal{D}_{jmt}^{\mathcal{F}*}$ is defined symmetrically and refers to firms. This allows us to back out the unobserved extra costs of lending to firms relative to households as:

$$C_{jmt}^F = (1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}) [P_{jmt}^F - P_{jmt}^H] + \frac{1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{F}*}}{(1 - S_{jmt}^F)\alpha^F} - \frac{1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{H}*}}{(1 - S_{jmt}^H)\alpha^H}. \quad (23)$$

Using first order conditions 18 and 23 we can derive the mean of the unobserved costs C_{jmt} as:

$$\begin{aligned} \mu_{jmt} = & \sigma_{jmt} \frac{\phi [\Phi^{-1}(1 - F_{jmt})]}{(1 - F_{jmt})} + (1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}) [1 + P_{jmt}^H] \\ & - 1 + \frac{1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{H}*}}{(1 - S_{jmt}^H)\alpha^H} - P_{jmt}^N - \frac{1}{(1 - S_{jmt}^N)\alpha^N}. \end{aligned} \quad (24)$$

Then, from 18 we can back out the costs of borrowing from the central bank as:

$$C_{jmt}^{\mathcal{C}} = w_{jmt}^{\mathcal{L}} P_{jmt}^{\mathcal{N}} + (1 - w_{jmt}^{\mathcal{L}}) [(1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}) [1 + P_{jmt}^{\mathcal{H}}] - 1] + w_{jmt}^{\mathcal{L}} \frac{1}{(1 - S_{jmt}^{\mathcal{N}}) \alpha^{\mathcal{N}}} - (1 - w_{jmt}^{\mathcal{L}}) \frac{1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{H}*}}{(1 - S_{jmt}^{\mathcal{H}})} - P_t^{\mathcal{C}}. \quad (25)$$

Since the only variable part of profits are costs, we can rewrite equation 11 as:

$$\underbrace{\Pi_{jmt} \left(\mu_{jmt} - \sigma_{jmt} \lambda \left(-\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}} \right) \right)}_{\text{conditional expected profit}} = \frac{F + r}{1 + r} M_{mt}^* S_{jmt}^* \left(\bar{C}_{jmt} - \mu_{jmt} + \sigma_{jmt} \lambda \left(-\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}} \right) \right), \quad (26)$$

and then substitute into 19 and 20 to get:

$$\begin{aligned} & - \underbrace{\frac{(1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{H}*}) M_{mt}^{\mathcal{H}} S_{jmt}^{\mathcal{H}}}{(1 - S_{jmt}^{\mathcal{H}}) \alpha^{\mathcal{H}}} - \frac{(1 - \mathcal{X}_{jt} \mathcal{D}_{jmt}^{\mathcal{F}*}) M_{mt}^{\mathcal{F}} S_{jmt}^{\mathcal{F}}}{(1 - S_{jmt}^{\mathcal{F}}) \alpha^{\mathcal{F}}}}_{\text{exp profit from loans}} + \underbrace{\frac{M_{mt}^{\mathcal{L}} S_{jmt}^{\mathcal{L}}}{(1 - S_{jmt}^{\mathcal{L}}) \alpha^{\mathcal{L}}} + \frac{M_{mt}^{\mathcal{N}} S_{jmt}^{\mathcal{N}}}{(1 - S_{jmt}^{\mathcal{N}}) \alpha^{\mathcal{N}}}}_{\text{exp profit from deposits}} \\ & - \underbrace{M_{jmt}^{\mathcal{B}} (P_{jmt}^{\mathcal{B}} - C_{jmt}^{\mathcal{C}} - P_t^{\mathcal{C}})}_{\text{net exogenous financing cost}} = \frac{F + r}{1 + r} \sigma_{jmt} M_{mt}^* S_{jmt}^* \left[\Phi^{-1}(1 - F_{jmt}) + \frac{\phi [\Phi^{-1}(1 - F_{jmt})]}{(1 - F_{jmt})} \right]. \end{aligned} \quad (27)$$

which determines the standard deviation σ_{jmt} of the unobserved costs C_{jmt} .

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